CHARLES UNIVERSITY
FACULTY OF SOCIAL SCIENCES
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Structural Modelling of Impact of Ethanol on U.S. Gasoline Prices

Master's thesis

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Year of defense: 2024

Declaration of Authorship

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Prague, July 31, 2024

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Abstract

This thesis investigates the impact of ethanol blending mandates and tax credits on fuel prices in the United States. Utilizing three microeconomics models - partial equilibrium models by de Gorter & Just and Drabik et al., with Wu & Langpap general equilibrium model - the research provides a comprehensive analysis of how these biofuel policies influence consumer fuel prices at the pump. The study employs data from 2009 to 2022, sourced from the Energy Information Administration (EIA) and the United States Department of Agriculture (USDA), to simulate various scenarios involving various ethanol blend rates and the Volumetric Ethanol Excise Tax Credit (VEETC). The findings indicate that increasing ethanol blend rates generally lead to lower fuel prices, contrary to initial hypothesis, while the reintroduction of ethanol tax credits like is shown to result in significant consumer savings. The thesis also extends the analysis into future projections, suggesting that higher ethanol blend rates could continue to reduce fuel prices through 2030. These results offer valuable insights for policymakers aiming to balance economic, environmental, and energy security goals through biofuel-related regulations.

JEL Classification	Q42, Q48, Q52, L71, D61, Q18, H23
Keywords	biofuels, ethanol, fuel prices, RFS, VEETC
Title	Structural Modelling of Impact of Ethanol on U.S. Gasoline Prices

Abstrakt

Tato diplomová práce zkoumá dopad mandátů na přimíchávání ethanolu a daňových úlev na ceny pohonných hmot ve Spojených státech. S využitím tří mikroekonomických modelů - modelů částečné rovnováhy od de Gortera & Justa a Drabika et al., spolu s modelem obecné rovnováhy od Wu & Langpapa - výzkum poskytuje komplexní analýzu toho, jak tyto politiky týkající se biopaliv ovlivňují ceny pohonných hmot pro spotřebitele u čerpacích stanic. Studie využívá data z let 2009 až 2022, získaná z *Energy Information Administration (EIA)* a *United States Department of Agriculture (USDA)*, aby simulovala různé scénáře zahrnující různé míry přimíchávání ethanolu a daňovou úlevu na etanol (Volumetric Ethanol Excise Tax Credit, VEETC). Zjištění naznačují, že zvyšování míry přimíchávání ethanolu obecně vede ke snížení cen pohonných hmot, což je v rozporu s původní hypotézou, zatímco znovuzavedení daňových úlev na etanol, jako je VEETC, vede k významným úsporám pro spotřebitele. Diplomová práce také rozšiřuje analýzu do budoucích projekcí, které naznačují, že vyšší míry přimíchávání ethanolu by mohly snižovat ceny pohonných hmot až do roku 2030. Tato zjištění poskytují cenné informace pro tvůrce politik, kteří se snaží vyvážit ekonomické, environmentální a energetické cíle prostřednictvím regulace biopaliv.

Klasifikace JEL	Q42, Q48, Q52, L71, D61, Q18, H23
Klíčová slova	biopaliva, ethanol, cena paliva, RFS, VEETC
Název práce	Modelování vlivu ethanolu na výslednou cenu benzinu v Americe

Acknowledgments

This thesis is part of a GEOCEP project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 870245.

I would like to express my deep gratitude to prof. Ing. Karel Janda M.A., Dr., Ph.D., for his guidance, valuable advice and for giving me the chance to be a part of the GEOCEP project. Also to Dusan Drabik and Christian Langpap for consultations.

To my mom, thank you so much for the incredible support during my studies. To the rest of my family and colleagues, thank you!

And finally, my closest friends. You have been there for me along the way, always listening to my complaints, encouraging me through the entire journey. Thank you so much for being you. Especially to the one beautiful, wise soul - love lift us up where we belong!

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Acronyms

RFS	Renewable Fuel Standard
VEETC	Volumetric Ethanol Excise Tax Credit
PE	Partial Equilibrium
GE	General Equilibrium
EIA	Energy Information Administration
USDA	United States Department of Agriculture
GHG	Greenhouse Gas

Master's Thesis Proposal

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Proposed topic	Structural Modelling of Impact of Ethanol on U.S. Gasoline Prices

Motivation The role of biofuels is controversial in the literature, yet the use of biofuels is still expanding due to public policy and is thus an important research topic. The broad discussion revolves around environmental and ecological impacts as well as economic implications, more specifically prices of other assets.

Since the beginning of the Renewable Fuel Standard program (RFS) in 2005, the U.S. ethanol industry has substantially increased its size and now has a direct effect, not only on the U.S. market alone but also on global crude oil prices. The size of the U.S. ethanol market has risen due to increased ethanol fuel production from 92,961 thousand barrels (Mbbl) in 2005 to 357,517 Mbbl in 2021. While several strands of research are interested in the consequences of blending mandates and policy supports, and they examine mainly the benefits for climate change mitigation, effects on the food market and food security, energy security for the United States, and not so much attention has been devoted to the consumer benefits in transportation.

Hypotheses

Hypothesis #1: How does the change in ethanol blending into the fuel change the price of gasoline at the U.S. pumps?

Hypothesis #2: How would the implementation of ethanol tax policy affect the price of gasoline at the U.S. pumps?

Hypothesis #3: Corn ethanol has an impact on food and fuel prices.

Methodology Simulation of the fuel price with different levels of blended ethanol and tax policies based on the general and partial equilibrium models, such as Drabik and Babcock. The main data sources are the U.S. Energy Information Administration (EIA) and the Economic Research Service of the U.S. Department of Agriculture (USDA). For the last couple of decades, EIA has been among other activities gathering and assessing energy data, hence providing an extensive database and information on energy production, stocks, demand, imports, exports and prices. The Economic Research Service (ERS) of USDA aims to research and analyse the US food supply system in order to forecast tendencies and issues mainly related to the agricultural environment and rural America, as well as provide independent and quality information for the general public. The Bloomberg datastream serves as a source for the ethanol market price.

Expected Contribution The contribution of the thesis is to provide an overview of the current state of the debate surrounding the role of biofuels, particularly in the context of the Renewable Fuel Standard program in the United States. The thesis highlights the significant growth of the U.S. ethanol industry since the implementation of the RFS program and the consequent impact on the global crude oil prices.

Additionally, the thesis notes the various strands of research that have explored the consequences of blending mandates and policy supports for biofuels, including the benefits for climate change mitigation, effects on the food market and food security, and energy security for the United States. The paper also points out that there is a lack of research on the consumer benefits in transportation from the use of biofuels. Overall, the paper highlights the controversial nature of the topic and the importance of continuing to research the role of biofuels in the energy market.

Outline

1. Introduction
2. Literature review
3. Data
4. Methodology
5. Empirical results
6. Conclusion

Core bibliography

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Chapter 1

Introduction

Biofuels have been globally gaining more importance in this millennium with the United States and Brazil being the world leaders in the industry. The position of biofuels within the environmental economics is quite controversial and sparks constant debates, however the use of biofuels continues to expand due to public policies and is therefore a relevant research topic. Ethanol and biodiesel are the two most widespread biofuels in the United States. The broad discussion revolves around environmental and social impacts, especially the food versus fuels debate, as well as economic implications.

This thesis focuses on ethanol usage in blending processes with gasoline in the United States. Several strands of research have been interested in the consequences of blending mandates and policy supports. These strands examine mainly the benefits for climate change mitigation, effects on the food market and food security or the energy security for the United States. The attention of the academic community towards the consumer benefits in transportation has been, however, relatively limited.

The aim of this thesis is therefore to analyse and quantify the impact of ethanol blending and associated policies on the consumer prices of blended fuel at the pump in the United States. The prevailing policy promotion of ethanol usage in the U.S. has been the Renewable Fuel Standard (RFS). Each year, the program determines the blend rate as an average share of the U.S. ethanol consumption in the total U.S. motor fuel consumption. Since the introduction of RFS in 2005, the U.S. ethanol industry has substantially expanded its size due to increased ethanol fuel production - from 92,961 thousand barrels of ethanol (Mbbl) in 2005 to 371,895 Mbbl in 2023 (U.S. Energy Information Administration (2024b)). Another policy associated with ethanol in the U.S.

used to be the Volumetric Ethanol Excise Tax Credit (VEETC). The tax credit was set to expire in December 2011 and provided subsidy on each gallon of pure ethanol that was blended into gasoline.

Based on the existing literature and economic intuition, the research topics are stated as follows:

1. The RFS leads to an increase in the end user fuel prices.

2. The VEETC type of tax credit results in higher fuel price savings for consumers.

The research builds on established microeconomics models, specifically those developed by de Gorter & Just (2009), Drabik *et al.* (2016), and Wu & Langpap (2015). These models are chosen for their significant academic relevance and alignment with the research questions as they provide a comprehensive framework for understanding the economic implications of biofuel policies. The de Gorter & Just model serves as a standard partial equilibrium (PE) model, while the Drabik et al. model elaborates and improves upon it. The Wu & Langpap model then offers a general equilibrium (GE) perspective.

The analysis involves a thorough understanding, decomposition and replication of each of the models in order to confirm their accuracy. The breakdown of the models into base variables and consequent replication with the original values results in the same values of the compound variables as obtained by the authors of the original source models. Therefore this verifies the approaches and frameworks of the models. Such validation enables further derivation of adjusted fuel price models as the chosen models do not primarily focus on the same research question as this thesis - the impact of the ethanol policies on the resulting blended fuel consumer prices at the pumps. The derived models are therefore modified to obtain direct outputs in the form of simulated blended fuel prices.

Incorporation of data for the time period 2009-2022 into derived models results in simulated fuel prices which are compared with the real blended fuel prices as reported by the U.S. Energy Information Administration (2024b). The simulation produces highly precise outcomes to the real values with identical trends and only slight deviations. Continuing with the analysis, different ethanol blend levels (representing the RFS) and implementation of the ethanol tax credit are employed within the simulation while keeping all of the other base variables at the real values. This way, new simulated fuel prices are obtained for each unique combination of derived model, year, and hypothetical level of an ethanol blend rate or ethanol tax credit. The simulations are an essential part of the thesis, validating the methodological analytical framework of the models through incorporation of the real data within the intrinsic structures.

The results are then reported in the form of savings tables, computed as the differences between the originally simulated prices from the respective derived models and new simulated fuel prices stemming from the changing levels of ethanol blend rate or ethanol tax credit. The simulations reject the first hypothesis as the outcomes report opposite behavior of the blended fuel prices - with increasing level of ethanol blending, the fuel price at the pump decreases. Testing the second hypothesis, the results do not reject it as the VEETC type of tax credit results in higher fuel price savings for consumers.

Finally, the derived models are suitable for long-term forecasts, allowing for simulation of future blended fuel prices that might be relevant for policymakers decisions. The methodology remains unchanged and the projected period is set from 2023 to 2030 - at the time of finishing this thesis, there were still incomplete source data for the base variables for the year 2023, hence opting for inclusion in projections. The results of projections suggest that there is an incentive to increase the blend rate of ethanol in gasoline as it may lead to future consumer savings and also that the reimplementation of the VEETC type of tax credit would result in future blended fuel prices reduction. Such outcomes may influence policy decisions regarding the Renewable Fuel Standards, the encouragement of alternative fuel use and government subsidies for ethanol.

Chapter 2

Literature Review

According to the U.S. Energy Information Administration - EIA, biofuels are “liquid fuels and blending components produced from biomass materials called feedstocks”. Even though they are primarily utilized in transportation, a small fraction of manufactured biofuels can be also used in heating and electricity generation. The most widely produced biofuels are bioethanol and biodiesel.

Bioethanol (or ethanol) is obtained through fermentation process of the sugar that is contained in sugar canes, sugar beets and starches of grains, for example corn or barley. The United States and Brazil have been the two largest producers and consumers of ethanol worldwide. The U.S. ethanol is made from corn kernel starch while Brazil utilizes its enormous production of sugar cane to make ethanol.

Biodiesel is made from vegetable oils such as soybean oil in the U.S. and rapeseed oil, sunflower oil and palm oil in other countries. Another sources for biodiesel are used cooking oils or animal fats from slaughterhouses. Biodiesel is made through transesterification, a chemical reaction that converts oils and fats into biodiesel and its by-product, glycerine. The European Union is the largest producer and consumer of biodiesel with the United States producing the second largest amount of biodiesel in the world (U.S. Energy Information Administration (2024a)).

The world consumption of crude oil and gas has been globally sharply increasing in the last couple of decades, causing a sincere concern with human liability on these non-renewable resources, especially in the environmental and academic circles. Even though there may be new oil discoveries, increases in efficiency of oil production or incentives leading to a decreased demand, altogether supplying enough resources to the society, the necessity of alternative, renewable and to some extent environmentally friendly sources still prevails. Among the principal factors contributing to the global utilization of biofuels are the need for energy security, the environmental issues related to the climate change and use of crude oil or gas, such as emissions and pollution, and the sustainable agricultural development. In particular the government support of biofuels may be viewed as a hidden support to agriculture.

In the following sections the literature relevant for the price transmission from ethanol to gasoline price is discussed in detail in subsections according to particular issues. Additional discussion of this literature is provided in a recent systematic review by Janda *et al.* (2022).

2.1 Food Versus Fuels Debate

Agriculture, a cornerstone of daily existence worldwide, plays a pivotal role in supplying both food and fuel. Over the years, the rise of the biofuel industry has been pronounced, specifically driven by biofuel initiatives instituted in the United States, the European Union, and Brazil. These initiatives aim to address issues such as the accessibility of transportation fuel, trade equilibrium, and climate change (Zilberman *et al.* 2013). This expansion in biofuel production has catalyzed a surge of research interest in various areas, encompassing energy and environmental objectives. The topic of biofuels in the U.S. has emerged as a significant subject pertinent to energy and food security, environmental shift, rural economic progress, and transportation, among other aspects.

During the 2008 food crisis, the narrative surrounding the development of ethanol took a turn towards negativity. The affordability of food resulting from a sharp turn in demand for corn became a focal point in a multitude of discussions and scholarly articles between 2008 and 2010 (Tokgoz *et al.* 2007; Abbott *et al.* 2008; Rosegrant 2008; Collins 2008; Trostle 2010; Hochman & Zilberman 2018), with a comprehensive literature review provided by Janda *et al.* (2012). Hochman *et al.* (2014) later demonstrated that biofuels were not the primary factor responsible for the surge in food commodity prices. They suggested that price spikes could be controlled by appropriate inventory-management policies or mechanisms that would permit impoverished countries to procure food at predetermined prices.

A meta-analysis by Hochman & Zilberman (2018) provides an evaluation of the impact of corn ethanol on food and fuel prices, a decade after the 2008 food crisis, and a review of biofuel impacts based on additional data. While not the only quantitative meta-analysis related to ethanol, it is the most comprehensive, covering various facets of the biofuel economy. This study ties concerns about food security to the overall discussion of ethanol for fuel prices, greenhouse gas emissions (GHG), and indirect land use change (ILUC). Key findings include the significant role of assumptions in evaluating the biofuels' effects, with models that account for feedback mechanisms generally reporting lower impacts of biofuels on food and petroleum prices. Similarly, emission effects are smaller in models that consider interconnections among markets and regions. Furthermore, Hochman & Zilberman (2018) report that studies with more inelastic supply and demand curves reveal greater price effects of biofuels.

Biofuels, as a research area, generate substantial debate and provide a wealth of research possibilities. One significant strand of research concentrates on the ecological impact of biofuels, particularly life-cycle analysis (Oehlschlaeger *et al.* 2013; Rajagopal & Plevin 2013; Hill *et al.* 2006; Demirbas 2008). Along this trajectory, Farrell *et al.* (2006) suggest that ethanol could make an early contribution to ecological and environmental objectives by considerably reducing greenhouse gas emissions, petroleum inputs, and soil erosion. This claim was subsequently disputed by many authors, in particular Goetz *et al.* (2018). Another substantial area of research delves into the price impacts of biofuels on oil or gasoline. The influence of ethanol on fuel prices remains a question to which this thesis aims to contribute.

2.2 The Renewable Fuel Standard (RFS)

The national U.S. biofuel mandate - in conjunction with tax incentives and growing energy needs, stimulated a decade-long surge in ethanol production by guaranteeing a market for biofuels. This mandate resulted from the Renewable Fuel Standard (RFS) program, established under the Energy Policy Act of 2005 and later expanded by the Energy Independence and Security Act of 2007. The Environmental Protection Agency (EPA), in consultation with the U.S. Department of Agriculture and the Department of Energy, oversees the RFS program, which stipulates annual quotas for biodiesel and ethanol that refiners and importers must meet.

RFS-mandated volumes are recalibrated annually into percentage standards that obligated parties use to calculate compliance obligations, known as Renewable Volume Obligations (RVOs). Compliance is tracked via Renewable

Identification Numbers (RINs), and obligated parties must meet their RIN obligations annually, either through the incorporation of renewable fuel into transportation fuel or through the purchase of RINs from others. Under the Energy Policy Act of 2005, Congress introduced the first RFS, mandating the blending of up to 7.5 billion gallons of biofuels into gasoline by 2012. This was enhanced under the Energy Independence and Security Act of 2007, introducing the four categories of renewable fuel, biomass-based diesel, cellulosic biofuel, and advanced biofuel. These fuels must reduce greenhouse gas emissions by 20% compared to a 2005 baseline to be considered renewable.

RFS fuel standards are percentage-based and used by each regulated entity to determine their renewable fuel volume obligations. If these obligations are met and if projections of gasoline and diesel use are accurate, the volume of renewable fuel used should meet national mandates. In 2013, the RFS was updated to include more production pathways to meet greenhouse gas emission reduction targets. The emission assessments must consider the full life cycle of fuel production, and the 2013 updates included renewable gasoline and renewable gasoline blend stock as new fuel types under the RFS program.

However, a 2016 report from the EPA's Office of Inspector General raised concerns about the EPA's failure to comply with statutory reporting obligations regarding the environmental impacts of the RFS. There have also been issues with meeting anti-backsliding requirements, which aim to address potential negative air quality impacts of the RFS. Nevertheless, stakeholders are calling for these analyses to bolster their arguments for increased biofuel use.

Notably, not all biofuels are equivalent in terms of size and source, and the EPA uses an equivalence value system to even the playing field. Ensuring compliance with RFS goals largely depends on these equivalence values. Interagency cooperation and public-private partnerships are also essential to strengthen compliance and enforcement mechanisms. (Ahmad (2018))

More recently, the EPA released the final rule - so called "set rule" - for the Renewable Fuel Standard volume requirements for the years 2023, 2024, and 2025, raising the total renewable fuel volumes from the 2022 levels. The rule is designed to enhance the program while addressing the uncertainties of long-term forecasts. Key actions include postponing the renewable electricity provisions (eRINs), likely not granting small refinery exemptions (SREs) for 2023–2025, and introducing an additional volume obligation of 250 million gallons for 2023. The rule also implements regulatory updates for biogas-derived renewable fuels, improves third-party oversight, adjusts the calculation formula for biomass-based diesel, and enhances RIN generation flexibility. Furthermore, the rule takes into account recent U.S. legislative changes, such as the Inflation Reduction Act, and considers changes in the transportation, energy, and environmental sectors to guide future regulatory decisions. (Bracmort (2023))

2.3 The Volumetric Ethanol Excise Tax Credit

The Volumetric Ethanol Excise Tax Credit (VEETC) was a policy which permitted a registered ethanol blender with the Internal Revenue Service (IRS) to qualify for a financial incentive of \$0.45 for each gallon of pure ethanol (with a minimum strength of 190 proof) blended with gasoline. The tax credit was only available to entities that have manufactured and either sold or utilised the eligible blend as a fuel in their professional or commercial activities. According to the U.S. Department of Energy, the incentive expired on December 31, 2011. (U.S. Department of Energy (2024b))

2.4 The U.S. Fuel Market

The fuel market of the United States, a complex interplay of global dynamics, policy regulations and consumer behavior, represents a crucial segment of the U.S. economy. Its intricate supply chain, from crude oil extraction to the final retail sale of gasoline and diesel, is influenced by a myriad of factors including geopolitical shifts, technological advancements, environmental policies and fluctuations in both domestic and international demand. The examination of this market is not only pivotal for understanding the current energy landscape but also for anticipating future trends in a rapidly evolving global energy paradigm.

The market operates within a complex framework of economic dynamics, where both macroeconomic and microeconomic elements exert a considerable influence on fuel pricing structures. Macroeconomic factors, which typically impact the industry at large, may include regulatory interventions triggered by state emergencies, fluctuations stemming from geopolitical crises, and systemic alterations due to industry-specific events. Moreover, changes in global weather patterns and supply-demand equilibrium also play a pivotal role. On the other hand, microeconomic variables directly influence the cost at the consumer level. These entail competitive pricing strategies, which necessitate continuous market repositioning, and strategic imperatives rooted in the pursuit of financial sustainability by retailers. Critical to the comprehension of these multifaceted influences is the price of crude oil, which constitutes the majority share of gasoline pricing, followed by refining costs, distribution and marketing, as well as tax-related components. (Energy Information Administration (2024b))

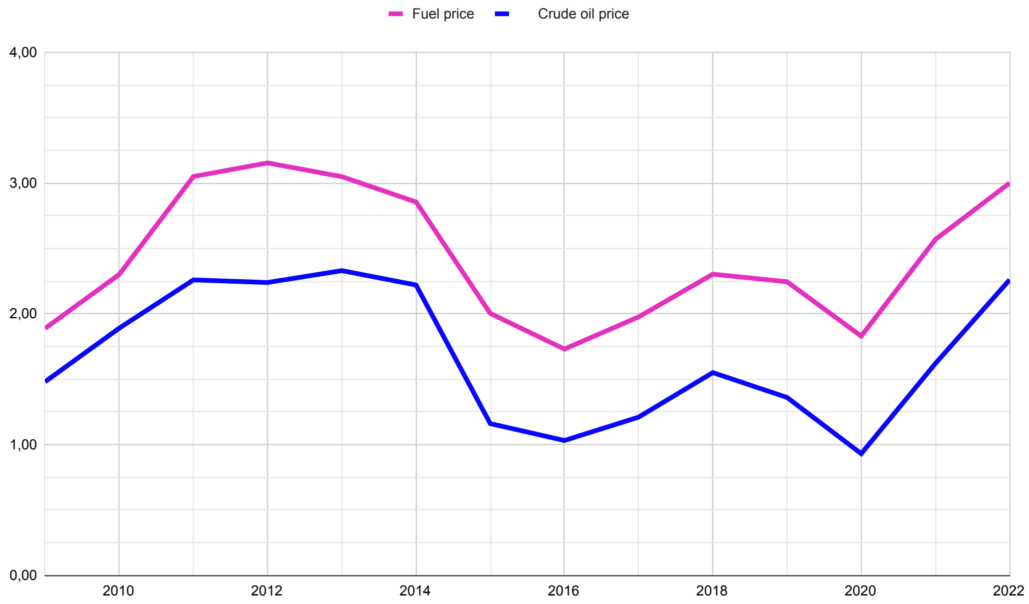

Figure 2.1: Illustration of crude oil and fuel prices in years 2009-2022, dollars per gallon

Figure 2.1 confirms strong correlation of crude oil and fuel prices. The graph is based on data for the sales to end users gasoline prices representing the fuel prices (where the fuel composes of the blended gasoline and ethanol) and West Texas Intermediate (WTI) crude oil prices, both metrics taken from U.S. Energy Information Administration (2024b) for the concerned period of 2009 to 2022. From the beginning of the decade until 2014, prices exhibit an increasing trend, indicating an economic rebound post the financial crisis of 2008, characterized by heightened energy demands. A pronounced decline in prices around 2014 to 2016, which was a subject of interest within the professional public, mirrors the worldwide crude oil price plunge.

As Baumeister & Kilian (2016) note, similar decline is comparable only to the falls witnessed around 1986, when Saudi Arabia shifted its oil policy, and during the 2008 global economic crisis. According to their analysis, the sudden drop in crude oil prices during the latter half of 2014 was influenced by a combination of partially predictable factors. They pinpoint a substantial portion of this decrease to adverse demand shocks, indicative of a slowing global economic landscape. Furthermore, a significant fraction of the reduction was anticipated due to optimistic shifts in both current and future oil production prior to July 2014. Beyond these predictable factors, the remaining cumulative drop in prices was unforeseen and resulted from a shock to oil price expectations, which diminished the demand for oil inventories, and a significant negative demand shock in December 2014, prompted by an unanticipated weakening of the global economy.

A gradual recovery in both crude oil and fuel prices is observable post-2016, reflecting market stabilization and the correction of supply-demand imbalances. The sharp drop observed in 2020 aligns with the economic consequences instigated by the COVID-19 pandemic, predominantly characterized by a substantial contraction in transport fuel demands, as well as the results of the Russia-Saudi Arabia oil price war. As the pandemic spread globally in March 2020, governments worldwide implemented containment measures that drastically reduced outdoor activities and significantly impacted sectors reliant on oil, such as tourism, airlines, and shipping. The global isolation led to an unprecedented drop in oil demand, causing a supply abundance resulting in a sharp fall in oil prices, massive inventory build-up and severely limited storage capacity. The situation was magnified by the price war initiated in March-April 2020 when Saudi Arabia and Russia, two of the largest oil-producing nations, engaged in a production conflict. While Saudi Arabia and OPEC's efforts to stabilize the market through proposed production cuts were answered by Russia's increased oil production, Saudi Arabia responded by heightened oil production as well, causing further depression of global oil prices (Ma *et al.* (2021)).

2.5 Economic Intuition Behind the Effect of Blend Mandate or Tax Credit on Fuel Prices

2.5.1 Blend Mandate - Literature Directly Related to Main Research Questions of This Thesis

The main hypothesis of this paper examines the effect of ethanol blending on the final fuel prices for end users. The basic intuition is that with increased level of ethanol blended into gasoline, the fuel price for consumers at the pump increases as well because the production costs for ethanol are higher than for gasoline. When blending more ethanol into gasoline, these higher costs are then transmitted to end users at the pump. Such intuition assumes two conditions: a perfect competition in the market, and gasoline and ethanol being perfect substitutes. The hypothesis is formulated as:

The RFS leads to an increase in the end user fuel prices.

Regarding the academic community, there seems to be no unequivocal consensus on the validity of this hypothesis - and the general perception of biofuels, whether positive or negative, brings no clarification to it. As de Gorter & Just (2009) write, a biofuel blend mandate could potentially increase or decrease the consumer price of fuel, depending on the relative supply elasticities of ethanol and gasoline. They suggest that in cases where ethanol supply demonstrates lower elasticity relative to gasoline, consumer fuel prices might increase due to an increment in the gasoline price relative to ethanol and vice versa. The most significant policy implication derived from de Gorter & Just (2009) analysis is the argument for the use of either a mandate or a tax credit, but not both simultaneously. Their paper proposes that a single policy tool can achieve the desired level of biofuel consumption more efficiently. According to de Gorter & Just, the advantage of using a mandate over a tax credit lies in avoiding direct taxpayer costs and the potential for higher gasoline prices, which may offset lower fuel taxes and align better with energy conservation goals.

De Gorter & Just finding is supported by Lapan & Moschini (2012). Their paper on welfare implications of biofuel policies, specifically focusing on the effects of quantity mandates and subsidies in the biofuels sector within a second-best policy framework, concludes that one might logically speculate that increasing a binding ethanol blend mandate would result in a growth in blended fuel prices, thereby reducing overall consumption. However, they continue with an important note that the outcome of such particular comparative statics scenario cannot be conclusively determined - it is possible that if ethanol supply exhibits greater elasticity compared to gasoline supply, increasing the ethanol blend requirement might actually decrease fuel prices and unintentionally increase overall fuel consumption within certain limits.

Based on the literature, Pouliot & Babcock (2014) examine the same research question with an important change in assumptions. In their study, ethanol and gasoline are treated as imperfect substitutes, meaning that the value of ethanol can vary greatly depending on consumer preferences, especially for those consumers buying higher ethanol blends. If there's a limit to how much of the high-blend fuel can be distributed, its demand becomes less responsive, making ethanol seem less valuable and its demand more fixed compared to gasoline. From that viewpoint, the study identifies several factors that play a role in how ethanol mandates affect fuel prices. These include how responsive the supply of ethanol is to price changes, how consumers react to changes in ethanol prices, and how these dynamics influence the cost of renewable fuel credits (RINs).

Lundberg *et al.* (2023) investigate impact of biofuel blending mandates on fuel prices on EU data up to 2020. They find negligible effect of biofuels blending on fuels prices. They argue that this may be due to low blending ratios in Europe (lower than 5 percent for ethanol).

2.5.2 Tax Credit (VEETC) - Literature Directly Related to Main Research Questions of This Thesis

Historically, another way of promoting biofuels besides the blending mandate has been a tax credit. As previously mentioned, the most prominent example of biofuels tax credit was the U.S. Volumetric Ethanol Excise Tax Credit (VEETC). The second research question therefore concerns this tax credit policy on ethanol, which was set to expire in December 2011 and provided subsidy on each gallon of pure ethanol that was blended into gasoline. The general intuition behind the subsidy was that, beyond the obvious support of ethanol producers and encouragement of the farmers, it should also lower the final blended fuel price, stating the thesis' hypothesis as:

The VEETC type of tax credit results in higher fuel price savings for consumers.

The underlying rationale is explored by de Gorter & Just (2009). Examining the impact of an ethanol tax credit alongside a mandatory blending requirement, it is noted that the tax credit specifically targets the share of fuel derived from biological materials. This approach differs significantly from a general fuel tax, which uniformly raises the supply cost of all fuel by a set amount. The share of fuel derived from biological sources is given by the ethanol blend mandate. As a result, an ethanol tax credit decreases the overall supply curve for fuel by the tax credit's value, leading to a reduction in the consumer price of fuel at the point where the revised supply curve meets existing demand. Consequently, this reduction in fuel prices prompts an increase in fuel consumption. In response to this heightened consumption, driven by both the tax credit and the blending mandate, the market price of ethanol rises to stimulate additional production to meet the increased demand.

Similarly to RFS, also this policy had its supporters and critics. Those in favor of the tax credit argued that the policy was successful at promotion of higher ethanol production while decreasing fuel prices for end users. In opposition, some viewed the tax credit as merely enrichment tool for ethanol producers. The findings by Bielen *et al.* (2018) agree with the critics of the subsidy. Bielen et al. calculate the effects of the tax credit using real data from the elimination of the VEETC instead of making predictions with estimated elasticities, which is a standard approach. Their technique offers a new methodology for evaluation of the impact of policies and market shifts through futures contracts. The findings indicate that a significant portion of the $0.45 per gallon of ethanol subsidy, likely around $0.25, went to ethanol producers when the subsidy ended. Additionally, there is evidence to suggest that corn farmers received about $0.05 per gallon. However, regarding the fuel consumers, the authors imply evidence of no or minimal benefits in the form of lower fuel prices resulting from the tax credit.

Chapter 3

Data

In the biofuels sector, one of the most reliable data sources are generally the United States Energy Information Administration (EIA) and the United States Department of Agriculture (USDA). Besides other activities, EIA focuses on the collection and assessment of energy data, hence providing an extensive database and information on energy production, stocks, demand, imports, exports, and prices. (U.S. Energy Information Administration (2024b)) The Economic Research Service (ERS) of USDA is dedicated to conducting rigorous research and analysis pertaining to the United States food supply system. Its primary objective is to anticipate trends and challenges predominantly associated with the agricultural sector and rural American communities. Furthermore, it endeavors to disseminate unbiased and high-caliber information to the general public. (U.S. Department of Agriculture (2024b))

This thesis focuses on the time period of the past fourteen years, from 2009 to 2022. The time period was selected after a careful consideration. Most of the models reviewed for the research of this thesis typically calibrate data from one year to another, providing results for a specific year. Nevertheless, the thesis aims to capture trends or abnormalities in the long-run scope, as well as to address the scarcity of research in the past few years in this particular academic field. Publication of de Gorter & Just (2009) framework and the model by Drabik *et al.* (2016) calibrated to data from 2009 also make the year of 2009 a reasonable starting point.

As the base variables of the models replicated in this thesis are often overlapping, one cumulative dataset was established, concerning prices, quantities, elasticities, policy variables and technical parameters for the basic commodities, i.e. corn, crude oil, gasoline and ethanol. All data were converted into integrated units in order to maintain the consistency of the data. In the United States, corn is measured in bushels where one bushel of corn yields around 2.8 gallons of ethanol. Crude oil, gasoline and ethanol are typically measured in gallons, even though some data streams apply the barrel measurement unit. All concerned data were therefore transferred to gallons, or dollars per gallons, with the conversion rate of 1 barrel equaling to 42 gallons.

Prices

The prices of ethanol and gasoline, two main components of the blended fuel, are one of the key factors of the models. When conducting the analysis, it is important to distinguish between their wholesale and retail prices. Ethanol is produced from corn in ethanol plants which sell ready-made ethanol to the blenders for a wholesale price. The same holds for gasoline - gasoline is produced from crude oil in refineries which sell ready-made gasoline to the blenders for a wholesale price. Both ingredients are then blended together with required shares of each and the gasoline blend is offered in the market for the retail price, including a constant markup. (Pouliot & Babcock (2016))

Ethanol Prices The wholesale ethanol prices are each year reported in The Annual Energy Outlook (AEO), published by U.S. Energy Information Administration (2024b). The study offers a comprehensive evaluation of the long run energy trends in the United States, delving into future projections of energy markets up to the year 2050. The AEO explores various aspects of the energy landscape, including the shifts in energy sources and consumption patterns, technological advancements and the impact of legislation on energy production and usage. The retail prices are then computed according to Pouliot & Babcock (2016) who define the wholesale-to-retail markup of $0.75/gal.

Gasoline Prices Both wholesale and retail gasoline prices are obtained from the detailed EIA dataset in the *Petroleum and Other Liquids* section. These prices represent the prices of gasoline before blending with ethanol. The source of the wholesale price is the U.S. Total Gasoline Wholesale/Resale Price by Refiners table which dates back to 1978, while the source for retail gasoline price is the U.S. All Grades All Formulations Retail Gasoline Price table from 1994.

Fuel Price The fuel price is the sales to end users gasoline price as reported by the U.S. Energy Information Administration (2024b) - it is a price of blended gasoline, already including ethanol. Additionally to sales through retail outlets, the metric also includes all direct sales to end users that were not made through company-operated retail outlets, e.g. sales to agricultural customers, commercial sales and industrial sales. For its comprehensiveness, the variable is used further on in this thesis as a comparison benchmark for the simulated fuel prices resulting from models.

Variable	**Unit**	**Mean**	**Max**	**Min**	**Range**
Corn price	$/gal	4.63	6.89	3.36	3.53
Crude oil price	$/gal	1.68	2.33	0.93	1.40
Ethanol price	$/gal	1.91	2.58	1.38	1.20
Gasoline price	$/gal	2.15	2.93	1.33	1.60
Fuel price	$/gal	2.43	3.15	1.73	1.42
Ethanol production	Mgal/d	39.40	44.09	29.97	14.12
Ethanol consumption	Mgal/d	36.93	39.87	30.24	9.63
Ethanol exports	Mgal/d	2.79	4.68	0.00	4.68
Motor fuel consumption	Mgal/d	376.76	392.26	342.25	50.01
Fuel tax	$/gal	0.46	0.49	0.45	0.05
Corn yield	bu/acre	164.36	176.70	123.10	53.60
Blend rate	%	9.80	10.43	7.95	2.49

Table 3.1: Summary statistics for the U.S. ethanol fuel market during the years 2009-2022
*Mgal/d stands for million gallons per day

Quantities

Quantities of crude oil, corn, ethanol and gasoline enter into the models mainly through supply and demand - production and consumption. Table 3.1 displays the summary statistics of the U.S. ethanol market for the time period of 2009-2022 with a focus on prices and quantities, the main inputs of the models.

Crude Oil and Gasoline Quantities All crude oil and gasoline quantities are taken from the EIA. The world crude oil production is reported in the *Petroleum and other liquids, International* data section. The U.S. crude oil imports and demand of finished motor gasoline (already blended with ethanol) are taken from the *This Week in Petroleum* summary. Finally, the U.S. crude oil supply is obtained from the *Short-term Energy Outlook (STEO)* report, which provides a comprehensive overview of the near-term trends and projections in the energy sector for commodities such as crude oil, natural gas, electricity, coal, and renewables.

Corn Quantities The data on U.S. corn demand as food or feed are obtained from *The World Agricultural Supply and Demand Estimates (WASDE)* report, released on a monthly basis by the World Agricultural Outlook Board of the USDA. The extensive forecast reports projections for major crops and livestock products, such as wheat, rice, coarse grains, oilseeds, cotton, sugar, meat and milk, on a global scale with a more detailed focus on the U.S. market. The domestic demand of corn as food or feed is computed based on the data from the WASDE as the difference between the total production of corn and the amount of corn used for production of ethanol and other by-products.

The remaining corn variables - the U.S. production of yellow corn, U.S. corn exports and corn yield - are taken from the Feed Grains Database of the Economic Research Service (ERS) of USDA. The database aggregates statistics focused on four principal feed grains (corn, grain sorghum, barley and oats), foreign coarse grains (inclusive of feed grains in addition to rye, millet, and assorted grains), hay, and associated articles. The data spectrum comprises of supply metrics, demand indicators, pricing information and feed-price ratios. The statistical compilation consists of data published in the monthly editions of the Feed Outlook as well as the annual Feed Grains Yearbook tables. The primary objective of the Feed Grain Database is to furnish a comprehensive array of both contemporary and historical time-series data.

Ethanol Quantities Both the U.S. ethanol production and consumption values are from the *Monthly Energy Review (MER)* by EIA. The U.S. exports of fuel ethanol are then obtained through the *Petroleum and other liquids, Ethanol* data section.

Elasticities

Important factor of the models are various elasticities, in the models usually utilized as weights of other base variables. The variables for demand and supply elasticities distinguish between values for the United States and for the rest of the world. Generally, elasticities have been quite difficult to determine and remain a matter in dispute within the academic circles, with research values varying across papers, sometimes indeed significantly. As Drabik *et al.* (2016) notes, the demand and supply curves exhibit constant price elasticities, therefore all of the presented estimates are ensured to represent the long-run data. The summary of elasticities chosen for the thesis, its values and sources is presented in Table 3.2 at the end of this section.

Gasoline Demand The price elasticity of demand for gasoline in the United States has been historically one of the most prevalent subjects of examination within the energy economics. Hausman & Newey (1995) examine the household pooled data through nonparametric estimation and find the long-run price elasticity of -0.81. Such result indicates high responsiveness of consumers to changes in gasoline prices. Later, Hamilton (2009) reports more plausible level of price elasticity to those presented in the 90s at estimate of -0.26 for the U.S. price elasticity. Another study by Havranek *et al.* (2012) uses mixed-effects multilevel meta-regression method to find the average long-run elasticity estimate of -0.31. Lin & Prince (2013) define static reduced-form demand model and dynamic partial adjustment model to determine long-run estimate at the level of -0.29. More recently, Coglianese *et al.* (2017) find the elasticity of -0.37 using the instrumental variable (IV) model regression adjusted by a lead and a lag, studying monthly data from January 1989 through March 2008. Comparing the result with other studies from 2008 to 2015, where many use completely different approaches and estimation methodologies, the authors confirm the validity and relevance of the result. The -0.37 value of price elasticity of demand for gasoline is therefore used in models of this thesis.

The literature on elasticity of world demand for gasoline does not provide such an extensive research as compared to the United States demand. The assumption is that there should not be significant differences between the US and world elasticity values. The chosen value of -0.40 follows findings presented by Galindo *et al.* (2015) and Drabik *et al.* (2016).

Gasoline Supply Both price elasticities of gasoline supply for the United States as well as for the rest of the world are taken from de Gorter & Just (2009) as they provide an in-depth framework for supply curves and prices in the biofuels market. The authors report a value of 0.20 for the price elasticity of gasoline supply for the United States and 0.71 for foreign countries, specifically for The Organization of the Petroleum Exporting Countries (OPEC). Later on, papers by Cui *et al.* (2011) and Drabik *et al.* (2016) refer to de Gorter & Just (2009) values as well. The elasticity of gasoline supply refers to pure gasoline before ethanol blending.

Corn de Gorter & Just (2009) are also the source for some of the corn related elasticities, namely the United States corn supply elasticity and nonethanol corn demand elasticity with reported values of 0.20 and -0.20, respectively.

Rest of the elasticities concerning the share of corn input in the production costs of fuel, food and other consumption goods, as presented in Wu & Langpap (2015) are kept at the same levels in line with the paper - 0.85 for the output elasticity of fuel, 0.07 for the output elasticity of food and 0.0004 for the output elasticity of other consumption goods. As the parameters are narrowly focused, the authors calculate the elasticities due to the lack of quantitative assessment of these particular elasticities within the academic community.

Ethanol Supply The price elasticity of ethanol supply was studied by Rask (1998) through Tobit and Probit models, reporting a value of 0.75 based on data for the time period January 1988 - May 1993. Later, Luchansky & Monks (2009) update Rask's models and results through two-stage least squares (2SLS) model regression and argue a lower elasticity value of 0.26. McPhail & Babcock (2012) use stochastic partial equilibrium simulation to define the elasticity of ethanol supply at even lower level of 0.13.

Elasticity	**Value**	**Source**
Gasoline demand - U.S.	-0.37	Coglianese *et al.* (2017)
Gasoline demand - foreign	-0.40	Galindo *et al.* (2015)
Gasoline supply - U.S.	0.20	de Gorter & Just (2009)
Gasoline supply - foreign	0.71	de Gorter & Just (2009)
Corn supply - U.S.	0.20	de Gorter & Just (2009)
Nonethanol corn demand - U.S.	-0.20	de Gorter & Just (2009)
Ethanol supply - U.S.	0.26	Luchansky & Monks (2009)
Output elasticity of fuel	0.85	Wu & Langpap (2015)
Output elasticity of food	0.07	Wu & Langpap (2015)
Output elasticity of other goods	0.0004	Wu & Langpap (2015)

Table 3.2: Elasticities, values and sources used in models

Technical Parameters & Other Values

Besides the already mentioned parameter for the wholesale-to-retail constant markup of \$0.75/gal, the dataset includes other technical parameters. Probably the most important is the level of ethanol blended into gasoline, obtained from the Renewable Fuels Association (RFA). The content of ethanol in blended fuel has been slightly above 10% in the past few years. The RFA reports the ethanol blend rate as the share of the total fuel ethanol consumption and total motor fuel consumption.

The lower energy efficiency of ethanol as compared to pure gasoline is expressed through the amount of miles a vehicle is able to travel per gallon of ethanol relative to the gasoline. The parameter is assigned a value of 0.7 as the average energy content of ethanol per gallon is around 30% less than gasoline. (U.S. Department of Energy (2024a)) The parameter for the ethanol-corn yield is set to 2.8 gallons of ethanol per one bushel of corn, following Eidman (2007). EIA reports 19-20 gallons of gasoline produced per barrel of crude oil, which converts to circa 0.5 gallons of gasoline obtained from a gallon of crude oil.

The value of consumers' time endowment is derived in Wu & Langpap (2015) as the average number of hours that every person divides between leisure and labour. The assumed value is 16 hours as an average human sleeps for 8 hours and is productive for the rest of the day. Finally, all data for the determination of the household consumption expenditures for leisure, food, gasoline and other consumption goods are taken from the Consumer Expenditure Survey, released annually by the U.S. Bureau of Labor Statistics.

Policy Variables

The U.S. fuel tax applied in this thesis is based on data provided by EIA and comprises of two components; federal and state fuel tax. The federal tax is a constant of 18.4 cents per gallon of gasoline and applies to all states. The tax has remained at the same level since its latest adjustment in 1993. The federal tax is not indexed for inflation hence in nominal terms, the tax has been gradually decreasing in its purchasing power, losing nearly half of its value since the last revision. The state fuel tax is the average state tax for a given year as the level of the tax is governed by each state separately and therefore varies across the country. The state fuel tax composes of the general sales tax and associated fees, which may include inspection fees, environmental fees, use taxes, or other charges. On January 1, 2024, the difference between the lowest and highest state taxes was 59.15 cents per gallon; Alaska with 8.95 cents per gallon and 68.1 cents per gallon in California. (Energy Information Administration (2024d)

The fuel tax in the rest of the world is taken as the 2019 average of the OECD countries, reported by the U.S. Department of Energy (DOE) at the level of 2.06 dollars per gallon of gasoline. The tax credit on ethanol, VEETC, had been effective since 1979 and was allowed to expire on December 31, 2011 at the level of 45 cents per gallon of pure ethanol.

Goulder & Williams (2003) assume a labor tax rate of 40 percent which had been the highest federal income tax bracket on ordinary income until 2018, when it was reduced to 37 percent. Both tax rates on food and other consumption goods were obtained from the Federation of Tax Administrators (2024). The tax rate of food is the average state sales tax rate on food taken only from the U.S. states that impose a tax on food while the taxation of other consumption goods is determined by the average state sales tax based on all 51 states.

Chapter 4

Methodology

The crucial part of the thesis was to select proper equilibrium models that would be able to reflect the studied hypotheses with a great precision and also whose authors are significantly relevant within the academic field. For that reason, the models introduced by de Gorter & Just (2009), Drabik *et al.* (2016) and Wu & Langpap (2015) were chosen as these three models are the most relevant to the research topic out of the existing academic literature.

All three models are microeconomics models based on microeconomics theory. The de Gorter & Just model is a theory based partial equilibrium (PE) model. It is widely cited with more than 400 Google Scholar citations as a foundational original model of ethanol impact on fuel price. The Drabik et al. model is a simulation PE model based on the de Gorter & Just model, substantially extending and enlarging the original model. Finally, the Wu & Langpap model is a general equilibrium (GE) model, chosen for its similarity and direct comparability to the first two PE models.

The analysis process was identical for all three models employed in the thesis as described below. First, a proper understanding and decomposition of each model into its base variables was conducted in order to gain the ability of rebuilding each model from the ground up. After the reconstruction, all of the initial original values from the respective years were put into the original models and the results were carefully compared with the numerical results obtained in those original models. Our replication process produced identical results to the original models, confirming the accuracy of the approach. This verification allowed for further extensions and development of our adjusted, derived fuel price models as the de Gorter & Just, Drabik et al., and Wu & Langpap models were not primarily focused on the same research question as this thesis. Altogether with calculations that employ new and updated data into the developed fuel prices models, the methodology is the cornerstone and main contribution of this thesis.

4.1 De Gorter & Just Model (2009)

Many of the papers published in the past 15 years on the topics associated with modelling of biofuels, in most cases focusing on ethanol and its policy and economic impacts such as Pouliot & Babcock (2016), Drabik *et al.* (2016) or Bento *et al.* (2015), are based on the framework and model introduced by de Gorter & Just (2009) in their AJAE paper *Economics of a Blend Mandate for Biofuels.* When analyzing the economics of a blend mandate and deriving implications of introduced policies, the authors develop a conceptual framework that studies the effect of a change in the level of ethanol blended into gasoline on the resulting blended fuel price, as well as the effect of combining the binding blend mandate with an ethanol tax credit. The framework has served as an important basis for further analysis and derivations concerning the topic within the academic community. For that reason, this thesis starts with this base model.

In consideration of a competitive market, the model necessitates the fulfillment of three equilibrium conditions. For the first condition, the upward sloping ethanol supply curve S_E, horizontal gasoline supply curve S_G and downward sloping fuel demand curve D_F are defined. Then, all of the fuel that is being traded in the market is obliged to contain a specific level of ethanol, α, following the current mandate. The weighted average consumer price of fuel including blended ethanol P_F equals the marginal cost that the customers are required to pay to the blenders for processing the blended fuel, as given by the right-hand side of the equation (4.1) that weighs the average prices of wholesale ethanol, P_E, and gasoline before blending, P_G, by the ethanol proportion blended into the gasoline while taking into account a volumetric tax on all fuel t and ethanol tax credit t_E:

$$P_F = \alpha(P_E + t - t_E) + (1 - \alpha)(P_G + t) \tag{4.1}$$

The model assumes endogenous gasoline prices, zero biofuels imports and a blended fuel composed of two ingredients only - gasoline and ethanol, where both of the components are considered perfect substitutes in consumption.

Further on, the authors determine such market prices of the blended fuel that result in equality of the total fuel supply and total fuel demand, $S_F(P_F) = D_F(P_F)$, in order to find the equilibrium prices for the wholesale ethanol and gasoline before blending, P_E and P_G respectively. The market-clearing condition is then found intuitively by setting the fuel mixture demand equal to the supply of gasoline and supply of ethanol curves:

$$D_F(P_F) = S_G(P_G) + S_E(P_E) \tag{4.2}$$

The third and last equilibrium assumption considers a constraint imposed by the mandate as the consumption of ethanol must be equal to $\alpha D_F(P_F)$ for any blended fuel price P_F. The equilibrium price of wholesale ethanol, P_E, is implicitly defined as:

$$\alpha D_F(P_F) = S_E(P_E) \tag{4.3}$$

The authors continue with an analysis of the increased blend mandate and the effect it has on the consumer fuel prices. In order to perform such an analysis, they carry out a thorough derivation of the base model, mainly through a partial differentiation of the blended fuel price equilibrium condition (4.1) with respect to the level of blended ethanol α:

$$\frac{\partial P_F}{\partial \alpha} = \frac{(P_G - P_E) - \left(\frac{P_E}{\eta_E^S} - \frac{P_G}{\eta_G^S}\right)}{\frac{P_E}{\eta_E^S}\left[\alpha\frac{\eta_G^D}{P_F} - \frac{\eta_E^S}{P_E}\right] + (1-\alpha)\frac{\eta_G^D}{P_F}\frac{P_G}{\eta_G^S}} \tag{4.4}$$

Here η_E^S, η_G^S, η_G^D, are the supply and demand elasticities (denoted by the superscript S and D) of ethanol and gasoline.

Through examination of all components of the derived expression (4.4), de Gorter & Just find that the denominator takes on a below zero value in every scenario. The numerator, however, might take on values both negative or positive. The blended fuel price P_F then increases with increasing the blend mandate α when both the numerator and denominator result in negative values, as the fraction of negative value and negative value results in a positive output - hence the positive direction of a change in fuel price P_F with an increase in the blend mandate α. The numerator is negative when the following condition holds:

$$P_G(1 + \frac{1}{\eta_G^S}) < P_E(1 + \frac{1}{\eta_E^S}) - t_E \tag{4.5}$$

Based on these derivations, the authors conclude that in the absence of an ethanol tax credit t_E, the blended fuel price P_F moves in the same direction as the level of ethanol blended into gasoline α if the price weighted elasticity of gasoline supply η_G^S is larger than the price weighted elasticity of ethanol supply η_E^S. Assuming a scenario where the elasticity of gasoline supply equals the elasticity of ethanol supply, i.e. $\eta_G^S = \eta_E^S$, the price of fuel P_F increases with higher ethanol blends α when the price of gasoline is lower than the price of ethanol: $P_G < P_E$.

Further studying the intuitive framework by de Gorter & Just (2009), it is found that the model does not account for energy equivalence of the ethanol as compared to gasoline. Being previously mentioned throughout the thesis, the importance of the equivalence lies in the fact that ethanol contains around 70% of effective gasoline energy, hence all values associated with ethanol should be adjusted and divided by 0.7 - approximate estimate reported by both the Energy Information Administration (2024c) and U.S. Department of Energy (2024a). As presented in the table 3.1, the average wholesale price of gasoline for the period 2009-2022 is $2.15 per gallon. A gallon of ethanol is then cheaper at an average wholesale price of $1.91. The condition for 4.5 assuming the same supply elasticities for gasoline and ethanol therefore does not hold.

However, after the energy density correction for comparison purposes, a gallon of ethanol results with an average wholesale price of $2.73. The energy-efficient adjusted price of a gallon of ethanol is then more expensive than the price of a gallon of gasoline - in other words, it is technically less expensive to obtain energy from crude oil than from corn. The outcome fulfills the condition 4.5, leading to a positive increase in the price of fuel associated with an increment in the level of ethanol blended into the gasoline.

The main hypothesis of this diploma thesis therefore reflects upon their finding, i.e. examining whether the increased level of blend mandate increases the blended fuel price.

4.2 Drabik et al. Model (2016)

Building up on the model introduced by de Gorter & Just (2009), Drabik *et al.* (2016) focus on the implications of ethanol policies to the price transmission in corn and food markets. As the biofuels production is generally significantly dependent on policies in force, the dominant policies affecting the amount of ethanol produced in 2009, the year of interest of the model, were the blend mandate and a blenders ethanol tax credit. The model by Drabik *et al.* (2016) therefore offers three different scenarios: a) the no biofuel benchmark, b) a binding blend mandate, and c) a binding blender's tax credit.

The first scenario establishes a baseline framework with absent biofuel production and hence no applicable, biofuels supporting laws. In such market, corn is being utilized in two ways only - (i) in a domestic food and feed consumption, i.e. cornstarch, corn oil, feed for hogs etc, and (ii) as an exported commodity. With that intuition, the authors define a system of equations for the total U.S. corn supply $S_C(P_C)$, total demand for food $D_f(p)$ and a profit maximizing first-order condition applicable in the corn processing industry:

$$S_C(P_C, Y_1) = x + \bar{D}(P_C, Y_2) \tag{4.6}$$

$$D_f(p, Y_3) = f(x) \tag{4.7}$$

$$pf_x = P_C \tag{4.8}$$

where x stands for the U.S. food and feed corn production and $\bar{D}$ is the export demand curve facing the U.S. market. Altogether, these equations define the equilibrium in the market. After including exogenous market shocks Y_i, where $i = 1, 2, 3$ stand for the corn supply, corn export demand and food demand respectively, Drabik *et al.* (2016) determine the price transmission elasticities.

Biofuels are presented into the framework through a linkage between ethanol and the corn-food supply chain through a definition of the general ethanol supply curve $S_E(P_E)$. The logic behind the ethanol supply is that the ethanol plants obtain only the amount of produced corn that is left after taking care of the domestic food and feed production and exports:

$$S_E(P_E) = \frac{\lambda\beta}{1 - r\delta}[S_C(P_C, Y_1) - x - \bar{D}(P_C, Y_2)] \tag{4.9}$$

The complete ethanol supply curve is weighted by several conversion parameters; λ is the energy equivalent coefficient of ethanol relative to the gasoline, β denotes the amount of ethanol (in gallons) commonly obtained from a bushel of corn and δ stands for the portion of an ethanol co-product, referred to as the DDGS (dried distillers grains with solubles), that is restored to the market in the form of an animal feed.

The fuel market with ethanol blended gasoline then reaches its equilibrium when the blended fuel demand, $D_F(P_F)$, is set equal to the sum of gasoline supply, $S_G(P_G)$, and ethanol supply, $S_E(P_E)$:

$$D_F(P_F) = S_G(P_G) + S_E(P_E) \tag{4.10}$$

The binding blend mandate and binding blender's tax credit scenarios refer to the previous work of de Gorter & Just (2009) by adapting their model as presented in the section 4.1 and accounting for the energy efficiency of ethanol, exogenous market shocks and others. The full biofuels model is then able to asses the price transmission in the fuel market under different policies and market shocks.

One of the most important improvements of the original de Gorter & Just (2009) model made by Drabik *et al.* (2016) is the implementation of the energy equivalent parameter, λ, which the authors apply throughout the framework to ethanol related variables. The adjustment is crucial for a proper analysis and suggests that results from Drabik *et al.* (2016) model should be more accurate and reliable.

4.2.1 Derived Fuel Price Model

The Drabik *et al.* (2016) framework examines solely the price transmission in the fuel and food market and the effect of various ethanol policies and market shocks on the transmission. This thesis is, however, focused on the price effect of the ethanol policies on the prices that consumers pay at the pump. One of the thesis' key contributions is therefore the derivation of the separate fuel price model in the form of a system of equations and resulting implementation of the model to the analysis while incorporating the collected dataset of base variables.

Extraction of the model as introduced by Drabik *et al.* (2016) with a focus on the essential components was executed through thorough examination and decomposition of the model into its prime factors and expressions. Then, a new model for simulated blended fuel price was derived. As this thesis focuses on the period of the past fourteen years, 2009-2022, the effective biofuels policies had to be reviewed. The Volume Ethanol Excise Tax Credit (VEETC) expired on Dec 31, 2011 and no other U.S. policy regarding ethanol tax credit has been implemented since then. Therefore, the VEETC variable is kept in the model and its value is set to zero after year 2011. The ethanol blend mandate, as determined by the Renewable Fuel Standard, is still effective and has been slowly increasing year after year.

The resulting model for simulated blended fuel price P_F is dependent on the U.S. gasoline supply S_G, foreign gasoline supply S_{G_F}, foreign gasoline consumption D_{G_F}, an auxiliary calibrated parameter for the U.S. fuel consumption A, the level of blend mandate α and U.S. gasoline demand elasticity η_G^D:

$$P_F = \left[\frac{S_G + S_{G_F} - D_{G_F}}{A(1-\alpha)}\right]^{\frac{1}{\eta_G^D}} \tag{4.11}$$

with

$$S_G = \frac{D_F - D_E}{S_O + I_O} S_O \tag{4.12}$$

$$S_{G_F} = \frac{D_F - D_E}{S_O + I_O}(\bar{S_O} - S_O) \tag{4.13}$$

$$D_{G_F} = S_G + S_{G_F} - GUS \tag{4.14}$$

where D_F is the motor fuel consumption, D_E is the U.S. ethanol consumption, S_O is the U.S. oil supply, $\bar{S_O}$ is the world oil production and I_O is the U.S. import of crude oil.

Substituting (4.14) into (4.11), the simulated blended fuel price equation can be simplified to

$$P_F = \left[\frac{GUS}{A(1-\alpha)}\right]^{\frac{1}{\eta_G^D}} \tag{4.15}$$

Variable GUS determines level of the U.S. gasoline consumption by subtracting the amount of U.S. ethanol supply from the total amount of the U.S. motor fuel consumption D_F:

$$GUS = D_F - \frac{E}{\lambda} \tag{4.16}$$

The energetic equivalent of ethanol production, E, is equal to the ethanol consumption and was derived from raw data on variables for the U.S. production of yellow corn S_C, U.S. domestic corn demand as food/feed D_x, U.S. corn exports X and ethanol parameters.

$$E = \lambda\beta(S_C - D_x - X) \tag{4.17}$$

The calibrated parameter for U.S. fuel consumption A equals to the ratio of U.S. blended fuel consumption D_F and de Gorter & Just (2009) equation for price of blended fuel, adjusted by the U.S. gasoline demand elasticity η_G^D:

$$A = \frac{D_F}{[\alpha(P_e + \frac{t}{\lambda} - \frac{t_E}{\lambda}) + (1-\alpha)(P_G + t)]^{\eta_G^D}} \tag{4.18}$$

Here P_e is the wholesale price of ethanol expressed in energy terms, computed as the ratio of the ethanol wholesale price, P_E, and the energetic equivalent of ethanol relative to gasoline, λ: $P_e = \frac{P_E}{\lambda}$. The U.S. blended fuel consumption D_F is the sum of the ethanol production E and the U.S. gasoline consumption GUS; $D_F = E + GUS$.

This theoretical framework allows for assessment of various policy programs that could influence the variable of our interest, P_F. According to the framework, a lower wholesale price of ethanol, P_E, would lead to a lower value of A in 4.18 and through the parameter would therefore affect the final fuel price at the pump, P_F, by decreasing its potential value. Theoretically, the wholesale price of ethanol could be effectively reduced by implementation of a government subsidy which would decrease the cost of ethanol production and hence encourage producers to make more ethanol. As a result, the ethanol supply curve shifts to the right as the supply is increased, with lower equilibrium ethanol price P_E and thus lower blended fuel price P_F.

Similarly to a government subsidy, the introduction of an ethanol tax credit would reduce the ethanol production cost and therefore influence the resulting ethanol price P_E in the same way as subsidy, lowering the blended fuel price P_F. The equilibrium effect of subsidy or ethanol tax credit is pictured in Figure 4.1.

The main difference between a subsidy and a tax credit is that subsidy provides direct financial support to a firm, whereas tax credit reduces the amount of tax a firm owes. Even though both policies would theoretically result in the same effect on final blended fuel price at the pump, P_F, the complexity of the policies and its effects on markets should be analysed with respect to real past examples, such as the VEETC mentioned in Chapter 2.3.

The final blended fuel price, P_F, could also be impacted through policy incentives targeted at the overall blended fuel consumption D_F. For example, the implementation of a fuel efficiency standards that promote or mandate higher fuel efficiency could reduce overall fuel consumption, requiring less ethanol to be blended into the fuel, shifting the ethanol demand curve to the left and

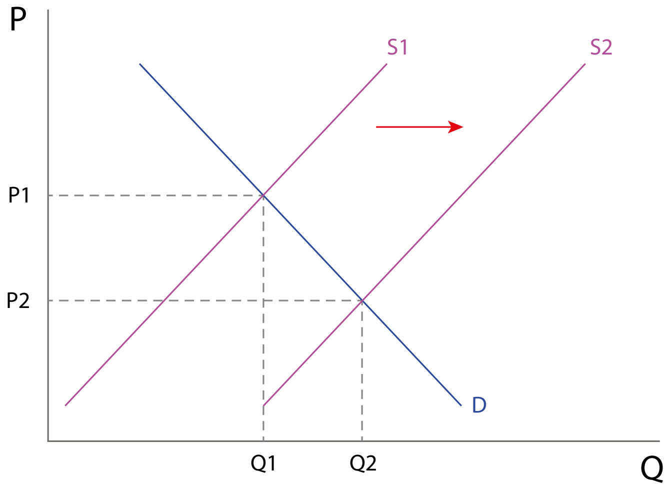

Figure 4.1: Shift in ethanol supply associated with subsidy or ethanol tax credit

leading to a decreased fuel price P_F. Figure 4.2 displays the effect of the policy on the market.

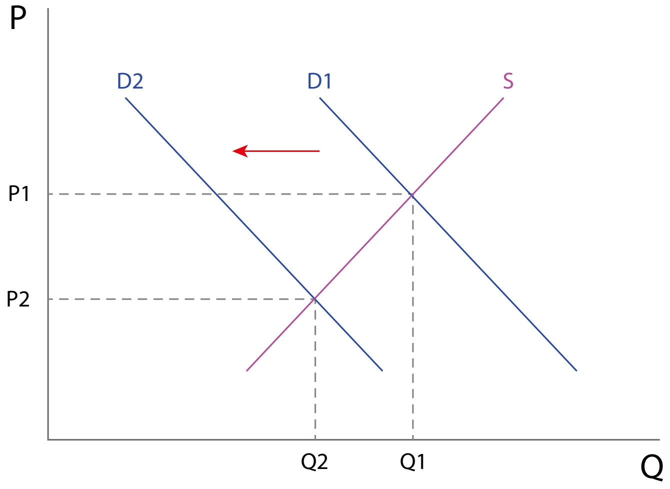

Figure 4.2: Shift in ethanol demand resulting from implementation of fuel efficiency standards

For other examples, investments in research and development sector focused on the advancement of new technologies and the improvement of ethanol production efficiency contribute to cuts in the long-run ethanol production costs, subsequently reducing the blended fuel price P_F.

4.3 Wu & Langpap Model (2015)

A third model is examined within the thesis for a comparison reference to the models by de Gorter & Just (2009) and Drabik *et al.* (2016), employing additional variables. Wu & Langpap (2015) define a general equilibrium framework in order to asses the interconnections between biofuel mandates and subsidies, especially focusing on their effect on crops, food and energy markets and prices, as well as the overall consumer welfare within the structure. The authors expand an original model introduced by Goulder & Williams (2003) and calibrate it to the 2011 data. The main reason for incorporating this model into our analysis is due to its ability to capture relationships among different markets. The framework distinguishes between two markets; (i) intermediate goods markets (specifically corn, C, crude oil, O and other intermediate goods markets, M) and (ii) consumption goods markets (gasoline, G, food, f, and markets with other goods, Z), with four agents in operation: consumers, producers of intermediate goods, producers of consumption goods and governments.

The authors introduce the continuous, quasi-concave household utility function, maximized by consumers spending of their income on different consumption goods i as measured by the total consumption, C_i,

$$U(l, C_G, C_f, C_Z), \tag{4.19}$$

with a household time constraint $T = l + \sum_i L_i + \sum_j L^j$. The time endowment is in reality different for each consumer as every person splits their time between leisure, l, and labor, L, differently according to their possibilities. However for purposes of the thesis, the time endowment is assumed a constant throughout the examined time period.

Within the context of a biofuel mandate, the United States primarily utilize corn-based ethanol for biofuels. The mandate necessitates a specific ratio of ethanol to crude oil for fuel production. A unit of ethanol, indicated by β, is defined by the amount of biofuel produced from one unit of corn, equivalent to 2.8 for corn-based ethanol with current technology. The volume of gasoline produced from one barrel of crude oil is signified by a and approximates to 0.5. The biofuel mandate, α, stipulates a minimum blend threshold and can be expressed through a and β as $\alpha \leq \beta I_F^C / (a I_F^O + \beta I_F^C)$.

The production function of fuel with a biofuel mandate is then defined:

$$C_F = F_G(L_G, a I_G^O + \beta I_G^C, I_G^M) \tag{4.20}$$

assuming that ethanol and gasoline are perfect substitutes below the minimum blend rate. The variable I_i^j determines the amount of intermediate good j (i.e. crude oil, corn and other intermediate goods) which is utilized in the production process of a consumption good i, in this case the fuel F. Generally, it must hold that this amount of an intermediate good j being utilized in the production process of a consumption goods i is equal to the actual produced amount of the intermediate good:

$$\sum_{i=G,f,Z} I_i^j = I^j \tag{4.21}$$

Concerning the amount of labor needed for the production of goods, the model by Wu & Langpap (2015) assumes normalized units where one unit of labor produces one unit of output.

4.3.1 Derived Fuel Price Model

The utilized model for equilibrium blended fuel price, P_F, is

$$P_F = \frac{\gamma_G^\lambda [(1-t_L)T + \mathrm{GOV}]^\lambda [a\alpha P_{C*} + \beta(1-\alpha)P_O]^{\eta_G^C}}{\phi_G (1-t_c)^{1-\lambda} (a\beta)^{\eta_G^C}} \tag{4.22}$$

where γ_G is the household consumption expenditure share for gasoline, λ is the miles per gallon of ethanol relative to gasoline adjustment for energy equivalence, t_L represents the labor tax rate and t_c is the calibrated tax rate of fuel, defined as the percentage share of fuel tax t in gasoline price P_G. The model also employs a consumer time endowment, T, which is the number of hours per day that the consumer divides between labor and leisure. The parameters a and β are used for efficiency scaling of the intermediate goods, crude oil and corn; a stands for the amount of gasoline produced from a gallon of crude oil and β stands for the amount of ethanol produced from a bushel of corn. P_{C*} represents the equilibrium price of corn and P_O is the West Texas Intermediate (WTI) price of crude oil. The output elasticity of gasoline, η_G^C, indicates the share of corn input in the production costs of blended fuel.

The model also employs a government lump-sum transfer payment, GOV, that the government compensates the households with and provides biofuel subsidies to biofuel producers. It enters the model as

$$GOV = T(1-t_L)\left[\frac{\gamma}{\gamma_l + (1-t_L)\sum_i (1-t_i)\gamma_i} - 1\right] \tag{4.23}$$

for $i = G, f, Z$, differentiating between gasoline, food and other consumption goods variables. Here γ is the total household consumption expenditure, summing up together fractional consumption expenditures of households, and t_i are different tax rates.

The equilibrium price of corn is obtained through variables for the time endowment, various tax rates, supply of corn S_C, elasticities, household consumption expenditures, crude oil price and ethanol blend level:

$$P_{C*} = \left\{ \frac{T(1-t_L)}{S_C[\gamma_l + (1-t_L)\sum_i (1-t_i)\gamma_i]} \left[(1-t_f)\eta_f^C \gamma_f + \right. \right.$$
$$\left. \left. (1-t_Z)\eta_Z^C \gamma_Z + (1-t_c)\eta_G^C \gamma_G \frac{a\alpha}{a\alpha + \beta(1-\alpha)\tilde{P_O}} \right] \right\}^{\frac{1}{1+\eta}}$$

Output elasticities of gasoline, food and other consumption goods; η_G^C, η_f^C and η_Z^C, determine the share of corn input in the production costs of the respective consumption goods. $\tilde{P_O}$ is the share of WTI crude oil price and corn price: $\tilde{P_O} = \frac{P_O}{P_C}$.

The final term incorporated into the equilibrium fuel price model reflects the utilization of the real price of corn P_C and the wholesale gasoline price P_G:

$$\phi_G = \frac{\gamma_G^\lambda [(1-t_L)T + \mathrm{GOV}]^\lambda [a\alpha P_C + \beta(1-\alpha)P_O]^{\eta_G^C}}{P_G(1-t_e)^{1-\lambda}(a\beta)^{\eta_G^C}} \tag{4.24}$$

Chapter 5

Empirical Results

The empirical analysis conducted in this thesis builds upon the theoretical underpinnings of biofuel economics and policies as discussed in the preceding chapters. With an emphasis on the United States' ethanol fuel market from 2009 to 2022, the empirical results presented herein are derived from the application of three equilibrium models: the de Gorter & Just model, the Drabik et al. model, and the Wu & Langpap model. These models offer varying perspectives on the impacts of ethanol blend rates and tax credits on fuel prices, providing a multi-faceted view of the market dynamics influenced by policy interventions such as the Renewable Fuel Standard (RFS) and the Volumetric Ethanol Excise Tax Credit (VEETC).

The three models discussed are grounded in microeconomics theory. The de Gorter & Just model, a widely cited partial equilibrium (PE) model, has garnered over 400 citations on Google Scholar. Building on this foundation, the Drabik et al. model expands the original de Gorter & Just model, serving as a simulation PE model. In contrast, the Wu & Langpap model employs a general equilibrium (GE) approach, chosen for its comparability to the other two PE models.

The aim of this thesis is a thorough examination of the ethanol fuel market and of the associated policies. The main hypotheses are:

1. The RFS leads to an increase in the end user fuel prices.

2. The VEETC type of tax credit results in higher fuel price savings for consumers.

Important notion regarding the energy equivalence of ethanol fuel and gasoline reflected in the results: A gallon of ethanol contains around 30% less energy content when compared to gasoline as stated by the United States Department of Energy (U.S. Department of Energy (2024a). Therefore it is crucial for an accurate analysis to take into account the energetic discrepancies and incorporate appropriate metrics within the framework of the models. Both Drabik et al. and Wu & Langpap, the two more elaborated models of this research, apply the technical parameter *Miles per gallon of ethanol relative to gasoline* within the structure of the models. The coefficient is a constant of 0.7 and bridges the differences of the energy contents.

5.1 Modelling of the Fuel Prices in 2009-2022

The replication analysis of all three papers as described in Chapter 4 preceded the simulation of fuel prices for the time period 2009-2022. A thorough decomposition and subsequent reconstruction of the models from the highest level to the base variables was carried out, in order to replicate the models with original variables and confirm the consistency of the models and accuracy of the analytical processes.

While the Drabik et al. framework focuses on price-transmission elasticities and the Wu & Langpap paper is concerned with percentage changes in prices and consumer utility associated with different levels of ethanol subsidies and mandates, the replication was performed from the ground up to a certain level of each of the models' needed for the analysis of this thesis. Therefore, the replication focused on a confirmation of the values of compound variables in each model as defined in Chapter 4. The original data for the respective calibrated years reported in the three papers resulted in identical values of the compound variables, confirming the accuracy of frameworks and further allowing for the derivation of fuel price models. The contribution of this paper lies in the derivation of these fuel price models as the original papers were aimed at different research questions.

Finally, the simulation of derived fuel prices models was performed for the examined period of the years 2009-2022 with the most current data as reported in Chapter 3. The results obtained from the simulation are presented in Table 5.1. The table summarizes the simulated fuel prices, as predicted by the studied models, compared with the actual fuel prices observed in the market. The blend rate of ethanol, which is the percentage of ethanol mixed with gasoline, shows a consistent increase over the analyzed period, reflecting a policy trajectory toward greater renewable fuels utilization. The blend rate is determined each year by the RFS as an average share of the U.S. ethanol consumption in the total U.S. motor fuel consumption.

Year	**Blend rate** %	**Fuel price** $/*gal*	**de Gorter** $/*gal*	**Drabik** $/*gal*	**Langpap** $/*gal*
2009	7.95%	**1.89**	2.20	2.18	1.90
2010	9.22%	**2.30**	2.53	2.34	2.29
2011	9.41%	**3.05**	3.24	3.08	2.98
2012	9.72%	**3.15**	3.35	3.11	3.03
2013	9.84%	**3.05**	3.22	3.24	2.97
2014	9.90%	**2.86**	3.03	3.07	2.79
2015	9.94%	**2.00**	2.23	2.18	1.86
2016	10.04%	**1.73**	1.98	2.02	1.60
2017	10.20%	**1.98**	2.13	2.06	1.84
2018	10.10%	**2.30**	2.40	2.31	2.14
2019	10.16%	**2.25**	2.28	2.15	2.02
2020	10.15%	**1.83**	1.82	1.73	1.46
2021	10.17%	**2.57**	2.60	2.52	2.31
2022	10.43%	**3.00**	3.13	2.95	2.90

Table 5.1: Resulting simulated fuel prices, dollars per gallon

The fuel price is the U.S. sales to end users fuel price reported by the U.S. Energy Information Administration (2024b) and serves as a chosen comparison benchmark for the simulated results, with values varying between 1.73 and 3.15 dollars per gallon. The fuel prices exhibit fluctuations that do not necessarily correlate with the increasing trend of ethanol blend rates, suggesting the presence of other influential factors in price determination. This observation is in line with the market's complexity, where variables such as crude oil prices, agricultural yields, and global economic events intertwine to shape the final cost to end-users.

When comparing the models' simulated prices with the actual fuel prices, the Drabik et al. model apparently adheres closest to the real-world data, indicating a possible superior calibration of this model to real market conditions. In contrast, the de Gorter & Just model and the Wu & Langpap model tend to overestimate and underestimate the prices, respectively. Each model's predictive ability varies in different contexts. For example, the Wu & Langpap (2014) model tends to yield underestimations of fuel prices during periods marked by elevated market prices, suggesting potential omissions of certain factors that catalyze price surges within its predictive framework. Conversely, the de Gorter & Just model demonstrates a tendency to overestimate fuel prices in instances where the market exhibits a downturn, such as observed in the year 2016. This pattern may imply an overemphasis on specific variables which actually exerted a diminished influence during that period.

Derived fuel prices fluctuate around real fuel price with significant deviations in only some years. The initial year of examination, 2009, is overestimated by 15-16%, or 0.30 dollars per gallon, by both de Gorter & Just (2009) and Drabik *et al.* (2016) derived models. Also, all three models seemingly fail to accurately capture the reality of the simulation period around year 2016 with 8-16% divergences (in absolute terms). The highest deviation of 20%, equal to 0.37 dollars per gallon, is reported in 2020 by the model derived from Wu & Langpap (2015).

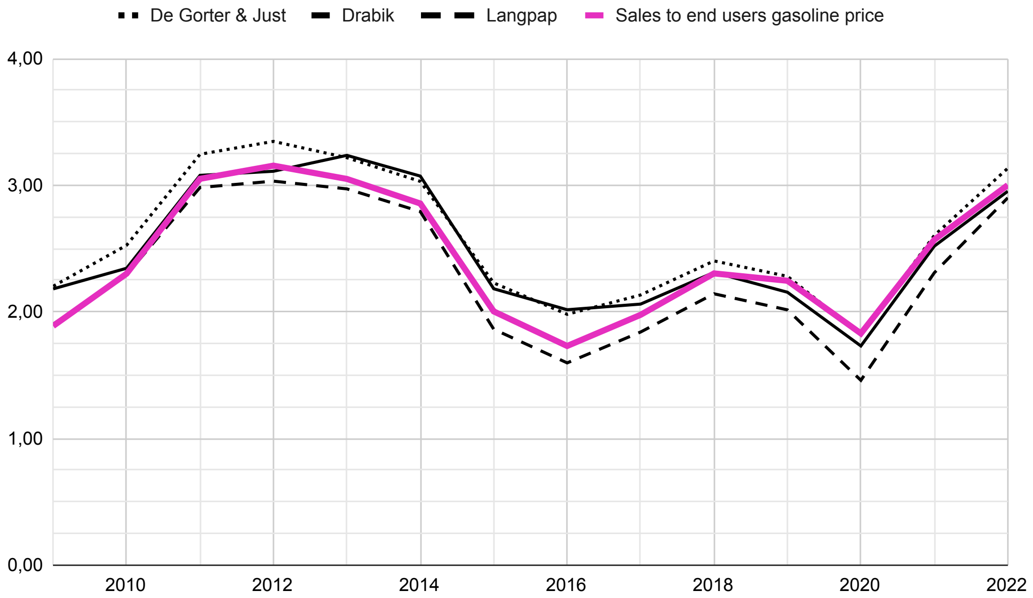

Figure 5.1: Comparison of simulated fuel prices obtained from the derived models and the actual sales to end users fuel price

The empirical findings are further visualized in Figure 5.1, which depicts the temporal evolution of the modeled prices against actual prices. The graphical representation confirms the tabular data's narrative, illustrating the relative accuracy of the Drabik et al. model and slightly greater systematic deviation of the other two models. However, all three models capture the overall trend of the fuel prices very well. It is particularly notable that despite the marginal divergence of the simulated prices from the real prices around year 2016, all three models capture the dramatic dip in prices between 2014-2016, a reflection of global crude oil price declines during that period.

As mentioned in Chapter 2.4, a major part of the decrease was due to adverse demand shocks, signaling a slowdown in the global economy. Additionally, a significant portion of the price drop was expected because of optimistic projections for both current and future oil production prior to July 2014. Besides these anticipated factors, the remaining overall drop in prices was unexpected and stemmed from a sudden change in oil price expectations, which reduced the demand for oil inventories. Moreover, a notable negative demand shock in December 2014, caused by an unpredicted downturn in the global economy, further contributed to the price decline.

Later on, all three models also depict the temporary decrease in 2020 driven by the economic impact of the COVID-19 pandemic, which led to a significant contraction in transport fuel demands, and the Russia-Saudi Arabia oil price war. The global spread of the pandemic in March 2020 prompted widespread government containment measures, drastically reducing outdoor activities and severely impacting sectors like tourism, airlines, and shipping. This led to an unprecedented decline in oil demand, causing a supply glut, a sharp fall in oil prices, massive inventory build-up, and limited storage capacity. The situation was worsened by a production conflict between Saudi Arabia and Russia, where both countries increased oil production, further depressing global oil prices.

The analysis also delves into the effectiveness of the RFS and VEETC policies in modulating fuel prices. The phased-out VEETC, up to its expiration in 2011, and the persistently adjusted RFS blend mandates appear to have exerted less influence on fuel prices than other market forces. This suggests a degree of market adaptation and possibly efficiency gains in ethanol production that have mitigated the cost impact of these policies.

5.2 Blending Scenarios in 2009-2022

The accuracy and consistency of studied models further allow for simulations of the fuel prices with different levels of the ethanol blend rate in the studied years 2009-2022. These scenarios offer a comprehensive outlook on the relationship between the fuel price and the level of ethanol blended into gasoline. The scenarios chosen for demonstration of the simulated fuel prices across the three studied models are 1%, 5%, 10%, 15%, 20%, 25% and 30% ethanol blend levels where the 10% is the average of the years 2009-2022 and hence serves as a benchmark for each of the models. Tables 5.2, 5.3 and 5.4 display the potential savings - or additional costs in case of the negative values occurring in scenarios with blend levels below 10% - the customers might have faced at the pump were the blend rates at these levels, expressed in dollars per gallon of fuel.

The savings (or costs) are computed as the differences between simulated fuel prices for each of the models where the simulation changes the level of ethanol blending. The benchmark ethanol blending level and fuel price for each model and year are the values reported in Table 5.1 for each particular model. The comparing price is then obtained by changing the ethanol blend rate within the setup. For each year, the base variables are kept from the dataset and kept at the same, reported real values. The simulation changes only the level of ethanol blend rate and therefore produces potential fuel price for the given - higher or lower - blend rate. This hypothetical, simulated fuel price is then subtracted from the benchmark fuel price.

For example, the Drabik et al. model reports a saving of 1.15 dollars per each gallon of fuel in 2022, were the ethanol blend rate increased from 10.43% (the real blend rate in 2022) to 25%. With the 10.43% share of ethanol in fuel, the Drabik et al. model reports a price of 2.95 dollars per gallon (Table 5.1, this being the benchmark price. The Drabik et al. simulation with higher blend rate of 25% then results in 1.80 dollars per gallon. The same approach was taken for scenarios with decreased levels of ethanol; reduction of ethanol content in the fuel to 5% would lead to increased price of 3.48 dollars per gallon of fuel. The consumer would therefore suffer additional cost of 0.53 dollars per gallon.

Year	**1%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
2009	-0.01	-0.01	0.00	0.01	0.02	0.03	0.04
2010	-0.08	-0.04	0.01	0.06	0.10	0.15	0.20
2011	-0.07	-0.03	0.00	0.04	0.08	0.12	0.16
2012	-0.03	-0.02	0.00	0.02	0.04	0.05	0.07
2013	-0.04	-0.02	0.00	0.02	0.04	0.07	0.09
2014	-0.03	-0.02	0.00	0.02	0.04	0.06	0.08
2015	0.04	0.02	0.00	-0.02	-0.05	-0.07	-0.10
2016	0.07	0.04	0.00	-0.04	-0.08	-0.11	-0.15
2017	-0.01	-0.01	0.00	0.01	0.01	0.02	0.03
2018	-0.04	-0.02	0.00	0.02	0.04	0.07	0.09
2019	-0.04	-0.02	0.00	0.02	0.05	0.07	0.09
2020	0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01
2021	-0.07	-0.04	0.00	0.04	0.07	0.11	0.15
2022	-0.11	-0.07	-0.01	0.06	0.12	0.18	0.24

Table 5.2: de Gorter model: Savings resulting from the simulated fuel prices with different ethanol blend rates, dollars per gallon

Year	1%	5%	10%	15%	20%	25%	30%
2009	-0.42	-0.17	0.12	0.39	0.63	0.86	1.07
2010	-0.64	-0.32	0.06	0.39	0.70	0.97	1.21
2011	-0.80	-0.41	0.05	0.47	0.86	1.20	1.52
2012	-0.78	-0.41	0.02	0.43	0.80	1.15	1.46
2013	-0.85	-0.45	0.01	0.44	0.84	1.20	1.53
2014	-0.81	-0.43	0.01	0.42	0.79	1.13	1.44
2015	-0.46	-0.25	0.00	0.25	0.49	0.71	0.92
2016	-0.38	-0.21	0.00	0.21	0.41	0.61	0.81
2017	-0.54	-0.30	-0.01	0.26	0.50	0.73	0.94
2018	-0.64	-0.35	-0.01	0.31	0.60	0.86	1.10
2019	-0.61	-0.33	-0.01	0.29	0.56	0.81	1.03
2020	-0.43	-0.23	-0.01	0.21	0.41	0.60	0.77
2021	-0.75	-0.41	-0.01	0.35	0.67	0.96	1.23
2022	-0.95	-0.53	-0.04	0.40	0.80	1.15	1.47

Table 5.3: Drabik model: Savings resulting from the simulated fuel prices with different ethanol blend rates, dollars per gallon

According to the results, all three models report the same trend; increasing blend rates lead to increasing savings and vice versa, lower blendings cause additional costs for the end users at the pump. In other words, higher levels of ethanol blending lower the fuel price. The trend is violated only within the de Gorter & Just model, specifically in the years 2015, 2016 and 2020. In all three cases, the model reports a contradictory trend where ethanol blend rates below 10% result in positive values, i.e. savings, and with increases of the ethanol share in the gasoline, the fuel price increases as well.

The reason behind the de Gorter & Just model's deviation in the years 2015, 2016 and 2020 is presumably due to its inability to properly capture unexpected market shocks within the fuel market as the model offers an intuitive framework for the blended fuel pricing based on the ethanol and gasoline prices, level of the ethanol blend and taxes. The gasoline and fuel prices are reflective of the fuel market factors and shocks, however only to a certain extent. As previously mentioned in the Chapter 2.4, the fuel market suffered from a few unanticipated shocks in years 2014-2016 and in 2020: first, a shock to oil price expectations diminished the demand for oil inventories in July 2014, followed by a significant negative demand shock in December 2014, prompted by an unanticipated weakening of the global economy. The market's gradual recovery and stabilization was then disturbed by the unprecedented coronavirus pandemic and the Russia-Saudi Arabia oil price war in 2020. The de Gorter & Just model then lacks any variables or systems to capture the unexpectedness

Year	1%	5%	10%	15%	20%	25%	30%
2009	-0.14	-0.08	-0.03	0.08	0.15	0.36	0.42
2010	-0.17	-0.09	-0.04	0.09	0.18	0.44	0.52
2011	-0.22	-0.12	-0.05	0.12	0.24	0.57	0.68
2012	-0.23	-0.12	-0.02	0.12	0.24	0.58	0.68
2013	-0.22	-0.12	-0.02	0.12	0.24	0.58	0.70
2014	-0.21	-0.11	-0.02	0.11	0.23	0.55	0.66
2015	-0.13	-0.07	0.00	0.07	0.14	0.33	0.38
2016	-0.12	-0.06	0.00	0.06	0.12	0.28	0.33
2017	-0.13	-0.07	0.01	0.07	0.14	0.33	0.39
2018	-0.16	-0.09	0.02	0.09	0.17	0.41	0.48
2019	-0.15	-0.08	0.02	0.08	0.16	0.37	0.44
2020	-0.11	-0.06	0.02	0.06	0.11	0.26	0.30
2021	-0.17	-0.09	0.04	0.09	0.18	0.44	0.51
2022	-0.22	-0.12	0.05	0.12	0.23	0.57	0.67

Table 5.4: Langpap model: Savings resulting from the simulated fuel prices with different ethanol blend rates, dollars per gallon

and extensiveness of these shocks, therefore resulting in a contradictory trend.

On the other hand, both the Drabik et al. model, which thoroughly elaborates on the de Gorter & Just model, and the Wu & Langpap model successfully encapsulate the unforeseen shocks of the fuel market through additional variables, such as various elasticities and technical parameters, as presented in Chapters 3 and 4.

For the entire studied period, both Drabik et al. and Wu & Langpap models fully reject the first hypothesis of the thesis and the economic intuition that the higher ethanol blend rates result in higher fuel prices and hence cause additional costs at the pump for the consumers. The de Gorter & Just model rejects the hypothesis to a greater extent as well, with the only exceptions being the three divergent years - 2015, 2016 and 2020.

The savings from different blend rate scenarios are further summarized in Table 5.5. The table presents descriptive statistics of the savings resulting from the three models assessing the impact of ethanol blend rates on simulated fuel price savings in the United States for the studied time period 2009-2022. The overall narrative suggests that increasing ethanol blends tends to correlate with consumer savings, though the extent and consistency of these savings vary across different models. These differences highlight the complexities involved in making accurate forecasts and emphasize the need for a flexible approach when evaluating the economic impacts of biofuel policies.

Blend	**1%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
de Gorter							
Mean	-0.03	-0.02	0.00	0.02	0.03	0.05	0.07
Min	-0.11	-0.07	-0.01	-0.04	-0.08	-0.11	-0.15
Max	0.07	0.04	0.01	0.06	0.12	0.18	0.24
Range	0.18	0.10	0.01	0.09	0.19	0.29	0.39
Drabik							
Mean	-0.65	-0.34	0.01	0.34	0.65	0.92	1.18
Min	-0.95	-0.53	-0.04	0.21	0.41	0.60	0.77
Max	-0.38	-0.17	0.12	0.47	0.86	1.20	1.53
Range	0.57	0.36	0.16	0.26	0.45	0.61	0.76
Langpap							
Mean	-0.17	-0.09	0.00	0.09	0.18	0.43	0.51
Min	-0.23	-0.12	-0.05	0.06	0.11	0.26	0.30
Max	-0.11	-0.06	0.05	0.12	0.24	0.58	0.70
Range	0.12	0.06	0.10	0.06	0.13	0.33	0.40

Table 5.5: Descriptive statistics of simulated fuel price savings with different ethanol blend rates (studied period 2009-2022), dollars per gallon

The convergence of results toward the higher end of the ethanol blend spectrum across all models suggests that there is a consistent, though not linear, relationship between higher ethanol blend rates and increased fuel savings. This could be attributed to a number of factors, including but not limited to the economic efficiencies of ethanol production, federal blending mandates, and relative movements in the global crude oil market.

An examination of the range values across the models provides further insights. The de Gorter & Just model, with its smaller range, indicates more stable model predictions, which could be indicative of a more robust model structure or assumptions that are less responsive to market volatility. Conversely, the Drabik et al. model, with its wider range, incorporates a broader set of market variables, allowing for greater responsiveness to market shocks but also increasing the uncertainty of its predictions.

5.3 VEETC Type of Tax Credit Scenarios in 2009-2022

Testing the second hypothesis, the models allow for a different simulation where the blend rates in the period 2009-2022 remain at the real values and the changing variable is the Volumetric Ethanol Excise Tax Credit (VEETC). The tax credit is an ethanol subsidy that was introduced in 1979 and was originally set to expire in 2010 at the level of 45 cents per gallon of pure ethanol, although the congress prolonged it until 2011. The VEETC was set to expire due to a combination of factors, including its high cost to taxpayers and the growing sentiment that it constituted a substantial subsidy to already established and mature industries like oil and corn ethanol. Criticism arose over the fact that the tax credit was essentially a payout to oil companies to blend corn ethanol into gasoline, an action they were already mandated to perform under the Renewable Fuel Standard. The argument for letting the VEETC expire also included the suggestion that taxpayer dollars could be better allocated to support emerging and more competitive non-polluting energy technologies, such as wind, solar, geothermal, and advanced biofuels, which would contribute to creating green jobs and less pollution.

VEETC	**0¢**	**10¢**	**20¢**	**30¢**	**40¢**	**50¢**	**60¢**	**70¢**	**80¢**	**90¢**
2009	-3.58	-2.78	-1.99	-1.19	-0.40	0.40	1.19	1.99	2.78	3.58
2010	-4.15	-3.23	-2.30	-1.38	-0.46	0.46	1.38	2.30	3.23	4.15
2011	-4.24	-3.29	-2.35	-1.41	-0.47	0.47	1.41	2.35	3.29	4.24
2012	0.00	0.97	1.94	2.92	3.89	4.86	5.83	6.81	7.78	8.75
2013	0.00	0.98	1.97	2.95	3.94	4.92	5.90	6.89	7.87	8.86
2014	0.00	0.99	1.98	2.97	3.96	4.95	5.94	6.93	7.92	8.91
2015	0.00	0.99	1.99	2.98	3.98	4.97	5.97	6.96	7.95	8.95
2016	0.00	1.00	2.01	3.01	4.02	5.02	6.02	7.03	8.03	9.04
2017	0.00	1.02	2.04	3.06	4.08	5.10	6.12	7.14	8.16	9.18
2018	0.00	1.01	2.02	3.03	4.04	5.05	6.06	7.07	8.08	9.09
2019	0.00	1.02	2.03	3.05	4.07	5.08	6.10	7.11	8.13	9.15
2020	0.00	1.02	2.03	3.05	4.06	5.08	6.09	7.11	8.12	9.14
2021	0.00	1.02	2.03	3.05	4.07	5.08	6.10	7.12	8.13	9.15
2022	0.00	1.04	2.09	3.13	4.17	5.22	6.26	7.30	8.35	9.39

Table 5.6: de Gorter model: Savings resulting from the simulated fuel prices with the implementation of VEETC, cents per gallon

The chosen VEETC scenarios for the demonstration of the changes in the fuel prices are ethanol tax credits ranging from 0 cents to 90 cents per gallon of pure ethanol blended into gasoline, representing a policy instrument that aims to incentivize ethanol use by lowering the effective cost to blenders and, consequently, to consumers. The tables 5.6, 5.7 and 5.8, extracted from the de

Gorter & Just model, Drabik et al. model and Wu & Langpap model respectively, represent a simulation output illustrating the theoretical savings associated with the implementation of the Volumetric Ethanol Excise Tax Credit, denominated in cents per gallon of fuel. These simulated results provide an abstract representation of the potential economic impact of the VEETC under various hypothetical scenarios.

The simulation spans from 2009 to 2022 and notably includes the period when a 45-cent per gallon ethanol tax credit was in effect (2009-2011). In these years, the models project increasing negative savings as the hypothetical tax credit reduces to zero, which theoretically suggests that the actual tax credit was essential in mitigating the higher costs associated with the production and consumption of ethanol-blended fuels. The negative values reflect the additional costs that consumers or other market participants would have borne in the absence of the tax credit.

Following the expiration of the VEETC at the end of 2011, the model's zero savings projections for a non-existent credit imply that the market did not utilize savings from the tax credit. The shift to positive savings from 2012 onward could be interpreted as the models' suggestion that other market forces reflecting enhanced efficiencies in the ethanol production, shifts in global oil prices, as well as the interplay with other renewable fuel policies such as the Renewable Fuel Standard, offset the loss of the tax credit. The consistent positive savings observed in subsequent years might imply the cost-competitiveness of ethanol due to these adaptive mechanisms.

Furthermore, the incremental increases in savings across the columns, representing different hypothetical ethanol tax credit scenarios, demonstrate a compelling economic argument for continued policy intervention. The simulations indicate that even modest tax credits could lead to consumer savings, with a somewhat linear relationship between the magnitude of the tax credit and the level of savings. The outcomes therefore do not reject the second hypothesis, stating that the VEETC type of tax credit results in higher fuel price savings for consumers.

The analysis can be an essential insight for policymakers considering the utility and impact of such fiscal incentives. In essence, the models capture the dynamic interplay between policy incentives and market economics. The evident fluctuations in savings emphasize the relevance of the VEETC in fostering a competitive ethanol market. Policymakers should consider these insights when deliberating the reinstatement or modification of such credits, as they

VEETC	**0¢**	**10¢**	**20¢**	**30¢**	**40¢**	**50¢**	**60¢**	**70¢**	**80¢**	**90¢**
2009	-4.90	-3.81	-2.72	-1.63	-0.54	0.54	1.63	2.72	3.81	4.90
2010	-5.36	-4.17	-2.98	-1.79	-0.60	0.60	1.79	2.98	4.17	5.36
2011	-5.56	-4.33	-3.09	-1.85	-0.62	0.62	1.85	3.09	4.33	5.56
2012	0.00	1.24	2.49	3.73	4.98	6.22	7.46	8.71	9.95	11.20
2013	0.00	1.36	2.73	4.09	5.45	6.82	8.18	9.54	10.91	12.27
2014	0.00	1.38	2.76	4.15	5.53	6.91	8.29	9.67	11.06	12.44
2015	0.00	1.32	2.65	3.97	5.29	6.62	7.94	9.26	10.59	11.91
2016	0.00	1.38	2.76	4.14	5.52	6.90	8.28	9.66	11.04	12.42
2017	0.00	1.35	2.70	4.06	5.41	6.76	8.11	9.46	10.82	12.17
2018	0.00	1.34	2.68	4.02	5.36	6.70	8.04	9.38	10.72	12.06
2019	0.00	1.32	2.65	3.97	5.30	6.62	7.95	9.27	10.60	11.92
2020	0.00	1.32	2.64	3.96	5.28	6.61	7.93	9.25	10.57	11.89
2021	0.00	1.36	2.72	4.08	5.44	6.81	8.17	9.53	10.89	12.25
2022	0.00	1.36	2.73	4.09	5.46	6.82	8.18	9.55	10.91	12.28

Table 5.7: Drabik model: Savings resulting from the simulated fuel prices with the implementation of VEETC, cents per gallon

not only impact consumer prices but also resonate through the broader energy economy, influencing supply chain behaviors, energy security, and environmental sustainability initiatives.

The summary of models' statistics is presented in Table 5.9. All results suggest a direct correlation between the magnitude of the tax credit and the mean fuel price savings. Initial negative mean values at the zero tax credit baseline imply potential increases in fuel costs or diminished savings in the absence of the subsidy. This negative outlook progressively inverts into positive terrain as the tax credit increments, peaking with the highest variability at the 90 cents credit. The de Gorter & Just model portrays a conservative response to the tax credit, with the range of savings indicating modest variability, suggesting a moderate level of certainty regarding the VEETC's effect on the market within the confines of this model.

Contrastingly, the Drabik et al. model depicts a more pronounced variance in savings, implying that this model perceives the tax credit as a powerful catalyst for economic change within the fuel sector. The sweeping rise in maximum savings with escalating tax credits indicates the model's projection of a significant reduction in fuel prices relative to the heightened government subsidies. The Drabik et al. model underscores a crucial assumption that fiscal incentives are highly effective in altering producer and consumer behaviors, thereby

VEETC	0¢	10¢	20¢	30¢	40¢	50¢	60¢	70¢	80¢	90¢
2009	-1.99	-1.54	-1.10	-0.65	-0.22	0.22	0.65	1.07	1.49	1.91
2010	-1.84	-1.42	-1.01	-0.60	-0.20	0.20	0.60	0.99	1.39	1.77
2011	-1.69	-1.31	-0.93	-0.56	-0.19	0.18	0.55	0.92	1.28	1.65
2012	0.00	0.37	0.73	1.09	1.45	1.81	2.17	2.52	2.87	3.23
2013	0.00	0.38	0.75	1.12	1.49	1.86	2.23	2.59	2.96	3.32
2014	0.00	0.39	0.77	1.15	1.53	1.90	2.28	2.65	3.02	3.39
2015	0.00	0.44	0.87	1.30	1.72	2.14	2.56	2.97	3.37	3.78
2016	0.00	0.47	0.94	1.40	1.86	2.31	2.75	3.19	3.63	4.06
2017	0.00	0.45	0.89	1.32	1.76	2.18	2.61	3.03	3.44	3.85
2018	0.00	0.42	0.84	1.26	1.67	2.08	2.48	2.89	3.29	3.68
2019	0.00	0.43	0.86	1.29	1.71	2.13	2.54	2.95	3.36	3.76
2020	0.00	0.51	1.02	1.51	2.00	2.48	2.96	3.43	3.89	4.35
2021	0.00	0.40	0.80	1.20	1.60	1.99	2.38	2.77	3.15	3.53
2022	0.00	0.38	0.76	1.14	1.52	1.89	2.26	2.63	3.00	3.36

Table 5.8: Langpap model: Savings resulting from the simulated fuel prices with the implementation of VEETC, cents per gallon

significantly influencing market prices. The Wu & Langpap model's portrayals are characterized by the most consistent savings across different tax credit scenarios, proposing that fuel price responses to varying levels of VEETC are relatively stable. The modest ranges emphasize the model's perspective of a more predictable and less volatile response to tax credit alterations, indicative of a robust ethanol market less sensitive to fluctuations from policy changes.

The descriptive statistics from these simulations offer a detailed understanding of the potential outcomes from implementing ethanol-related fiscal policies. The noticeable discontinuity in 2011, coinciding with the end of the VEETC, establishes the zero-credit condition as a crucial reference point. This link allows for a systematic analysis of the potential impacts if such a subsidy were to be reintroduced or modified.

Economic intuition suggests that these simulated savings could be reflective of an intrinsic connection between ethanol production incentives, market-driven adjustments in gasoline demand, and the following equilibrium fuel prices. Tax credits, serving as fiscal stimulants, effectively diminish the market price of ethanol, potentially fostering a more substantial adoption of ethanol blends, investment in biofuel technology, and a diversification of energy resources. Consequently, this could induce a broader economic ripple effect, leading to lower retail gasoline prices due to diminished pure gasoline demand and a more vibrant ethanol market.

VEETC	**0¢**	**10¢**	**20¢**	**30¢**	**40¢**	**50¢**	**60¢**	**70¢**	**80¢**	**90¢**
de Gorter										
Mean	-0.85	0.13	1.11	2.09	3.07	4.05	5.03	6.01	6.99	7.97
Min	-4.24	-3.29	-2.35	-1.41	-0.47	0.40	1.19	1.99	2.78	3.58
Max	0.00	1.04	2.09	3.13	4.17	5.22	6.26	7.30	8.35	9.39
Range	4.24	4.34	4.44	4.54	4.64	4.82	5.07	5.32	5.56	5.81
Drabik										
Mean	-1.13	0.17	1.48	2.79	4.09	5.40	6.70	8.01	9.31	10.62
Min	-5.56	-4.33	-3.09	-1.85	-0.62	0.54	1.63	2.72	3.81	4.90
Max	0.00	1.38	2.76	4.15	5.53	6.91	8.29	9.67	11.06	12.44
Range	5.56	5.71	5.86	6.00	6.15	6.36	6.66	6.95	7.24	7.53
Langpap										
Mean	-0.39	0.03	0.44	0.86	1.26	1.67	2.07	2.47	2.87	3.26
Min	-1.99	-1.54	-1.10	-0.65	-0.22	0.18	0.55	0.92	1.28	1.65
Max	0.00	0.51	1.02	1.51	2.00	2.48	2.96	3.43	3.89	4.35
Range	1.99	2.06	2.11	2.17	2.22	2.30	2.41	2.51	2.61	2.70

Table 5.9: Descriptive statistics of simulated fuel price savings with different ethanol tax credits (studied period 2009-2022), cents per gallon

Chapter 6

Forecasting

The modelling and scenarios from Chapter 5 are focused on the past, presenting possible outcomes of the policies in place. The results from all three models unequivocally show that with higher blend mandates, the fuel prices to end users decrease and that re-implementation of the VEETC would bring further savings for the consumers, although the volume of the differences can be measured in cents. Nevertheless, there is a direct evidence of savings for customers resulting from the ethanol policies.

Relying on the results from modelling past years based on the historic values might not be the most compelling and relevant argument for policymakers. This chapter therefore takes the analysis further in order to examine the behaviour of the fuel prices and associated policies in the future as the conceptual framework for each of the models allows for projections and hypothetical scenarios. The methodology of each of the models is suitable for a long-run examination hence the structure does not require any changes. The forecasted period is chosen for the years 2023-2030. The dataset utilizes databases from the Energy Information Administration (EIA) and the United States Department of Agriculture (USDA) as both of these institutions frequently release future projections in line with the market expectations.

The predictions of the future values of variables representing the prices and quantities of crude oil, gasoline and ethanol were obtained from EIA's *Annual Energy Outlook, 2023* which explores long-term energy trends in the United States. (Energy Information Administration (2024a) The USDA's forecast *Agricultural Projections to 2032* then provides expectations for the corn market - especially the development of corn prices, exports, production and demand. (U.S. Department of Agriculture (2024a)) The technical parameters, policy variables and elasticities were with the best knowledge and conscience carried forward from the known values of 2022. Such approach was carefully considered within the frameworks of the models in order to secure the accuracy and consistency and it was concluded that most of the parameters are constant throughout time, therefore the last known values from 2022 serve as the best predictions for the near future.

Lastly, the projections are contingent upon the blend rates and all of the other predicted variables holding to the EIA's and USDA's anticipated trajectory, making the actual future prices subject to change should the real values of the variables deviate from these forecasts.

6.1 Projections of the Fuel Prices in 2023-2030

The Table 6.1 presents the projected fuel prices over the period 2023 to 2030 in the United States, based on the three distinct models: the de Gorter & Just, Drabik et al., and Wu & Langpap. These projections are premised on blend rates obtained separately for each year as the share of blended ethanol consumption in the total motor fuel consumption; both of these metrics are forecasted by the Energy Information Administration (EIA). The projections follow same approach and principles as the modelling of historic prices in Chapter 5. Drabik et al. and Wu & Langpap models account for the energy content discrepancies between fuel ethanol and gasoline through the incorporation of the *Miles per gallon of ethanol relative to gasoline* technical coefficient. All of the base variables are integrated through same units in order to secure the consistency of the results.

Year	**Blend rate** %	**de Gorter** $/*gal*	**Drabik** $/*gal*	**Langpap** $/*gal*
2023	10.13%	3.13	3.15	2.89
2024	10.30%	2.87	2.87	2.62
2025	10.37%	2.68	2.68	2.43
2026	10.44%	2.69	2.72	2.44
2027	10.51%	2.72	2.74	2.46
2028	10.57%	2.76	2.80	2.50
2029	10.63%	2.81	2.89	2.56
2030	10.70%	2.87	2.98	2.62

Table 6.1: Forecasted fuel prices for 2023-2030, dollars per gallon

The de Gorter & Just model forecasts a steady increase in fuel prices across the period, with the lowest price of \$2.68 per gallon in 2025, gradually escalating to \$2.87 per gallon by 2030. The model suggests a moderate but consistent upward trend, possibly reflecting a view that the blend rates and other market factors will contribute to incremental price rises after 2025. The Drabik et al. model mirrors the trajectory of the de Gorter & Just model with almost identical prices. Such observation is partially logical as Drabik et al. model expands the base framework introduced by de Gorter & Just, however the modelling based on historical values in Chapter 5 results in fairly different prices for these two models so one would expect some degree of variation within the projections as well. Finally, the Wu & Langpap model is characterized by the lowest projected prices among the three models. Starting at \$2.89 per gallon in 2023, the prices experience a gradual decrease, reaching the lowest at \$2.43 per gallon in 2025, before slightly rising to \$2.62 per gallon by 2030. It is generally quite difficult to determine the source of such shift as the model utilizes many different elasticities and parameters to the ones incorporated in Drabik et al. model (and de Gorter & Just as well). From an economic perspective, the variance between these models' predictions can be attributed to differing assumptions about the base variables, such as the costs of raw materials, advancements in ethanol production technologies, policy changes or market-driven supply and demand dynamics.

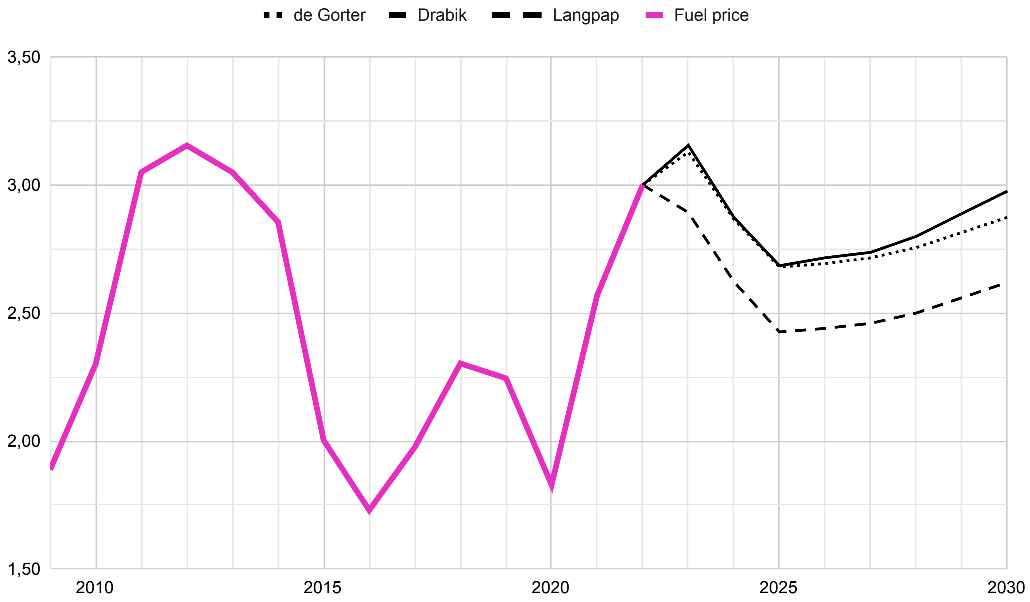

Figure 6.1: Projection of the fuel prices for 2023-2030

Figure 6.1 displays the real fuel prices reported by the EIA for the period 2009-2022, once more applying the sales to end users fuel prices as throughout the entire thesis. The time period 2023 to 2030 then pictures the projections of fuel prices from the three models with a clear view on the almost identical trajectories of the de Gorter & Just and Drabik et al. models and the downward shift of the Wu & Langpap forecast, although keeping the same trend as the other two models. When modelling the historic prices, the Wu & Langpap model results in very slight underestimations of the reality, however the pair of scissors is open fairly widely in the case of these forecasts. One of the possible reasons for the divergence might be in the volume of predicted West Texas Intermediate (WTI) crude oil price which is a corner stone of the Wu & Langpap model for the simulated fuel price, while the other two models utilize directly the predicted gasoline prices. In their predictions obtained from the *Annual Energy Outlook, 2023*, the EIA assumes crude oil prices higher by almost a one-third when comparing the average of the past ten years to the predicted average of the next ten years. Such expectations might be the explanation for the sudden shift in the model.

Overall, the projections imply a stabilizing effect of the RFS policy, indicating that the future fuel market may not experience the volatility seen in the historical data. The converging patterns of the models suggest a market consensus on the direction of future fuel prices, although with some divergence in the magnitude of the changes. That aligns with the economic rationale that, as the market adapts and policies evolve, the influence of ethanol on fuel prices will become more predictable and integrated into the general fuel pricing mechanism.

6.2 Blending Projections in 2023-2030

The scenarios of fuel prices savings or costs resulting from different blend levels projected for the period 2023 to 2030 are reported in Tables 6.2, 6.3 and 6.4. The methodology follows the same process as the simulations of historical prices and consequent consumer savings in Chapter 5 - the savings (or costs) are computed as the differences between projected fuel prices for each of the models where the projection changes the level of ethanol blending with the base values reported in Table 6.1 for each particular model. Through potential changes in levels of ethanol blended into gasoline, the comparing prices are obtained. The forecast changes only the hypothetical level of ethanol blend rate and therefore produces potential fuel price for the given - higher or lower - blend rate. This projected fuel price is then subtracted from the benchmark fuel price.

The scheme again offers the scale of blend rates from 1% up to 30% with the assumed real blend rate fluctuating between 10-11%. Similarly to the simulated historical results, the projected fuel prices clearly demonstrate the same trend: increasing the level of ethanol blended into gasoline results in lower fuel prices hence higher savings for the end users. The vice versa scenario, i.e. decreased level of ethanol blending, leads to higher prices and translates to negative values of savings, causing additional costs for the consumers. For instance, in 2025, a 1% blend rate corresponds to a \$0.06 - \$0.80 - \$0.18 per gallon additional costs resulting from the three models respectively, while a 30% blend rate predicts a \$0.13 - \$1.28 - \$0.39 per gallon savings. This pattern remains consistent through the years, with the savings for a 30% blend rate being the highest and the additional costs peaking at the 1% blend rate.

Year	**1%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
2023	-0.10	-0.06	0.00	0.06	0.11	0.17	0.23
2024	-0.07	-0.04	0.00	0.04	0.07	0.11	0.15
2025	-0.06	-0.03	0.00	0.03	0.06	0.09	0.13
2026	-0.06	-0.03	0.00	0.03	0.06	0.09	0.12
2027	-0.06	-0.03	0.00	0.03	0.06	0.09	0.12
2028	-0.06	-0.03	0.00	0.03	0.06	0.09	0.12
2029	-0.06	-0.04	0.00	0.03	0.06	0.09	0.12
2030	-0.06	-0.04	0.00	0.03	0.06	0.09	0.12

Table 6.2: de Gorter model: Savings resulting from the projected fuel prices with different ethanol blend rates, dollars per gallon

Year	**1%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
2023	-0.97	-0.52	-0.01	0.45	0.87	1.24	1.57
2024	-0.86	-0.47	-0.03	0.38	0.75	1.09	1.39
2025	-0.80	-0.44	-0.03	0.35	0.69	1.00	1.28
2026	-0.81	-0.45	-0.03	0.35	0.69	1.01	1.29
2027	-0.82	-0.46	-0.04	0.34	0.69	1.01	1.30
2028	-0.84	-0.47	-0.05	0.35	0.70	1.03	1.32
2029	-0.88	-0.50	-0.05	0.35	0.72	1.06	1.36
2030	-0.91	-0.52	-0.06	0.36	0.74	1.09	1.40

Table 6.3: Drabik model: Savings resulting from the projected fuel prices with different ethanol blend rates, dollars per gallon

Year	**1%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
2023	-0.22	-0.12	0.00	0.12	0.23	0.34	0.45
2024	-0.20	-0.11	0.00	0.11	0.21	0.32	0.42
2025	-0.18	-0.10	0.00	0.10	0.20	0.30	0.39
2026	-0.19	-0.10	0.00	0.10	0.20	0.30	0.39
2027	-0.19	-0.10	0.00	0.10	0.20	0.30	0.40
2028	-0.19	-0.11	0.00	0.10	0.21	0.31	0.40
2029	-0.19	-0.11	0.00	0.11	0.21	0.31	0.41
2030	-0.20	-0.11	0.00	0.11	0.22	0.32	0.42

Table 6.4: Langpap model: Savings resulting from the projected fuel prices with different ethanol blend rates, dollars per gallon

From an economic perspective, the tables suggest that there is an incentive to increase the blend rate of ethanol in gasoline as it may lead to consumer savings. Such outcome may influence policy decisions regarding the Renewable Fuel Standards and the encouragement of alternative fuel use. The outcomes might find important use for stakeholders in the fuel industry, including producers, retailers, and consumers, to understand how changes in ethanol blending can impact fuel pricing.

The magnitude and course of the savings from the three models are represented in Figure 6.2. For better portrayal, the values for each model and blend level are taken as the averages of the period 2023-2030. The Drabik et al. model suggests a robust positive correlation between the blend rate and savings, implying that as the ethanol content in fuel increases, the savings on fuel prices are expected to rise. This trend could be indicative of the efficiency gains from blending ethanol, possibly due to improved production processes or better utilization within engines.

In contrast, the projections from the de Gorter & Just and Wu & Langpap models are relatively static, hinting at a prediction that changes in ethanol blend rates within the examined range might not influence savings in fuel costs that significantly as in the Drabik et al. case. Such flatter trends can be interpreted as conservative estimates, possibly factoring in market barriers like the ethanol blend wall, which limits the feasible amount of ethanol that can be mixed into fuel without necessitating engine or infrastructure modifications. The projections shed light on the intricate dynamics at play in the fuel market and highlight the importance of a multifaceted approach to policy-making. If the more optimistic outlook of the Drabik et al. model holds true, then supportive policies towards higher ethanol blends might yield considerable economic

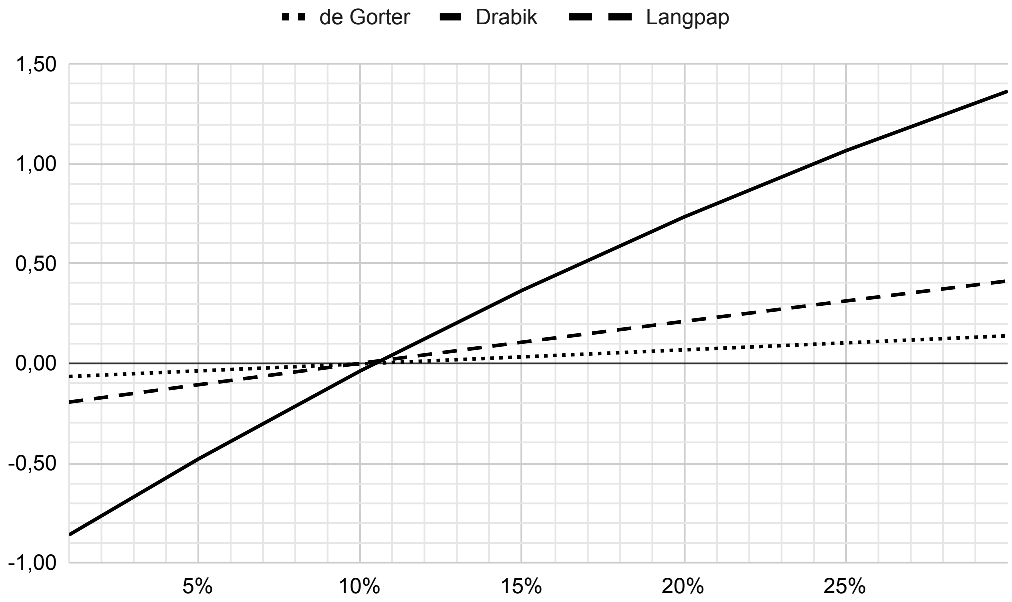

Figure 6.2: Projection of the savings resulting from different blend levels, averages of 2023-2030 in cents per gallon

benefits through fuel savings. Conversely, if the market behaves as suggested by the more conservative de Gorter & Just and Wu & Langpap models, then the economic intuition for pushing higher blend rates could be less compelling.

6.3 VEETC Type of Tax Credit Projections in 2023-2030

Projected fuel prices with implementation of the tax credit with a binding mandate in place follow the same approach as the modelled scenarios of fuel prices with VEETC for the period 2009-2022 in Section 5.3. The frameworks of all three models include variables for the ethanol tax credit and hence allow for different scenarios when changing the value of these variables. Tables 6.5, 6.6 and 6.7 then summarize savings resulting from the scenarios. For each model, year and level of tax credit, a forecasted fuel price is obtained. The savings as reported in tables are then the differences between the originally projected fuel prices in Table 6.1 and these new forecasted fuel prices dependent on the varying level of ethanol tax credit. The savings are denoted in cents per gallon across a range of ethanol tax credits, from 10 to 90 cents per gallon of pure ethanol. The models assume that the ethanol blend mandate is in effect through the RFS policy and remains at the predicted levels over the years, reported in Table 6.1.

VEETC	**10¢**	**20¢**	**30¢**	**40¢**	**50¢**	**60¢**	**70¢**	**80¢**	**90¢**
2023	1.01	2.03	3.04	4.05	5.06	6.08	7.09	8.10	9.12
2024	1.03	2.06	3.09	4.12	5.15	6.18	7.21	8.24	9.27
2025	1.04	2.07	3.11	4.15	5.19	6.22	7.26	8.30	9.34
2026	1.04	2.09	3.13	4.18	5.22	6.26	7.31	8.35	9.40
2027	1.05	2.10	3.15	4.20	5.25	6.30	7.35	8.40	9.46
2028	1.06	2.11	3.17	4.23	5.28	6.34	7.40	8.46	9.51
2029	1.06	2.13	3.19	4.25	5.32	6.38	7.44	8.51	9.57
2030	1.07	2.14	3.21	4.28	5.35	6.42	7.49	8.56	9.63

Table 6.5: de Gorter model: Savings resulting from the projected fuel prices with the implementation of VEETC, cents per gallon

VEETC	**10¢**	**20¢**	**30¢**	**40¢**	**50¢**	**60¢**	**70¢**	**80¢**	**90¢**
2023	1.42	2.84	4.25	5.67	7.09	8.51	9.92	11.34	12.76
2024	1.43	2.86	4.28	5.71	7.14	8.57	9.99	11.42	12.85
2025	1.43	2.87	4.30	5.74	7.17	8.61	10.04	11.48	12.91
2026	1.45	2.90	4.36	5.81	7.26	8.71	10.17	11.62	13.07
2027	1.46	2.92	4.38	5.84	7.30	8.76	10.22	11.68	13.14
2028	1.48	2.96	4.44	5.92	7.40	8.88	10.36	11.84	13.32
2029	1.50	3.01	4.51	6.02	7.52	9.02	10.53	12.03	13.54
2030	1.53	3.05	4.58	6.11	7.63	9.16	10.69	12.21	13.74

Table 6.6: Drabik model: Savings resulting from the projected fuel prices with the implementation of VEETC, cents per gallon

The results from all three models illustrate a positive correlation between the ethanol tax credit and the amount of savings; as the tax credit for ethanol increases, the projected savings per gallon also increase. For example, in 2023, a $0.10 tax credit would have saved 1.01 cents per gallon (de Gorter & Just model), 1.42 cents per gallon (Drabik et al. model) or 2.35 cents per gallon (Wu & Langpap model). On the other hand, a $0.90 tax credit introduced in 2023 would have saved 9.12 cents per gallon (de Gorter & Just model), 12.76 cents per gallon (Drabik et al. model) or 20.86 cents per gallon (Wu & Langpap model). This trend remains consistent over the years. By 2030, the savings at a $0.10 tax credit are projected at 1.07 - 1.53 - 2.18 cents per gallon resulting

VEETC	**10¢**	**20¢**	**30¢**	**40¢**	**50¢**	**60¢**	**70¢**	**80¢**	**90¢**
2023	2.35	4.69	7.03	9.36	11.67	13.98	16.28	18.58	20.86
2024	2.18	4.35	6.51	8.67	10.82	12.97	15.10	17.24	19.36
2025	2.02	4.04	6.05	8.05	10.04	12.03	14.02	15.99	17.96
2026	2.04	4.06	6.09	8.10	10.11	12.12	14.12	16.11	18.09
2027	2.05	4.10	6.14	8.18	10.21	12.23	14.24	16.25	18.25
2028	2.09	4.17	6.25	8.31	10.38	12.43	14.48	16.53	18.56
2029	2.14	4.26	6.39	8.50	10.61	12.72	14.82	16.91	18.99
2030	2.18	4.36	6.53	8.70	10.85	13.00	15.15	17.29	19.42

Table 6.7: Langpap model: Savings resulting from the projected fuel prices with the implementation of VEETC, cents per gallon

from the respective models, and savings at a $0.90 tax credit are expected to reach 9.63 - 13.74 - 19.42 cents per gallon.

An interesting aspect of the de Gorter & Just and Drabik et al. model outcomes is the year-over-year increase in projected savings for each level of tax credit. From 2023 to 2030, there is a gradual increase in savings across all tax credits. This suggests that over time, either the production and blending of ethanol are becoming more efficient, reducing costs, or that the VEETC's impact is magnified as market conditions evolve, possibly due to changes in production technology, market demand, or the scale of ethanol use in the industry.

The projections could serve as an argument for reintroduction of the VEETC, as they indicate a potential for reducing fuel prices for consumers and possibly offsetting some of the costs associated with ethanol production and blending. In interpreting these projections, it is however critical to consider that they are model-based and assume ceteris paribus; other influencing factors on fuel prices remain constant. The real-world scenario might differ due to fluctuating oil prices, technological advancements in ethanol production or changes in the global economic environment. Additionally, policy shifts concerning ethanol blending and biofuel support could significantly alter the projected paths of savings.

The positive correlation between the amount of the tax credit and the savings on fuel prices is pictured in Figure 6.3, which displays the averages of savings for the examined period at different tax credit levels. The rate of increase varies between the models, suggesting divergent levels of sensitivity to changes in tax credit within each model. The de Gorter & Just model, indicated by the dotted line, predicts the lowest savings across all levels of tax credit, while the Wu & Langpap model, shown by the dashed line, generally anticipates the highest savings. The Drabik et al. model, represented by the solid line, predicts savings that are between those forecasted by the other two models.

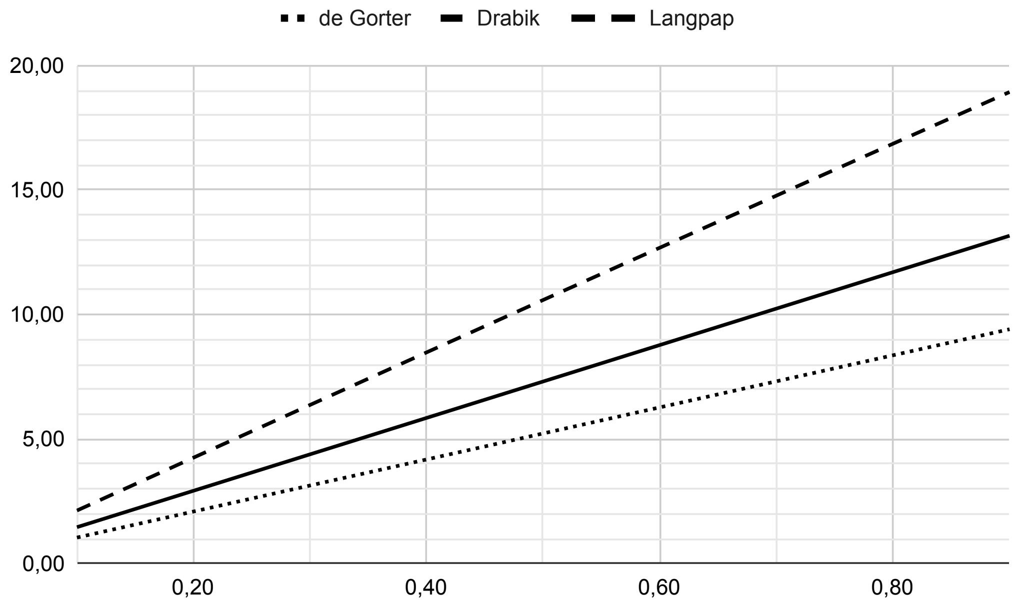

Figure 6.3: Projection of the savings resulting from different tax credits, averages of 2023-2030 in cents per gallon

The varying slopes of the lines illustrate the different elasticities of supply and demand embedded within each model. For instance, the steeper slope of the Wu & Langpap model line suggests it assumes a more responsive market to tax credits, where increased incentives lead to significantly greater savings. Another aspect evident from the graph is the consistency of the trend across the projected period. There are no abrupt changes or anomalies, indicating a stable response to the tax credit across time within the conditions set by each model.

The graph shows only positive values of savings because in the benchmark scenario, the VEETC is set to zero (as is the predicted value for the future period 2023-2030) and even the lowest level of ethanol tax credit results in lower fuel price for end users and hence positive savings.

Chapter 7

Conclusion

This thesis contributes to existing literature in multiple ways. Firstly, our thorough replication of the original established microeconomics models as chosen from de Gorter & Just (2009), Drabik *et al.* (2016) and Wu & Langpap (2015) papers results in the same values of the compound variables for the calibrated years of the models as the ones obtained by de Gorter and Just, Drabik et al., Wu and Langpap. In this way we provide a replication based verification of these three models. As these models provide conceptual framework for the price-transmission elasticies and percentage changes in prices and consumer utility associated with different levels of ethanol subsidies and mandates, the main contribution of this thesis is the derivation of adjusted fuel price models based on the original models.

Our empirical analysis consists of simulations and projections of the blended fuel prices, providing numerical results of the derived models. The simulations are run for the period 2009-2022 and results report the same trend for all three considered models with only minor differences from the U.S. sales to end users blended fuel price as reported by U.S. Energy Information Administration (2024b). The general equilibrium Wu & Langpap model is mostly underestimating and the partial equilibrium de Gorter & Just model is, in contrast, mostly overestimating the real prices while the results of Drabik et al. model fluctuate around the U.S. sales to end users blended fuel prices inside the Wu & Langpap and de Gorter & Just band. Our analysis then simulates blended fuel prices under various ethanol blend levels and the implementation of an ethanol tax credit, keeping other variables constant. These simulations generate new fuel prices for each scenario, which are compared to the original simulated prices. The results, presented as savings tables, show that increasing ethanol blending actually decreases fuel prices at the pump, rejecting our first hypothesis. Our second hypothesis is not rejected, as the ethanol tax credit results in higher consumer savings.

The long-term forecasts in the form of projections of blended fuel prices in the years 2023-2030 are based on predicted values of the base variables used within the derived models. The predictions are made by the Energy Information Administration (2024a) in their *Annual Energy Outlook, 2023* and the U.S. Department of Agriculture (2024a) forecast *Agricultural Projections to 2032*. These projections suggest that higher ethanol blend rates could lead to consumer savings and that reimplementing the ethanol tax credit could further reduce fuel prices. These findings are an important contribution for policy decision making related to the Renewable Fuel Standards, alternative fuel use, and government subsidies for ethanol.

Our results might find important use for stakeholders both in government and in the fuel industry, including producers, retailers, and consumers, to understand how changes in ethanol blending can impact fuel pricing.

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