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FACULTY OF SOCIAL SCIENCES
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Analysis of Dynamic Networks in Large Biofuels Related Financial and Economic System

Master's thesis

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Declaration of Authorship

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Abstract

This thesis discusses the significance of ethanol as a biofuel in the United States, investigating its role in affecting retail gasoline price. The empirical analysis replicates previous studies by Du and Hayes, and Knittel and Smith, revealing dynamics between ethanol production and gasoline prices. Contrary to earlier findings, this research demonstrates a positive and statistically significant effect of ethanol on gasoline prices as well as its negative but insignificant effect. A novel approach using wavelet coherence analysis provides deeper insights into the time-frequency relationships between ethanol production, retail gasoline prices, and oil producers' margins, indicating that ethanol's impact is less significant than other factors like natural gas and oil prices.

JEL Classification	F12, Q41, Q02
Keywords	biofuels, ethanol, energy economics, wavelet coherence
Title	Analysis of Dynamic Networks in Large Biofuels Related Financial and Economic System

Abstrakt

Tato práce se zabývá významem etanolu jako biopaliva ve Spojených státech a zkoumá jeho roli při ovlivňování maloobchodní ceny benzinu. Empirická analýza opakuje předchozí studie Dua a Hayese a Knittela a Smithe a odhaluje dynamiku mezi výrobou etanolu a cenami benzinu. Na rozdíl od dřívějších zjištění tento výzkum prokazuje pozitivní a statisticky významný vliv etanolu na ceny benzinu, stejně jako jeho negativní, ale nevýznamný vliv. Nový přístup využívající vlnkovou analýzu poskytuje hlubší vhled do časově-frekvenčních vztahů mezi výrobou etanolu, maloobchodními cenami benzinu a maržemi výrobců ropy a naznačuje, že vliv etanolu je méně významný než vliv jiných faktorů, jako jsou ceny zemního plynu a ropy.

Klasifikace JEL	F12, Q41, Q02
Klíčová slova	biopaliva, etanol, energetická ekonomika, vlnková koherence
Název práce	Analýza dynamických sítí ve velkém finančním a ekonomickém systému souvisejícím s biopalivy

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Contents

List of Tables

List of Figures

Acronyms

CS Crack spread

CR Crack ratio

CWT Continuos wavelet transformation

DH Du and Hayes; refers to paper Du & Hayes (2009) unless stated otherwise

PADD Petroleum Administration for Defense Districts

RFS Renewable Fuel Standard Program

Master's Thesis Proposal

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Proposed topic	Analysis of Dynamic Networks in Large Biofuels Related Financial and Economic System

Motivation

The use of biofuels has stabilized in recent years as a way to reduce the dependence on fossil fuels and mitigate their negative impact on the environment. Biofuels, such as ethanol and biodiesel, are renewable and produced from crops or waste materials. With the increasing demand for biofuels, it is important to understand the potential impact they have on retail gasoline prices. This information can help policy makers, consumers, and fuel producers make informed decisions about the use of biofuels and their place in the energy mix.

My thesis is set to focus on assessing the impact of biofuel blending into gasoline and its subsequent price effect on gasoline retail prices for end customers.

Contemporary literature finds little negative effect. Du and Hayes (2009) estimate the impact of ethanol on regional wholesale gasoline prices between 1995 and 2008. By modeling the crack ratio and the crack spread, they find that the impact varies considerably across regions with savings of $0.07 per gallon in the Rocky Mountains, $0.28 per gallon in the Midwest, and $0.14 per gallon on average. An updated study (Du and Hayes 2012) concludes that the average ethanol cost cut across all regions increases to $1.09/gallon and regionally ranges between $0.73/gallon in the Gulf Coast to $1.69/gallon in the Midwest.

Hypothesis

- Inclusion of biofuels as content of gasoline lowers the retail price.
- Furthermore, the higher the blend volume, the larger the price effect.

Methodology

Du and Hayes (2009), as described above, chose a regional approach to form a full picture of the price effect of biofuels (US energy market is for statistical purposes divided into so-called PADDs which allow for regional analysis). It also employs the method of not estimating directly through end prices but rather through profit margins refiners. So-called crack ratio and crack spread are computed to observe the effect on retail prices. A fixed-effects panel data model is then applied. I will replicate this method considering the critique by Knittel and Smith (2015).

This will be further enhanced by Wavelet analysis which presents a model-free approach for investigating the relationship between two-time series. Specifically, it allows us to study the correlation between two series in time and across frequencies without making any prior assumptions. The wavelet framework will be introduced as well as how to understand the concept and use it as a tool. Grinsted et al. (2004) will form the foundation of my thesis. I shall refer to Vacha et al. (2013), Vacha & Barunik (2012) as pioneers in the use of wavelets in the context of biofuels as well as very recent Guo Tanaka (2022).

Expected Contribution

The future of individual automobility and transportation in general is a crucial issue. The EU is set to ban the selling of new internal combustion engine cars by 2035. A thesis on the effects of biofuels on retail gasoline prices would be valuable for several reasons in this sense. Firstly, it would provide a deeper understanding of the relationship between biofuels and gasoline prices, which is essential for predicting future trends. This information can help policymakers develop and implement policies that promote the use of biofuels in a manner that is economically viable.

Furthermore, a study on the effects of biofuels on retail gasoline prices would also provide valuable information for fuel producers. Producers need to know the economic feasibility of producing biofuels and the potential market demand for them. This information can help them make decisions about the scale of production, and the pricing strategy.

Additionally, my thesis would broaden existing literature for a more comprehensive understanding of the phenomenon in question. By using different approaches, I will improve my findings and increase the validity and reliability of the results. Additionally, using multiple methodologies can also help to mitigate the limitations of any one method, leading to a more robust understanding of the effects of biofuels on retail gasoline prices.

Outline

1. Introduction
2. Motivation
3. Literature review: Studies on biofuels impact: I will briefly describe findings of researchers in the past
4. Data: I will explain how I will collect my data as well as its structure.
5. Methods: I will explain methods described above
6. Results: I will discuss my baseline regressions and robustness checks.
7. Concluding remarks: I will summarize my findings and their implications for policy and future research.

Core Bibliography

- Du X, Hayes DJ (2009) The impact of ethanol production on US and regional gasoline markets. Energy Policy 37(8):3227–3234.
- Du X, Hayes DJ (2012) The impact of ethanol production on US and regional gasoline markets: an update to 2012. Technical report.
- Janda, Karel, Ladislav Krištoufek, and David Zilberman. Modeling the Environmental and Socio-Economic Impacts of Biofuels. No. 33/2011. IES Working Paper, 2011.
- Vacha, L., Janda, K., Kristoufek, L., & Zilberman, D. (2013). Time–frequency dynamics of biofuel–fuel–food system. Energy Economics, 40, 233-241.
- Ellington M, Barunik J (2020) Dynamic Networks in Large Financial and Economic Systems. SSRN Electronic Journal ISSN 1556-5068, URL `http://dx.doi.org/10.2139/ssrn.3651134`.
- Verleger Jr, Philip K. Renewable fuel standard (RFS): Measuring the Impact on Crude Oil and Gasoline Prices.
- Zilberman, David, et al. "The economics of biofuels, food, and the environment." The Economics of Alternative Energy Sources and Globalization (2011): 24-34.
- Guo, Jin, and Tetsuji Tanaka. "Energy security versus food security: An analysis of fuel ethanol-related markets using the spillover index and partial wavelet coherence approaches." Energy Economics 112 (2022): 106142.

Chapter 1

Introduction

In recent years, the global energy landscape has witnessed a paradigm shift towards sustainable and environmentally friendly solutions. One such solution gaining significant attention is the integration of biofuels into the conventional gasoline supply chain. Governments and policymakers worldwide have initiated measures to promote the adoption of biofuels. These initiatives often involve blending a certain percentage of biofuels into conventional gasoline, thereby creating a fuel mixture with reduced carbon intensity. However, while the environmental benefits of biofuels are widely acknowledged, the economic implications of their integration remain a subject of intense debate and scrutiny.

In addition to growing concerns over climate change and the depletion of fossil fuel reserves, prices play a pivotal role in the global economy, influencing a wide range of sectors and affecting the daily lives of consumers. As a primary source of energy for transportation, the affordability and stability of gasoline prices are critical factors in maintaining economic growth and ensuring the mobility of individuals and goods. Understanding the economic consequences of biofuels integration is of paramount importance for policymakers, industry stakeholders, and consumers alike. The potential impacts on fuel prices can significantly influence various sectors, including transportation, agriculture, and energy markets, ultimately shaping the overall economy.

The objective of this thesis is to conduct a comprehensive evaluation of the *"at pump"* price effects associated with the blending of biofuels into conventional gasoline.

In order to do so, I will adopt a multifaceted approach, combining quantitative analysis and frequency-analysis technique.

The first approach involves econometric modeling, where I will replicate the methodology proposed by Du & Hayes (2009) for modeling the margins of oil producers. Building upon Hayes' framework, I will also consider the critique presented by Knittel & Smith (2015) and thus shall evaluate the effects of ethanol production on gasoline prices at the pump. Drawing from the methodology initially proposed by Du and Hayes and scrutinized by Knittel and Smith, the research will examine whether increased ethanol production leads to lower gasoline prices, focusing on the margins of oil producers through the crack spread and crack ratio. This hypothesis is grounded in the notion that ethanol, by displacing the demand for crude oil, might lower its price

The second approach I will employ is wavelet analysis. Wavelet analysis is a mathematical tool used to analyze and decompose complex data wavelets into different frequency components. It allows for the examination of both time and frequency domains simultaneously, capturing localized changes and patterns in a dataset.This will all be conducted by drawing on an extensive range of primary and secondary data sources, this research aims to provide a comprehensive assessment of the price effects resulting from biofuels blending into conventional gasoline.

The findings of this research will contribute to the existing body of knowledge by shedding light on the complex relationship between biofuels blending and fuel prices. By providing empirical evidence and insights, this study might help policymakers make informed decisions regarding biofuels implementation.

The thesis is structured as follows: Firstly, I provide deeper insight into the subject in chapter 2 by providing a comprehensive overview of biofuels, their types, and significance. As well as RFS initiave which sets biofuel mandates requirments.

In chapter 3, I present relevant publications related to the price effects of biofuels blending into conventional gasoline. This chapter synthesizes the findings from previous studies, highlighting different methodologies, and analytical frameworks employed in evaluating price effects.

Next, the data chapter outlines the data collection process, sources, and variables used in your study. It describes the primary and secondary data sets utilized, such as energy price and availability data, biofuels production statistics and relevant economic indicators. This chapter also discusses the data limitations and how they were dealt with.

The methodology chapter presents the research design, analytical techniques, and models employed in your study. It explains the quantitative methods used to analyze the data and test your hypothesis. This chapter discusses the econometric modeling approach, regression techniques, and any other statistical methods applied to evaluate the price effects of biofuels blending into conventional gasoline. It also justifies the chosen methodology, discussing its strengths and limitations.

The results chapter presents the findings of my analysis. It showcases the empirical results obtained from the application of the selected methodology to the collected data. This chapter interprets extract numerical results based on a replicable and structured review procedure. Eventualy, I shall discuss the significance of the results, compare them with existing literature, and addresses any unexpected findings or limitations encountered during the analysis.

Eventualy, in conclusion chapter 7 I provide a summary of my research and the key findings.I shall evaluate the hypothesis and discusses the implications of the results. This chapter also highlights the contributions of my thesis to the field of biofuels implementation, identifies areas for future exploration, and offers policy recommendations.

Chapter 2

Topic Backround

Biofuels have become a key element in the search for sustainable energy solutions. Among these, ethanol stands out as a prominent biofuel in the United States. This chapter explores the importance of ethanol, its roles, and the policies that have shaped its development and usage.

2.1 Biofuels

Biofuels are renewable additives used in combustion engines, offering a promising alternative to fossil fuels due to their potential to cut greenhouse gas emissions and lessen the impact of climate change. The two primary forms of biofuel are bioethanol and biodiesel. The United States is the top producer of bioethanol, while the European Union leads in biodiesel production. These biofuels can be made from various organic materials, including agricultural crops like sugarcane, palm oil and cassava (also known as energy crops) forest residues, and energy-rich algae. including palm oil, sugarcane, and cassava. (Letcher (2020), IEA (2022))

Ethanol combustion releases fewer pollutants compared to conventional gasoline, leading to lower emissions of carbon monoxide, particulate matter, and hydrocarbons. The use of ethanol can result in a significant reduction in lifecycle greenhouse gas emissions, contributing to efforts against climate change Agency (2010).

The history of ethanol production and policy is well documented by the Energy Information Agency (Administration 2005). Ethanol's first recorded use was in 1826 to power an engine when Samuel Morey developed an engine that ran on ethanol and turpentine. In 1876, Nicolaus Otto, the inventor of the modern four-cycle internal combustion engine, utilized ethanol to power an automobile engine. Ethanol was also used as a lighting fuel in the 1850s, but its use was curtailed when it was taxed as liquor to help pay for the Civil War. After the tax was repealed, ethanol continued to be used as a fuel and even powered Henry Ford's Model T in 1908. The blending of ethanol with gasoline for use as an octane booster began in the 1920s and 1930s and saw high demand during World War II due to fuel shortages.

The modern ethanol industry began in the 1970s when the high cost of petroleum-based fuel and environmental concerns about leaded gasoline created a need for an alternative octane booster. The Solar Energy Research, Development, and Demonstration Act of 1974 led to research on converting cellulose and other organic materials into useful energy or fuels. The Energy Tax Act of 1978 defined gasohol as a blend of gasoline with at least 10% alcohol by volume. This law provided a 40-cents-per-gallon subsidy for ethanol blended into gasoline. The marketing of commercial alcohol-blended fuels began by Amoco Oil Company in 1979, followed by Ashland, Chevron, Beacon, and Texaco. Corn became the predominant feedstock for the production of ethanol as a result of its abundance and ease of transformation into alcohol. Federal and state subsidies for ethanol helped maintain production when ethanol prices fell along with crude oil and gasoline prices in the early 1980s. This led to the creation of the "Minnesota Model" for ethanol production, where farmers produced ethanol to add value to their corn. The first U.S. survey of ethanol production found fewer than 10 facilities producing about 50 million gallons of ethanol per year. Congress enacted tax benefits to encourage ethanol production, including the Energy Security Act of 1980, which offered insured loans for small ethanol producers and placed an import fee on foreign ethanol. The Gasohol Competition Act of 1980 banned retaliation against ethanol resellers, and the Crude Windfall Tax Act of 1980 extended the ethanol-gasoline blend tax credit. (Bevill 2008).

The phasing out of Methyl Tertiary Butyl Ether (MTBE) as an oxygenate and the desire to decrease dependence on imported oil while increasing the use of environmentally friendly fuels led to a dramatic rise in ethanol demand. By 1986, no lead was allowed in motor gasoline. In 1997, leading U.S. auto manufacturers began mass production of flexible-fueled vehicle models capable of operating on E-85, gasoline, or both. Despite their ability to use E-85, most of these vehicles used gasoline as their only fuel because of the scarcity of E-85 stations. The first Renewable Fuel Standard (RFS) became law in 2005 as part of the United States' energy policy (Administration 2005). It mandated ethanol production to reach four billion gallons in 2006 and seven and a half billion gallons by 2012. The 2007 Energy Independence and Security Act signed by President Bush further required the use of renewable fuel to increase to 36 billion gallons annually by 2022 (Administration 2005). The new RFS, which currently guides the national ethanol policy, stipulates that only 15 billion gallons of corn starch should be produced, the remaining 22 billion gallons coming from other advanced and cellulosic feedstock sources.

The ethanol industry provides substantial economic benefits, particularly in rural areas. It creates jobs in agriculture, manufacturing, and distribution, and contributes to the overall economy by enhancing the value of agricultural products Urbanchuk (2012).

2.2 Corn as a Feedstock

Corn is the predominant feedstock for ethanol production in the United States. This section delves into the significance of corn in the ethanol industry, its production processes, and its economic implications.

Corn's high starch content makes it an ideal raw material for ethanol production. The starch is converted into sugars, which are then fermented to produce ethanol. This process not only yields ethanol but also produces valuable co-products such as distillers grains, which are used as animal feed (Association 2020).

USA is world's largest producer, consumer and exporter of corn. The demand for corn for ethanol production has significantly influenced the agricultural landscape. It has led to increased corn prices, incentivizing farmers to expand corn cultivation. This demand supports farm incomes and rural economies, making ethanol production a critical component of agricultural policy (Farzad Taheripour & Birur 2010).

In 2022, total U.S. cash receipts for corn amounted to $87.2 billion, with farmers planting approximately 90 million acres annually, covering about 5% of the contiguous U.S. land surface. A significant portion of corn production, 45%, is utilized for ethanol (See map of land usage in the USA (A.1) to consult how much land area in the contiguous USA is dedicated to ethanol production.), 40% serves as livestock feed, and the remaining 15% is allocated for food, seed, and industrial uses. In particular, only a sixth of this, sweet corn, is produced for direct human consumption, with the majority being dent corn.

Modern farm policy, originating during the Great Depression, aimed to stabilize farm product prices during oversupply periods through measures such as paying farmers to plant less. However, a shift in the 1970s, particularly under Nixon's 1973 Farm bill, reversed this approach, encouraging farmers to expand their operations by compensating for price drops below a target level. These policies have led to substantial surpluses in commodity crops, especially corn, and continue to influence agricultural practices today. Government subsidies now cover a significant portion of crop insurance premiums, benefiting primarily the largest producers. Over the past 28 years, the top 10% of farm subsidy recipients received 79% of the benefits, with a quarter going to the top 1%. Conversely, small farms, which often grow a variety of crops, rarely benefit from these subsidies, which are difficult to qualify for and prone to exploitation by large landowners. (Si *et al.* (2023), Kirwan (2015))

Corn's dominance in U.S. agriculture market comes at the expense of our environment, our health, and some of our farming communities. The production of corn requires extensive use of nitrogen fertilizer, which is essential for the intensive farming of monocultures. Corn consumes more fertilizer than any other major U.S. crop, leading to environmental concerns such as nitrogen runoff, which contaminates groundwater and causes conditions like "Blue Baby Syndrome." (Knobeloch *et al.* 2000)

Furthermore, the substantial portion of corn (40%) used as livestock feed exacerbates digestive problems in animals, requiring the use of antibiotics, which contributes to antibiotic resistance, since corn causes problems in the digestive systems of livestock, which is not naturally adapted to have a predominately corn-based diet and can leave cattle more susceptible to liver abscesses, which is a major reason why antibiotics are often added to the feed of entire herds of beef cattle, a practice the WHO has discouraged (Wallinga 2020).

2.3 The Renewable Fuel Standard (RFS)

One of the most debated uses of corn in the United States is for ethanol production, which accounts for 45% of American corn use. Ethanol, initially known as gasohol, gained prominence during the 1970s energy crisis. To encourage the use of ethanol, the Energy Tax Act of 1978 was passed. However, it was the 2005 Energy Bill that truly set the stage for the current ethanol industry by establishing the Renewable Fuel Standard (RFS). This legislation mandated the blending of renewable fuels, like ethanol, into domestic gasoline, thereby significantly increasing the demand for corn.

The Renewable Fuel Standard (RFS) is a federal program designed to integrate renewable fuels into the transportation fuel supply. The primary objectives of the RFS are to reduce greenhouse gas emissions, enhance energy security, and promote rural economic development. By setting annual targets for the volume of renewable fuels to be incorporated into the fuel supply, the RFS has driven the growth of the biofuel sector.

In the context of ethanol blends, the letter "E" followed by a numeric value represents the percentage of ethanol in the blend. For example:

E10 means the fuel is composed of 10% ethanol and 90% gasoline. E10 is the most common blend in the United States and is required by law, with a few exemptions. E10 is widely used due to its compatibility with most modern vehicles and its role in meeting Renewable Fuel Standard (RFS) requirements. E85, on the other hand, is used only by so called (Fuel Vehicles FFVs), which are specially designed to run on higher ethanol content fuels. For that reason it is sold in limited locations, when gasoline is expensive then E85 becomes more attractive to use from an monetary point of view.

In recent years, the Trump administration granted numerous small refinery exemptions (SREs) that reduced the overall volume of ethanol required under the RFS, leading to legal challenges and policy debates.

The Energy Bill, which established the RFS, mandated that a certain amount of renewable fuel must be blended into the domestic gasoline supply. This means that every gallon of domestic gasoline legally must contain at least a small percentage of ethanol. This mandate has understandably created a significant increase in demand for corn within the domestic market (Agency (2020), Schnepf & Yacobucci (2011)).

While the RFS has been instrumental in increasing ethanol production and consumption, it has also faced significant challenges. Critiques highlight that the production of corn-based ethanol has failed to meet the policy's own greenhouse gas emissions targets and has negatively impacted water quality, conservation land use, and other ecosystem processes. Specifically, the RFS has increased corn prices by 30% and the prices of other crops by 20%, expanding US corn cultivation by 2.8 million hectares (8.7%) and total cropland by 2.1 million hectares (2.4%) between 2008 and 2016. These changes have resulted in increased fertilizer use by 3 to 8%, degraded water quality by increasing nitrate leaching and phosphorus runoff, and caused soil erosion. Moreover, the RFS has led to domestic land use change emissions, making the carbon intensity of corn ethanol comparable to, if not higher than, that of gasoline. Specifically, the carbon intensity of corn ethanol produced under the RFS is at least 24% higher than gasoline Lark *et al.* (2022).

In conclusion, while the Renewable Fuel Standard (RFS) has promoted the growth of the ethanol industry and driven advancements in biofuel technologies, it has also resulted in significant environmental trade-offs. These include increased greenhouse gas emissions, adverse impacts on water quality, and expanded agricultural land use. To achieve the intended environmental benefits, further technological advancements and policy adjustments are necessary. Policymakers must weigh these trade-offs carefully when considering the future of renewable energy policies and the role of biofuels in climate mitigation efforts.

Chapter 3

Literature Review

The aim of this section is to provide a review of literature regarding the impact and contributions of ethanol on retail gasoline prices. The question of how ethanol affects fuel prices is of significant importance due to its implications for various stakeholders, including consumers, industry players, and policymakers.

In this chapter, I first explore classical models estimating numerically what the price effect of biofuels is, providing a foundation for understanding the quantitative impacts. This includes an examination of various studies and their findings on the economic effects of ethanol on fuel prices. Additionally, I review the specific timeline and development of the Du and Hayes model, detailing how their research was updated over time and the critiques and responses it generated.

Subsequently , I also explore model-free mutual responsiveness methods literature, which does not produce numerical results but rather provides a qualitative picture of the interactions between biofuels and prices or other energy commodities. Finally, I narrow down the focus to wavelet analysis literature, aligning with the empirical analysis of my thesis to investigate how these methods contribute to understanding the dynamics of fuel prices and biofuel production.

3.1 Biofuels Price Effects

The findings in Hochman & Zilberman (2018) estimate an average fuel savings of $0.12 in 2005 US dollars. However, the meta-analysis discovers significant heterogeneity among the included studies. Khanna *et al.* (2021) compares the most recent results in a similar manner, but their study focuses on the effects of biofuels on food commodity prices, GHG emissions, and ILUC-related issues rather than the economic benefits of biofuels for transportation.

Wu & Langpap (2015) conducted a study examining the impact of ethanol mandates and subsidies on the price of gasoline. The findings reveal that the combination of ethanol mandates and subsidies resulted in a notable reduction in gasoline prices, specifically in the range of 5-10%. This suggests that the implementation of ethanol mandates, along with supportive subsidies, creates a favorable market environment that contributes to lower gasoline prices. Additionally, Chen *et al.* (2021) explored the effects of ethanol mandates alone and found that that the introduction of an ethanol mandate led to a significant decrease in gasoline price by 8% in 2022.

Study of de Gorter & Just (2009) indicates that the implementation of tax credits, when combined with mandates, leads to lower fuel prices compared to a mandate alone. Similarly, Drabik *et al.* (2016) finds that tax credits alone result in a 3.8% decrease in world gasoline prices, while RFS mandates alone lead to a decrease ranging from 5.2% to 5.9%. However, the combined effect of the RFS mandates and tax credits leads to a slightly lower decrease in world gasoline prices, ranging from 4.9% to 5.2%.

The findings of Whistance & Thompson (2010) showed that ethanol production drives even the price of natural gas up. They found that corn-ethanol production under biofuel policies at the time could result in natural gas prices 0.1% higher than if there were no US biofuel policies in place by. Furthermore, if ethanol production is reduced to the only minimal mandates (E5), natural gas prices fall by up to 0.5% percent in the medium-term future.

According to systematic literature review by Janda *et al.* (2022), the addition of ethanol generally reduces the price of gasoline at the pump in the US, with estimates ranging from no effect to nearly 10%. The prevailing consensus in the analyzed literature is that the Volumetric Ethanol Excise Tax Credit (VEETC) and Renewable Fuel Standard (RFS) mandate have played significant roles in reducing gasoline prices.

Recently, Lundberg *et al.* (2023) investigate the effects of biofuel blending mandates on biofuel consumption, production, emission reductions, and consumer fuel prices across the EU from 2009 to 2020. The study converts various national mandates to a common unit and examines their impact. The study includes data on biofuel consumption, production, and emission reductions, along with an exploration of the price effects of biofuel blending mandates on diesel and gasoline. The analysis suggests that biofuel consumption has a negligible impact on consumer prices of gasoline and diesel compared to other factors like global oil prices. Historical data indicates that even with increased biofuel blending mandates, the consumer price effect remains minimal

3.1.1 Du & Hayes Taking into Account Knittel & Smith

The interplay between ethanol production and gasoline prices has been a subject of considerable research and debate. A foundational study in this domain was conducted by Xiaodong Du and Dermot J. Hayes, who examined the impact of ethanol production on U.S. gasoline markets. Their initial study, published in 2009, provided significant insights into the economic effects of ethanol on fuel prices. This study was subsequently updated in 2011 and 2012 to incorporate new data and refine the analysis. Concurrently, the methodology and findings of Du and Hayes were scrutinized by other scholars, notably Christopher R. Knittel and Aaron Smith. While Du and Hayes' studies provide strong evidence of ethanol's role in reducing fuel prices, the critiques highlight the importance of methodological rigor and the need for robust, unbiased models. The subsequent responses by Du and Hayes demonstrate their commitment to addressing valid concerns and refining their analyses. This literature review provides a comprehensive examination of these studies, critiques, and subsequent discussions.

Du and Hayes (2009): Initial Study

Du and Hayes' initial study, titled "The Impact of Ethanol Production on U.S. and Regional Gasoline Markets," was published in 2009. The authors used data spanning from January 2000 to December 2008 to assess how increased ethanol production influenced wholesale gasoline prices by modeling the margins of oil producers (the so-called "crack ratio" and "crack spread," which measure the price relationship between crude oil and refined petroleum products; for more details, see Chapter 4). They found that ethanol production had a significant negative impact on gasoline prices, reducing them by an average of $0.25 per gallon nationwide. The most pronounced effects were observed in the Midwest, where prices decreased by $0.39 per gallon. This study highlighted the role of ethanol as a substitute for gasoline, which contributes to lowering fuel prices by increasing the supply of fuel alternatives.

First Update (2011)

In 2011, Du and Hayes extended their analysis to include data up to December 2010. This update, encapsulated in the working paper "The Impact of Ethanol Production on U.S. and Regional Gasoline Markets: An Update to May 2009," reaffirmed and amplified the findings of their initial study. Over the extended period, they observed that the impact of ethanol production on gasoline prices had become more pronounced, with an average reduction of $0.89 per gallon nationally, and up to $1.37 per gallon in the Midwest based on 2010 data alone. This increase in the estimated impact was attributed to the substantial rise in ethanol production during the latter part of the decade and higher crude oil prices. The update reinforced the conclusion that ethanol production plays a critical role in moderating gasoline prices.

Second Update (2012)

The second update, conducted in 2012 and titled "The Impact of Ethanol Production on U.S. and Regional Gasoline Markets: An Update to 2012," further extended the data analysis to December 2011. Du and Hayes reported that the average reduction in gasoline prices due to ethanol production had increased to $0.29 per gallon over the entire period from January 2000 to December 2011. In 2011 alone, the reduction was estimated at $1.09 per gallon on average across all regions. The Midwest continued to experience the most significant reductions, with a decrease of $0.45 per gallon over the entire period. The updates provided robust evidence supporting the initial findings and underscored the increasing importance of ethanol production in the U.S. fuel market.

Critique by Knittel and Smith (2015)

The methodology and conclusions of Du and Hayes were critically examined by Knittel and Smith in their 2015 paper. Knittel and Smith argued that Du and Hayes' approach contained several methodological flaws that potentially biased their results. One of their primary critiques centered on the assumption regarding the relationship between changes in output prices and refiners' profits. Knittel and Smith contended that Du and Hayes incorrectly assumed a one-to-one relationship between these variables, which oversimplified the complex dynamics of the refining industry. They also criticized the use of the crack spread model, arguing that it failed to adequately account for the endogeneity between gasoline and crude oil prices. Additionally, Knittel and Smith suggested that the Du and Hayes model lacked robustness and did not sufficiently control for external factors influencing gasoline prices, such as changes in demand and supply conditions unrelated to ethanol production.

Responses by Du and Hayes

In response to the critiques by Knittel and Smith, Du and Hayes published two rebuttals: "First Response to Knittel and Smith" (2012) and "Second Response to Knittel and Smith" (2012). In these papers, Du and Hayes addressed the points raised by Knittel & Smith (2015).

In their first response, Du and Hayes refuted the claim that they failed to cite errors in Knittel and Smith's original paper. They clarified that they had indeed identified significant errors, particularly in the assumptions about refiners' profit margins. Du and Hayes argued that refiners, being multi-input and multi-output firms, have various ways to mitigate profit threats, making the one-to-one assumption unrealistic. O the other hand, they pointed out that Knittel and Smith misunderstood the reported changes in refiners' margins, erroneously interpreting them as changes in gasoline prices. Furthermore, Du and Hayes highlighted the endogeneity issue in Knittel and Smith's models, demonstrating through statistical tests that crude oil prices are endogenous and correcting for this endogeneity produced results similar to their original findings. Du and Hayes reproached Knittel and Smith for unrelated regressions that reportedly mittigated findings of D&H critisizing additional regressions included by Knittel and Smith that they believed were unrelated to the core analysis, such as those involving employment and natural gas prices.

In their second response, Du and Hayes expanded on their defense by presenting alternative specifications of their model that yielded larger price impacts. They incorporated additional explanatory variables and instrumental variables to address potential biases and endogeneity concerns. The results from these alternative models reinforced the robustness of their initial conclusions. Du and Hayes also criticized Knittel and Smith for not reporting model versions that could produce larger coefficients, suggesting that their selective reporting biased the critique. Moreover, they argued that Knittel and Smith's additional regressions, which included unrelated variables such as employment and natural gas prices, lacked appropriate controls and were designed to produce spurious correlations.

3.2 Interdependencies Analysis Methods

Kristoufek *et al.* (2012a) utilize Minimal Spanning Tree (MST) and Hierarchical Tree (HT) to extract the most important connections in the network among the prices of biodiesel, ethanol and related fuels. They found that in the short term, both ethanol and biodiesel are very weakly connected with other commodities. In the medium term, the system splits into two well-separated branches: one for fuels and one for food. Biodiesel tends to the fuels branch, and ethanol to the food branch. Furthermore, they found that before food crisis of 2007-8 Biofuels are only weakly connected to the network, and soybeans, wheat, and corn are only weakly correlated with the rest of the network. Whilst in post-crisis, ethanol becomes well connected to corn, wheat, and soybeans, especially in the medium term.

A novel approach to analyze the relationships and dependencies between biofuels, fuels and food prices was introduced by Kristoufek *et al.* (2012b) using mutual responsiveness (MR) and Granger causality tests. They find that ethanol and biodiesel prices are sensitive to their production factors (corn, sugarcane, soybeans) and substitute fossil fuels (US gasoline and German diesel). The study highlights a marked increase in responsiveness during the 2007-2008 food crisis. Granger causality tests reveal that changes in the prices of production factors lead to changes in biofuels prices, with corn prices Granger-causing ethanol prices in the short term and German diesel prices Granger-causing biodiesel prices in both the short and medium term. The study emphasizes the importance of considering price-level effects and suggests that policy differentiation is necessary due to the distinct impacts of ethanol and biodiesel on commodity prices.

Kristoufek *et al.* (2013) explore the price dynamics between biofuels, fossil fuels, and agricultural commodities using a combination of Prais-Winsten methodology and two-stage least squares (2SLS) to address endogeneity and autocorrelation. They find that ethanol prices are significantly connected to corn and crude oil, with non-linear and price-dependent relationships. Specifically, the transmission effect from corn to ethanol is minimal at low corn prices but becomes substantial at higher prices. Biodiesel prices are significantly connected to German diesel, showing a more pronounced transmission effect at higher diesel prices. The study highlights that these relationships intensified during the 2007/2008 food crisis, suggesting that market shocks can amplify interconnection among commodities. The findings underscore the importance of incorporating dynamic and non-linear price transmissions in economic models and policy formulations related to biofuels.

Natanelov *et al.* (2013) employs a the Johansen co-integration and Vector Error Correction Model to map out the relationships between crude oil, corn, and ethanol prices during the period from 2006 to 2011. The study reveals that the ethanol does not directly impact the price levels of corn. Instead, ethanol production contributes to the volatility of corn prices, particularly when crude oil prices are high, The study indicates that corn markets have become more prone to volatility due to ethanol production. This volatility is especially evident when the demand for corn is high, and/or crude oil prices are sufficiently high to make ethanol production economically viable.

With evidence from USA using monthly data from January 2004 to June 2014, Pal & Mitra (2017) employs the quantile autoregressive distributed lag (QADL) model to investigate the relationship between diesel and soybean prices. The study finds that soybean prices respond differently to diesel price fluctuations across various quantiles, highlighting the asymmetric nature of the price transmission. The results indicate that soybean prices do not necessarily follow long-term changes in diesel prices. Instead, stronger responses are observed in the upper quantiles, suggesting that soybean prices react more significantly to diesel price changes when diesel prices are high.

Kang *et al.* (2019) employ a frequency domain spillover method method of Baruník & Křehlík (2018) to examine the interconnectedness between crude oil and agricultural commodity prices from 1990 to 2017. The study uses a time-varying Granger causality approach to establish the non-linear bi-directional relationship between oil and agricultural commodities. The analysis reveals that vegetable oils are the most influential source of price volatility for other agricultural commodities and crude oil, particularly at all frequency bands. The study finds that the connectedness between these markets intensifies during periods of economic and financial turmoil, such as the 2007-2009 global financial crisis and the 2010-2012 European debt crisis.

3.2.1 Wavelet Analysis

By combining time and frequency information, wavelet analysis offers a deeper understanding of the underlying processes that drive market behaviors. The ability to capture both global and local patterns makes wavelet analysis a valuable tool in economic and financial research. This subsection reviews relevant literature that, alike this thesis, used wavelet analysis to explore relationships in energy markets.

Vacha & Barunik (2012) pioneered wavelet coherence analysis to study the co-movement of energy commodities, specifically crude oil, gasoline, heating oil, and natural gas, over a 16.5-year period. Using wavelet tools, they uncover the dynamics of correlations in the time-frequency domain, highlighting how these correlations evolve over time and across different investment horizons. Their findings indicate that heating oil and crude oil show the strongest dependence, while natural gas exhibits the weakest. The wavelet coherence approach reveals that periods of high correlation often coincide with economic downturns, such as the Asian financial crisis and the 2008 global financial crisis, suggesting that market turmoil strengthens commodity interdependencies. In a related study, Vacha *et al.* (2013) explore the time-frequency dynamics of the biofuels-fuels-food system. They analyze the relationships between biofuels (ethanol and biodiesel), their feedstock (corn and soybeans), and fossil fuels (crude oil and German diesel) from 2003 to 2011. The study finds that the correlations between these commodities vary over time and frequency, intensifying during the 2007/2008 food crisis. Ethanol is primarily connected to corn, while biodiesel is linked to German diesel, with the leadership dynamics changing post-crisis. The authors emphasize the potential of wavelet coherence for analyzing complex commodity markets.

Raza *et al.* (2022) utilize wavelet coherence analysis to examine the co-movement between food and oil prices, revealing that biofuel production affects food prices primarily through its impact on oil prices. The study highlights that oil price fluctuations, especially during significant global events like the COVID-19 pandemic and geopolitical tensions, directly influence the dynamics between food and biofuel prices. The findings indicate a strong connection between oil price changes and the volatility in food prices.

With evidence form Thailand spanning from March 2017 to December 2022, examining monthly data on biofuel production, food prices, and crude oil prices, Khamphiranon & Thammaboosadee (2023) found a significant short-term correlation between biofuel production and food prices, with stronger co-movement observed during periods of economic and financial crises. The study highlights the impact of biofuel production on food price volatility, particularly in the short term.

Chapter 4

Data

To provide additional evidence to answer the question of how increasing U.S. ethanol production affects the retail price of gasoline, I replicate, adjust and update Du & Hayes (2009) who quantify the impact of increasing ethanol production on wholesale/retail gasoline prices employing pooled regional time-series data from January 1995 to March 2008 (with Du & Hayes (2011; 2012) updates using 2000 - 2010 and 2000 - 2011 data). I take into account and control for the comments and critique of Knittel & Smith (2015).

Du & Hayes (2009) propose to measure the impact of ethanol policies on retail prices by the impact on the margin of oil refiners. They estimate the relationship between ethanol production and two refining margin indicators, which are the crack spread and the crack ratio. Following Du & Hayes (2009), I model two dependent variables. The first is the crack ratio (π_{CR}), the relative gasoline price to the price of crude oil, defined as:

$$\pi_{CR} = \frac{42P_G}{P_O} \tag{4.1}$$

where P_G is the average wholesale gasoline price (\$/gallon), and P_O is the U.S. crude oil composite acquisition cost to refiners (\$/barrel).

The second dependent variable is the crack spread (π_{CS}) which is defined as:

$$\pi_{CS} = 42\frac{2}{3}P_G + 42\frac{1}{3}P_H - P_O \tag{4.2}$$

where P_H is the wholesale price of No. 2 distillate fuel (\$/gallon).

Du & Hayes (2009) motivate the model with the observation that the profitability of a refinery depends on the difference between the prices of various refined products and the costs of production, which are dominated by the price of crude oil. If ethanol production reduces refinery margins, it will alter the difference between gasoline and oil prices rather than cause gasoline prices to change proportionately to oil prices, as the crack ratio model assumes. For instance, Knittel & Smith (2015) note that if the price of oil is \$2.00 per gallon and the price of gasoline is \$2.40 per gallon, making a crack spread of \$0.40 and a crack ratio of 1.2, and the energy cost of refining is \$0.10 per gallon, refineries would then have a producer surplus of \$0.30 per gallon. If the price of oil were to increase to \$4.00 per gallon and the energy cost of refining were to increase to \$0.20 per gallon, the crack ratio model would suggest that the price of gasoline would increase to \$4.80 per gallon, resulting in a producer surplus of \$0.60 per gallon. Even if a marginal refinery were breaking even at the original oil price, then entry into the business would be expected as it would start yielding a profit now.

Another unique feature of Du & Hayes (2009) is the regional approach. They estimate fixed effects associated with the so-called PADD regions. To facilitate the distribution of petroleum products during WWII, 50 states and the District of Columbia were divided into five Petroleum Administration for Defense Districts (PADDs: PADD 1 is the East Coast, PADD 2 the Midwest, PADD 3 the Gulf Coast, PADD 4 the Rocky Mountain Region, and PADD 5 the West Coast). They exist to this day solely for data collection purposes. The PADDs, therefore, allow data users to analyze patterns of crude oil and petroleum product movements throughout the nation. Du & Hayes (2009) state that the regions are very different in terms of their economic conditions, oil and petroleum characteristics, oil-related pipeline infrastructure, and local supply and demand conditions of products. Both crack ratio and crack spread data are gathered by each PADD separately.

Specification and Data

The empirical models in Du & Hayes (2009) use monthly PADD-level data on either the crack ratio or the crack spread and include a set of independent variables. Both Du & Hayes (2009) and Knittel & Smith (2015) cite no source other than the U.S. Energy Information Administration (EIA) website.

Consumer Price Index (CPI) and Producer Price Index (PPI) were extracted from Federal Reserve Economic Data (FRED) website.

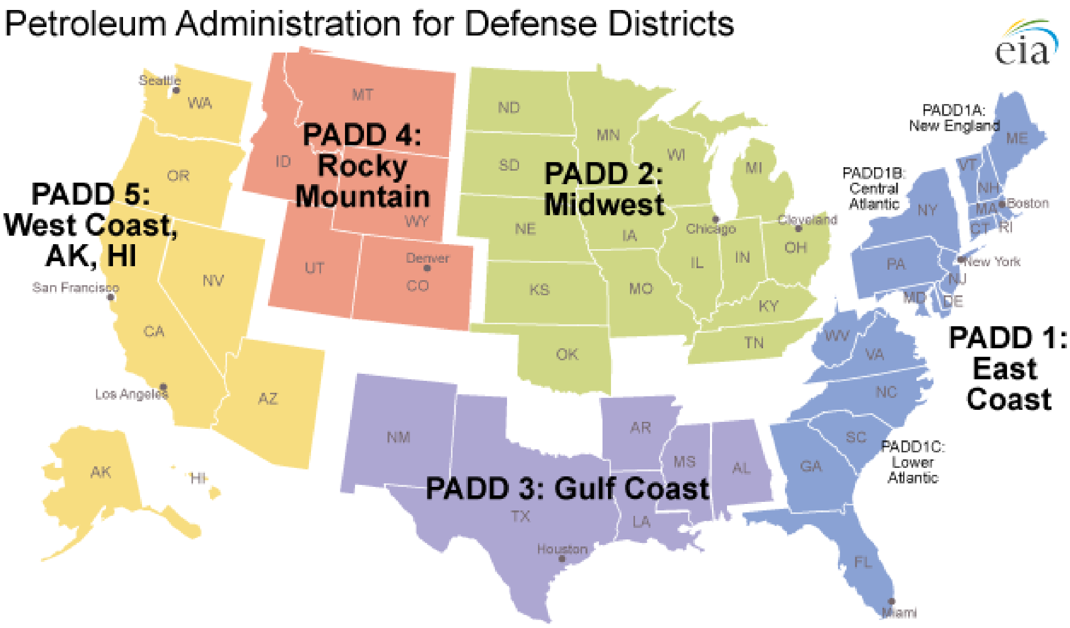

Figure 4.1: PADDs' Map

$$\begin{aligned}\pi_{it} = \beta_0 + \beta_1 Ethanol\ Prod._t + \beta_2 Gasoline\ Import_{it} + \beta_3 Oil\ Stock_{it} \\ + \beta_4 Gasoline\ Stock_{it} + \beta_5 RefiningCapacity_it \\ + \beta_6 Supply\ Disruptions_t + \beta_7 HHI_{it} + \beta_X Months + \epsilon_t\end{aligned} \tag{4.3}$$

$$\begin{aligned}\pi_{it} = \beta_0 + \beta_1 Ethanol\ Prod._t + \gamma_1 Oil\ price_t + \gamma_2 NG\ price_t \\ + \gamma_3 Lagged\ Dependent\ Variable_{it-1} \\ + \beta_2 Gasoline\ Import_{it} + \beta_3 Oil\ Stock_{it} \\ + \beta_4 Gasoline\ Stock_{it} + \beta_5 RefiningCapacity_{it} \\ + \beta_6 Supply\ Disruptions_t + \beta_7 HHI_{it} + \beta_X Months + \epsilon_t\end{aligned} \tag{4.4}$$

The π_{it} in Equation 4.3 and Equation 4.4 above represents the dependent variable which is either the $\pi_{CS_{it}}$ for the Crack Spread or $\pi_{CR_{it}}$ for the Crack Ratio, with the same right-hand-side variables. The equations represent Du & Hayes and Knittel & Smith specifications, respectively. The subscript $i = 1, ..., N$ denotes the cross-section dimension across the PADD regions, and $t = 1, ..., T$ denotes the time dimension. $\pi_{CS_{it}}$ is the crack spread and $\pi_{CR_{it}}$ is the crack ratio for the i-th region for a time period t.

Included independent variables are as follows:

- **Ethanol Prod.** is the variable of interest that allows us to observe the desired effect on retail gasoline price. Unlike in the case of other variables, Du & Hayes (2009) do not use a PADD-specific approach. They utilize nationwide data instead. Ethanol production is heavily concentrated in one part of the country. In Q1 of 2022, PADD 2 (Midwest) accounted for almost 95% of total U.S. Ethanol production (1.11%, 94.49%, 2.16%, 1.38% and 0.85% for each PADD, respectively).

- **PADD-level stock of oil and gasoline reserves** Monthly stocks, excluding strategic petroleum reserves (SPR), by PADD;

- **PADD-level refining capacity** - it is believed that with increased ethanol production, the price of gasoline would decrease by relieving refining capacity constraints. Annual data.

- **PADD-level gasoline imports** is the only independent variable which Du & Hayes (2009) consider endogenous. The fitted regional gasoline imports are obtained from the first stage of the IV estimation as the sum of its first lag + the one-and two-month-lagged price differentials of the conventional regular gasoline between each PADD and price in the EU. Only then are gasoline imports applied as exogenous in the second-stage estimation. This is because increases in U.S. gasoline prices relative to European gasoline prices will provide an incentive for additional gasoline imports from Europe and vice versa. It can be transcribed as:

$$\text{Import}_{it} = \alpha + \beta\,\text{Import}_{i,t-1} + \delta_1 dP_{i,t-1} + \delta_2 dP_{i,t-2} \tag{4.5}$$

  where Import_{it} represents imports of gasoline to PADD i at month t, and $dP_{i,t-1}$ and $dP_{i,t-2}$ are the one- and two-month-lagged price differentials of the conventional regular gasoline between region i.

- **PADD-level Hirschman-Herfindahl Index** (**HHI**) for refining concentration. The Herfindahl-Hirschman Index (HHI) is a commonly accepted measure of market concentration used to determine market competitiveness, particularly in the context of mergers and acquisitions. It is calculated by squaring the market share of each firm competing in a market and summing the resulting numbers.

$$HHI = s_1^2 + s_2^2 + s_3^2 + \cdots + s_n^2 \tag{4.6}$$

where: s_n is the market share percentage of firm n expressed as a whole number, not a decimal.

The HHI ranges from close to zero, indicating a highly competitive market with many firms of relatively equal size, to 10,000, indicating a monopoly where a single firm controls the entire market. Markets with an HHI below 1,500 are considered competitive, those between 1,500 and 2,500 are moderately concentrated, and those above 2,500 are highly concentrated. The HHI helps regulators assess the impact of mergers on market competition, with increases in the HHI by more than 200 points in highly concentrated markets raising antitrust concerns. Despite its simplicity and ease of calculation, the main limitation of the HHI is that it does not account for the complexities of different markets (U.S. Department of Justice (2018), U.S. Department of Justice and the Federal Trade Commission (2010)).

- a **dummy variable for supply disruptions** – which are originally represented by dummies hurricanes[1], is further enhanced by a set of dummies for February through April 2020 as a result of COVID-19 pandemic disruptions
- a **set dummies for each month of the year**.

To deal with inflation Du & Hayes (2009) suggest deflating prices (to derive the crack spread) by the producer price index (PPI) for crude energy material to produce the real crack spread. On the other hand, Knittel & Smith (2015) advocate deflating it by general urban consumer price index (CPI), stating that PPI is strongly correlated to the oil price, and deflating the crack ratio by PPI essentially produces an observation that is close to the crack ratio. I run the models using both PPI and CPI index as well.

Knittel & Smith (2015) further argue that the model should be complemented with **prices of crude oil** and **natural gas** to control for the energy cost of refining dramatically reduces the estimated effect of ethanol on the crack spread and crack ratio. The two approaches are compile in a separate regression and I discuss the respective differences and results in the following section.

[1] Michael (October 2018), Florence (September 2018), Nate (October 2017), Irma (September 2017), Harvey (August 2017), Sandy (October 2012), Isaac (August 2012), Earl (September 2010), Ike (September 2008), Gustav (September 2008), Rita (September 2005), Katrina (August 2005)

Remark about Wavelet Analysis Data

I utilize the collected dataset to conduct wavelet analysis, ensuring that the same data is examined for selected time-series pairs. This analysis will be performed for the entire United States as well as regionally for each of the PADD.

Chapter 5

Methodology

In this chapter, the reader will find a detailed description of the research methods employed to analyze the data in this study. The chapter is divided into two main sections: the first explains the application of the analytical model presented by Du and Hayes, and the second explores the use of model-free Wavelet analysis. Each section outlines the theoretical foundations, the practical implementation steps, and the rationale behind choosing these methods. My approach ensures robust analysis that combines the advantages of model-dependent and model-free techniques.

5.1 Du & Hayes Model

Based on the specification above, I employ model proposed by Du & Hayes (2009) which uses a combination of regional panel data and classical econometric models to analyze the impact of ethanol production on gasoline prices and refiner profit margins. Specifically, the methodology involves a fixed-effects panel data model and following Du & Hayes (2009), the parameter estimates are obtained by the two-step feasible efficient generalized method of moments (GMM) estimator:

- **Fixed-Effects Model**: A fixed-effects panel data model is used to account for heterogeneity across regions and to control for various factors that might affect gasoline prices and refinery profit margins, including crude oil and gasoline stocks, refinery capacity, market concentration, supply disruptions, and gasoline imports.

  Fixed-effects panel data model is used to account for time-invariant unobserved heterogeneities. This approach incorporates individual-specific dummy variables in the regression model to capture the effects across entities (e.g., individuals, firms, etc, i.e. in our case regions - PADD districts) that remain constant over time. By accounting for these fixed effects, the FE model enables the examination of within-individual variations, identifying the relationship between the independent and dependent variables for each specific individual. This model is particularly useful when there are unobserved factors that are constant over time and might be correlated with the independent variables. It provides unbiased estimators of the coefficients by differencing out the individual-specific effects.

This way I am able to control for unobserved heterogeneity that may be correlated with the Crack Spread or Crack Ratio. The fixed effects model assumes that each PADD has its own individual characteristics that do not change over time. These individual characteristics, represented by fixed effects, can be correlated with other explanatory variables in the model.

Mathematically, the fixed effects model can be written as:

$$\pi_{it} = \alpha_i + X'_{it}\beta + \varepsilon_{it} \tag{5.1}$$

where:

- π_{it} is the dependent variable - CS (CR) for PADD i at time t.
- α_i is the PADD-specific effect.
- X_{it} is a vector of explanatory variables.
- β is a vector of coefficients.
- ϵ_{it} is the error term which in case on D&H model is corrected for first-order serial correlation

$$\epsilon_{it} = \rho\epsilon_{i,t-1} + \phi_{it} \quad \phi_{it} \sim \mathcal{N}(0, \sigma^2_{\phi_i}) \tag{5.2}$$

  with he autocorrelation coefficient $|\rho| < 1$ and ϕ_{it} is independently distributed with zero mean and region-specific variance $\sigma^2_{\phi_i}$.

- **Generalized Method of Moments (GMM)**: The two-step feasible efficient GMM estimator is applied to obtain parameter estimates, correcting for first-order serial correlation and groupwise heteroskedasticity.

The Generalized Method of Moments (GMM) is an econometric technique (as presented by Hansen (1982) that estimates parameters by exploiting moment conditions derived from the data. These moment conditions are typically based on the assumptions about the statistical properties of the error terms in a model.

Steps in GMM:

1. **Model Specification**: Identify the economic model and derive moment conditions. For instance, if $E[Z_i(Y_i - X_i\beta)] = 0$, where Z_i are instruments and $(Y_i - X_i\beta)$ are residuals, these are used as moment conditions.
    - Gasoline imports serve as Instrumental Variable (IV) here, as Du & Hayes (2009) suspect them to be endogenous. Consult previous Chapter.
2. **First Step**: Estimate the parameters using a preliminary method, such as ordinary least squares (OLS), to get initial parameter values.
3. **Weighting Matrix**: Calculate a weighting matrix, often the inverse of the covariance matrix of the moment conditions, to give appropriate weights to different moment conditions.
4. **Second Step**: Re-estimate the parameters using the weighting matrix to improve efficiency.
5. **Iteration**: Iterate between estimating the parameters and updating the weighting matrix until convergence (Baum *et al.* 2007).

Knittel and Smith Specifiacation

The following specifications were estimated for models using the deflated crack spread and crack ratio as the outcome measure. First, I estimated the original Du & Hayes (2009) specification using the updated dataset, and then I continuously apply steps proposed by Knittel & Smith (2015):

1. Deflating the crack spread and crack ratio using the Producer Price Index for crude energy material (the Du & Hayes (2009) specification).
2. Deflating the crack spread with the Consumer Price Index (This step is not applied to the crack ratio as it makes no meaningful sense to deflate the ratio of two variables).

3. Adding the price of oil.

4. Adding the price of natural gas.

5. Adding the lagged dependent variable.

5.2 Wavelet Analysis

Wavelet transformation

Wavelet analysis is a powerful technique widely recognized for its ability to capture the co-movement between variables across both time and frequency domains. This section is built on the foundational work of Torrence & Compo (1998) and Grinsted *et al.* (2004), with subsequent enhancements by Rua & Nunes (2009), Vacha & Barunik (2012) and Raza *et al.* (2022).

Wavelet analysis provides a robust framework for studying the dynamic relationships in time series data. By combining time and frequency information, it offers a deeper understanding of the underlying processes driving market behaviors. The ability to capture both global and local patterns makes wavelet analysis a valuable tool in economic and financial research.

It explains how the two diverse variables time-series co-moves in a time frequency. The wavelet technique is a bivariate framework that depends on a continuous wavelet transform and allows scaled localizations (Rua & Nunes (2009), Raza *et al.* (2022), Rubbaniy *et al.* (2021)).

5.2.1 Wavelet Transform

The wavelet transform of a time series $x(t)$ is defined as:

$$F(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{+\infty} f(t)\psi^* \left(\frac{t-\tau}{s}\right) dt \tag{5.3}$$

where $\psi(t)$ is the mother wavelet, u is the location parameter, and s is the scale parameter. The mother wavelet is a function that oscillates and decays to zero. The choice of the mother wavelet depends on the specific application and the properties of the data being analyzed.

Continuous Wavelet Transform

The Continuous Wavelet Transform (CWT) is used to decompose a time series into time-frequency space, providing information about both the amplitude of any periodic signals within the series, and how this amplitude varies with time. The CWT is particularly useful for analyzing non-stationary time series data, where statistical properties change over time (Vacha & Barunik 2012).

In simple terms, a wavelet can be described as a small wave that varies in amplitude within a limited time frame. The CWT of a time series $x(t)$ using a mother wavelet $\Psi(t)$ is defined as:

$$\Psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\Psi\left(\frac{t-\tau}{s}\right) \tag{5.4}$$

where τ is the translation parameter indicating time localization, and s is the scale parameter related to frequency. The wavelet transform of $x(t)$ at scale s and translation τ is given by:

$$W_x(\tau, s) = \frac{1}{\sqrt{s}}\int_{-\infty}^{\infty} x(t)\Psi^*\left(\frac{t-\tau}{s}\right)dt \tag{5.5}$$

The mother wavelet $\Psi(t)$ must satisfy certain conditions to be admissible: its mean must be zero, its square must integrate to one, and it must adhere to the admissibility condition ensuring the invertibility of the wavelet transform.

5.2.2 Wavelet Coherence

Wavelet coherence is a measure of the correlation between two time series as a function of both time and frequency. It is defined as:

$$R^2_{xy}(u, s) = \frac{|\langle W_x(u, s)W_y^*(u, s)\rangle|^2}{\langle|W_x(u, s)|^2\rangle\langle|W_y(u, s)|^2\rangle}, \tag{5.6}$$

where $W_x(u, s)$ and $W_y(u, s)$ are the wavelet transforms of the two time series $x(t)$ and $y(t)$, respectively, and $\langle\cdot\rangle$ denotes a smoothing operator in both time and scale. Wavelet coherence values range from 0 to 1, with values close to 1 indicating a high degree of correlation.

Cross-Wavelet and Wavelet Coherence

The cross-wavelet transform for two time series $x(t)$ and $y(t)$ is defined as:

$$W_{xy}(\tau, s) = W_x(\tau, s)W_y^*(\tau, s) \tag{5.7}$$

The wavelet coherence is analogous to the Fourier-based coherence and measures the local correlation between two time series in the time-frequency domain. It is computed as:

$$R^2(\tau, s) = \frac{|S\left(s^{-1}W_{xy}(\tau, s)\right)|^2}{S\left(s^{-1}|W_x(\tau, s)|^2\right) S\left(s^{-1}|W_y(\tau, s)|^2\right)} \tag{5.8}$$

where S denotes a smoothing operator in time and scale. The squared wavelet coherence $R^2(\tau, s)$ ranges from 0 to 1, indicating no correlation to perfect correlation, respectively. Phase differences are used to determine the lead-lag relationship between the time series, with the phase angle ϕ_{xy} computed as:

$$\phi_{xy} = \tan^{-1}\left(\frac{\Im\{W_{xy}(\tau, s)\}}{\Re\{W_{xy}(\tau, s)\}}\right) \tag{5.9}$$

where $\Im$ and $\Re$ denote the imaginary and real parts of the cross-wavelet transform, respectively. A zero phase difference indicates in-phase movement, while a phase difference of π (or $-\pi$) indicates anti-phase movement.

5.2.3 Implementation and Analysis

For this thesis, the Morlet wavelet is chosen as the mother wavelet due to its widespread use and effectiveness in economic and financial time series analysis. The Morlet wavelet is defined as:

$$\Psi(t) = \pi^{-\frac{1}{4}} e^{i\omega_0 t} e^{-\frac{t^2}{2}} \tag{5.10}$$

with ω_0 set to 6 to balance time and frequency localization.

Wavelet coherence analysis is applied to examine the co-movement and causal relationships between the studied variables. The significance of the coherence is assessed using Monte Carlo simulations with 1000 replications to ensure robust statistical inference.

This methodology provides a comprehensive framework for understanding the dynamic interactions between variables, capturing the complexity and variability inherent in economic and financial time series.

5.2.4 Phase Differences

As Vacha & Barunik (2012) In addition to measuring the magnitude of the correlation, wavelet coherence can also be used to determine the phase difference between two time series. The phase difference provides information about the lead-lag relationship between the series. It is calculated as:

$$\phi_{xy}(u,s) = \tan^{-1}\left(\frac{\mathrm{Im}\langle W_x(u,s)W_y^*(u,s)\rangle}{\mathrm{Re}\langle W_x(u,s)W_y^*(u,s)\rangle}\right), \tag{5.11}$$

or alternatively:

$$\varphi_{xy}(u,s) = \tan^{-1}\left(\frac{\mathcal{S}\left\{S(s^{-1}W_{xy}(u,s))\right\}}{\Re\left\{S(s^{-1}W_{xy}(u,s))\right\}}\right). \tag{5.12}$$

where Im and Re denote the imaginary and real parts, respectively.

In wavelet coherence plots, phase differences are indicated by arrows, providing insight into the lead-lag relationships and the nature of the correlation between two time series. A zero phase difference means that the examined time series move together. The arrows point to the right (→) when the time series are in-phase and positively correlated, and to the left (←) when they are out-phase and negatively correlated.

An arrow pointing up (↑) in a wavelet coherence plot indicates that the first time series is ahead of or leads the second time series by a quarter cycle (90 degrees). An arrow pointing down (↓) means that the second time series is ahead of or leads the first time series by a quarter cycle (90 degrees) (Vacha & Barunik 2012). In essence, the direction of the arrow shows which time series is leading and which one is lagging by a phase difference of 90 degrees. Diagonal arrows (↗, ↙) suggest that the first time series (x) leads to fluctuations in the second time series (y), while the arrows (↘, ↖) indicate that y leads to fluctuations in x.

Usually, we observe a mixture of these positions. For example, an arrow pointing up and to the right (↗) means that the time series are in-phase, with the first time series leading the second one. Conversely, vertical arrows (↓, ↑) denote that x is respectively lagging and leading. These visual cues help in understanding the causality and interdependence between the variables in the time-frequency space (Raza *et al.* 2022).

5.2.5 Applications in Energy and Biofuels Markets

Wavelet analysis has been successfully applied to study the co-movement and dynamic correlations in various markets. For instance, Vacha and Barunik

Vacha & Barunik (2012) utilized wavelet coherence to analyze the interconnections between crude oil, gasoline, heating oil, and natural gas. They found that these correlations vary significantly over time and across different investment horizons. In another study, Vacha et al. Vacha *et al.* (2013) explored the time-frequency dynamics of the biofuels-fuels-food system, revealing complex interdependencies between these commodities.

Chapter 6

Results

The *Results* section of this thesis is dedicated to presenting the findings of the conducted research. This section details the outcomes of implementing the Du and Hayes model, as well as the results obtained from the model-free approach utilizing Wavelet analysis. The Du and Hayes model provides a structured framework for analyzing the data, while the Wavelet analysis offers a complementary, non-parametric method to uncover underlying patterns. By comparing the results from both approaches, this section aims to provide a comprehensive answer what is teh the effect of biofuel production on gas prices in the USA.

6.1 Du & Hayes

The following specifications were estimated for models using the deflated crack spread and crack ratio as the outcome measure. First, I estimated the original Du & Hayes (2009) specification using the updated dataset, and then I continuously apply steps proposed by Knittel & Smith (2015):

1. Deflating the crack spread and crack ratio using the Producer Price Index for crude energy material (the Du & Hayes (2009) specification).

2. Deflating the crack spread with the Consumer Price Index (This step is not applied to the crack ratio as it makes no meaningful sense to deflate the ratio of two variables).

3. Adding the price of oil.

4. Adding the price of natural gas.

5. Adding the lagged dependent variable.

Based on the specification above, I employ a fixed-effects panel data model and following Du & Hayes (2009), the parameter estimates are obtained by the two-step feasible efficient generalized method of moments (GMM) estimator.

Study	Crack Spread	Crack Ratio	Sample Period
Du & Hayes (2009)	-\$0.28***	-\$0.37***	1995 - 2008
Du & Hayes (2011) *update*	-\$0.29***	-\$1.09***	2000 - 2010
Du & Hayes (2012) *update*	-\$0.25***	-\$0.9***	2000 - 2011
Knittel & Smith (2015):			2000 - 2010
using CPI to deflate prices	-\$0.09		
+ including oil price	-\$0.30***	-\$0.48***	
+ including natural gas price	-\$0.13	-\$0.35***	
+ including lagged dependent variable	-\$0.09	-\$0.12*	
This Thesis:			2010 - 2022
replicating Du & Hayes (2009)	+\$0.34***	+\$0.58**	
replicating Knittel & Smith (2015):			
using CPI to deflate prices	+\$0.22**		
+ including oil price	+\$0.32***	-\$0.19	
+ including natural gas price	+\$0.32***	-\$0.22	
+ including lagged dependent variable	+\$0.15	-\$0.20	

Table 6.1: This compares the results of the original studies and my replication with the extended time period. The Crack Spread column estimates the impact of the RFS program on retail gasoline prices. The superscript reports on the statistical significance of the underlying *U.S. Ethanol Production* coefficient at *** 99%, ** 95%, and * at 90%, respectively. my results are all based on the data from 2010 to 2022.

I ran nine regressions using nine different specifications in the period 2010 - 2022. The results of these regressions are reported in Table 6.1 for the Crack Spread and in Table 6.2 for the Crack Ratio. Each table provides the results from each regression which represent the ethanol effect from the crack spread or crack ratio models as the implied increase in the crack spread from eliminating all ethanol production. To produce the final estimate of the ethanol production effect, my estimate has to be multiplied by average ethanol production and further by crude oil price in the case of crack ratio. I report those findings in Table 6.1.

The regression results delivered surprisingly mixed results that did not provide a clear answer to the research question nor were consistent with existing literature. Replicating the Du & Hayes (2009) crack spread model using data from 2010 to 2022, I estimate a positive and statistically significant impact of ethanol production on gasoline prices of $0.35 per gallon. This suggests that contrary to the original results, as well as other results in this report, higher ethanol production increases the cost of gasoline at the pump. Estimating the impact on refineries' margins with crack ratio, using the Du & Hayes (2009) specification, my results suggest that ethanol blending increases the profits of the refineries as well. This suggests that increased ethanol production can make gasoline more expensive.

Replicating the Crack Spread model with specifications in Knittel & Smith (2015), I obtain a positive and mostly statistically significant effect of ethanol production on the prices of gasoline at the pump. Compared to the Du & Hayes (2009) model, it is roughly the same when I control for oil and natural gas prices but drops to $0.22 when I consider only deflated prices with the CPI. As for the crack ratio, using Knittel & Smith (2015) models, I do not find a statistically significant impact in any of the variants.

When the energy costs of refining are controlled for using oil and natural gas prices, the estimated effect on the crack spread is positive $0.32 and negative $0.23 in the case of crack ratio, which is statistically insignificant. Eventually, the estimate with the smallest effect (+$0.15 and -$0.20) is that of lagged dependent variable is statistically insignificant and again contradictory positive and negative. Overall, I cannot confirm the findings of Du & Hayes (2009) or Knittel & Smith (2015) using the updated data from 2010 to 2022.

This might be a consequence of the fact that both Du & Hayes (2009) and Knittel & Smith (2015) conducted their analyses with sample periods that saw steady growth of ethanol production. See graphs that depicts how the crack spread, crack ratio, and ethanol production evolved over time. Ethanol production has since stagnated. It is easy to draw correlations between ethanol production and other variables (such as energy prices in our case) when ethanol production is increasing, but when ethanol production stagnates or oscillates strongly, the correlations may not be as strong or meaningful. This is supported by the fact that if I shift our sample period to 2001-2012, I obtain significant and negative results see Table A.13 and Table A.12 in Appendix. Maybe the production of ethanol itself is not the best choice as a variable of interest, and it is important to note that ethanol blend mandates may have a more direct influence on gasoline prices, but they are not explicitly considered in those models. This is because the mandates dictate the amount of ethanol that must be blended into gasoline, which affects the supply and demand for gasoline (this, in theory, is not the consequence of mere ethanol production). Additionally, the cost of producing ethanol may also have an indirect impact on gasoline prices. Therefore, it is possible that ethanol blend mandates may have a greater impact on gasoline prices than ethanol production.

Hayes himself finds that the war in Ukraine reduces global corn supply due to decreased Ukrainian exports and higher production costs due to increased fertilizer prices have caused US corn prices to rise.[1] The USA, being a significant producer and exporter of corn, benefits from higher export prices, the domestic market experiences increased costs. (He *et al.* 2023)

[1]He *et al.* (2023) modeled different scenarios to project the impacts of the conflict. In scenarios where Ukraine's corn exports were reduced by 25% and fertilizer prices increased by 100%, corn prices were projected to increase by 24. 9% worldwide by the 2025/26 marketing year.

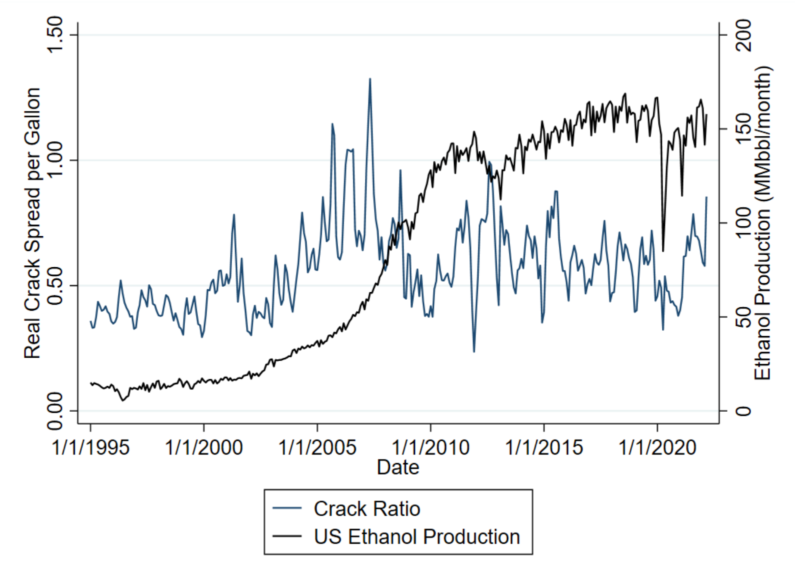

Figure 6.1: Real Crack Spread

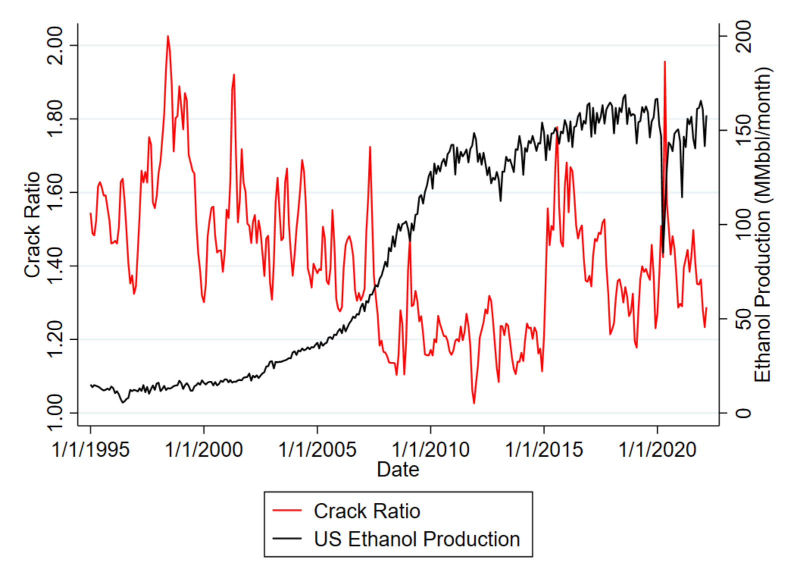

Figure 6.2: Crack Ratio

Table 6.2: Crack Ratio Results

	(1)	(2)	(3)	(4)
VARIABLES	Crack Ratio DH	Crack Ratio oil price	Crack Ratio oil price NG price	Crack Ratio oil price NG price lag
U.S. Ethanol Production	0.0121*	-0.0036	-0.0045	-0.0042
	(0.0068)	(0.0056)	(0.0056)	(0.0063)
Real Price of Oil		-0.0048***	-0.0046***	-0.0021***
		(0.0004)	(0.0004)	(0.0006)
Natural Gas Price			-0.0110**	-0.0050
			(0.0043)	(0.0033)
Lagged Crack Ratio				0.6044***
				(0.0748)
Gasoline Imports	-0.0012	-0.0174**	-0.0170**	-0.0118**
	(0.0097)	(0.0069)	(0.0068)	(0.0053)
Stock of Oil Reserves	0.0032***	-0.0004	-0.0005*	-0.0004
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Stock of Gasoline Reserves	0.0037*	-0.0062***	-0.0065***	-0.0042***
	(0.0020)	(0.0011)	(0.0011)	(0.0008)
Refining Capacity	-0.0311***	-0.0124***	-0.0122***	-0.0024
	(0.0031)	(0.0032)	(0.0032)	(0.0025)
HHI	1.5566***	-0.5340	-0.5364*	-0.1811
	(0.5554)	(0.3328)	(0.3240)	(0.1907)
Hurricane	0.0360	-0.0100	-0.0187	-0.0216
	(0.0342)	(0.0327)	(0.0330)	(0.0261)
January	-0.0015	0.0239	0.0317	0.0361
	(0.0476)	(0.0365)	(0.0362)	(0.0270)
February	0.0525	0.0359	0.0401	0.0380
	(0.0517)	(0.0370)	(0.0362)	(0.0343)
March	0.0971**	0.1239***	0.1194***	0.1088***
	(0.0479)	(0.0322)	(0.0317)	(0.0250)
April	0.1317***	0.1198***	0.1050***	0.0518*
	(0.0502)	(0.0331)	(0.0332)	(0.0310)
May	0.1734***	0.1866***	0.1718***	0.1167***
	(0.0577)	(0.0352)	(0.0344)	(0.0382)
June	0.1328***	0.1324***	0.1194***	0.0283
	(0.0428)	(0.0289)	(0.0295)	(0.0266)
July	0.1326***	0.1331***	0.1212***	0.0591**
	(0.0463)	(0.0319)	(0.0322)	(0.0291)
August	0.1582***	0.1388***	0.1276***	0.0740**
	(0.0533)	(0.0381)	(0.0387)	(0.0302)
September	0.1460***	0.1070***	0.0940***	0.0265
	(0.0474)	(0.0340)	(0.0343)	(0.0295)
October	0.0744	0.0591*	0.0503	0.0026
	(0.0453)	(0.0310)	(0.0309)	(0.0271)
November	0.0384	0.0166	0.0101	-0.0105
	(0.0399)	(0.0288)	(0.0287)	(0.0248)
PADD 2	0.5087***	0.1107**	0.1094**	0.0001
	(0.0834)	(0.0443)	(0.0452)	(0.0278)
PADD 3	1.4572***	0.8617***	0.8655***	0.2633**
	(0.1625)	(0.1466)	(0.1474)	(0.1112)
PADD 4	0.2924*	-0.4201***	-0.4352***	-0.2537***
	(0.1547)	(0.0762)	(0.0752)	(0.0579)
PADD 5	0.6818***	0.0989**	0.0895*	-0.0386
	(0.0967)	(0.0485)	(0.0495)	(0.0310)
Constant	0.4902***	2.3533***	2.4274***	1.1299***
	(0.1334)	(0.2151)	(0.2143)	(0.3047)
Observations	735	735	735	730
R-squared	0.4214	0.7194	0.7241	0.8391

Table 6.3: Crack Spread Results

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	0.0099***	0.0085**	0.0118***	0.0119***	0.0053
	(0.0035)	(0.0041)	(0.0038)	(0.0039)	(0.0039)
Real Price of Oil			0.0010***	0.0010**	0.0004
			(0.0004)	(0.0004)	(0.0004)
Natural Gas Price				0.0009	-0.0015
				(0.0066)	(0.0050)
Lagged Real Crack Spread					0.6820***
					(0.0414)
Gasoline Imports	-0.0011	-0.0277***	-0.0243***	-0.0243***	-0.0114*
	(0.0069)	(0.0094)	(0.0092)	(0.0092)	(0.0061)
Stock of Oil Reserves	0.0013***	-0.0006**	0.0002	0.0002	0.0001
	(0.0002)	(0.0003)	(0.0003)	(0.0003)	(0.0002)
Stock of Gasoline Reserves	0.0019*	-0.0088***	-0.0067***	-0.0067***	-0.0042***
	(0.0011)	(0.0012)	(0.0013)	(0.0013)	(0.0009)
Refining Capacity	-0.0135***	-0.0111***	-0.0150***	-0.0150***	-0.0054**
	(0.0018)	(0.0038)	(0.0038)	(0.0038)	(0.0026)
HHI	1.1724***	-0.3883	0.0520	0.0522	0.2792
	(0.3461)	(0.4655)	(0.4263)	(0.4265)	(0.2639)
Hurricane	0.0635***	0.0752	0.0849*	0.0856*	0.0294
	(0.0239)	(0.0506)	(0.0450)	(0.0453)	(0.0328)
January	-0.0023	0.0324	0.0270	0.0264	0.0759***
	(0.0219)	(0.0377)	(0.0390)	(0.0382)	(0.0285)
February	0.0526*	0.1140***	0.1175***	0.1171***	0.1492***
	(0.0296)	(0.0440)	(0.0438)	(0.0433)	(0.0397)
March	0.0919***	0.1843***	0.1786***	0.1790***	0.1868***
	(0.0268)	(0.0430)	(0.0429)	(0.0438)	(0.0320)
April	0.1128***	0.1836***	0.1861***	0.1874***	0.1238***
	(0.0261)	(0.0370)	(0.0373)	(0.0409)	(0.0317)
May	0.1283***	0.2322***	0.2295***	0.2307***	0.1682***
	(0.0295)	(0.0356)	(0.0370)	(0.0405)	(0.0317)
June	0.1028***	0.1818***	0.1819***	0.1830***	0.0823***
	(0.0237)	(0.0360)	(0.0367)	(0.0394)	(0.0280)
July	0.0964***	0.1706***	0.1705***	0.1715***	0.1092***
	(0.0271)	(0.0415)	(0.0429)	(0.0451)	(0.0318)
August	0.1125***	0.1900***	0.1941***	0.1950***	0.1419***
	(0.0287)	(0.0490)	(0.0496)	(0.0513)	(0.0335)
September	0.1105***	0.1756***	0.1838***	0.1849***	0.0936***
	(0.0269)	(0.0486)	(0.0486)	(0.0495)	(0.0311)
October	0.0685**	0.0988**	0.1020**	0.1028**	0.0523
	(0.0298)	(0.0445)	(0.0452)	(0.0461)	(0.0326)
November	0.0534**	0.0746*	0.0792*	0.0798*	0.0413
	(0.0238)	(0.0405)	(0.0419)	(0.0425)	(0.0325)
PADD 2	0.3008***	0.0822	0.1660**	0.1661**	0.0680
	(0.0533)	(0.0707)	(0.0672)	(0.0671)	(0.0445)
PADD 3	0.6992***	0.8400***	0.9654***	0.9651***	0.4034***
	(0.1009)	(0.1961)	(0.1862)	(0.1858)	(0.1222)
PADD 4	0.2332***	-0.5179***	-0.3678***	-0.3665***	-0.2051***
	(0.0841)	(0.0961)	(0.0890)	(0.0878)	(0.0659)
PADD 5	0.3989***	0.0462	0.1690**	0.1698**	0.0134
	(0.0548)	(0.0682)	(0.0686)	(0.0686)	(0.0451)
Constant	-0.3804***	0.9423***	0.5499***	0.5435***	0.1514
	(0.0977)	(0.1679)	(0.1882)	(0.1907)	(0.1595)
Observations	735	735	735	735	730
R-squared	0.4661	0.5431	0.5565	0.5566	0.7672

6.1.1 Discussion

- **Simplified Assumptions:** Knittel and Smith argued that Du and Hayes' assumption of a one-to-one relationship between changes in output prices and refiners' profits was overly simplistic and did not capture the complexity of the refining industry.

  There indeed is not *penny-to-penny* relationship between said refiners' margins. We simply cannot plug numbers back into their formulas and expect immediate effect. Moreover, Refiners do not only produce gasoline; they produce a range of products from crude oil, such as diesel, jet fuel, and heating oil. Each of these products has its own supply and demand dynamics, which can influence the overall margin a refiner achieves.

  This does not mean that these margins are without use. Using refiners' profits as a metric when examining the effect on gasoline prices can provide valuable insights into the economic dynamics of the refining industry. Refiners' profits are directly influenced by the margins between the prices of crude oil and refined products and ultimately retail price. By analyzing these profits, researchers can measure the profitability and operational efficiency of refineries, which in turn affects their pricing strategies. For instance, if refiners experience increased profits due to lower input costs or higher demand for refined products, they might pass on some of these savings to consumers in the form of lower gasoline prices. In contrast, if profit margins shrink, refiners may need to increase gasoline prices to maintain profitability. This relationship highlights the importance of considering refiners' profits as they reflect the broader economic environment and operational decisions within the refining sector. With refiners' profits, researchers might observe swifter reactions of the market.

- **Model Robustness:** Knittel and Smith suggested that Du and Hayes' model lacked robustness, as it did not sufficiently control for external factors influencing gasoline prices, such as demand and supply variations unrelated to ethanol production.

  In conclusion, I show that estimates with the updated dataset are inconclusive and inconsistent with the previous results across multiple specifications. Thus the refinery margin approach turns out not to be an appropriate approach to analyze the economic impacts of ethanol production. This is in line with the general argument of Knittel & Smith (2015).

Recent global events, such as the war in Ukraine, have also influenced agricultural and energy markets. Hayes (2023) notes that the conflict has reduced global corn supply and increased production costs due to higher fertilizer prices. This has raised US corn prices, affecting ethanol production costs and, consequently, gasoline prices. Such geopolitical factors add another layer of complexity to the analysis, as they can significantly disrupt market dynamics and affect the validity of historical models.

- **Selective Reporting:** Knittel & Smith (2015) highlighted that Du and Hayes did not report model versions that could produce larger coefficients, potentially leading to biased conclusions. Cautiousness is therefore advised, when interpreting results.

6.2 Wavelet Analysis

I have conducted a Wavelet Coherence analysis to examine the relationship between ethanol biofuel production and several gas price indicators. The detailed results and interpretations of this analysis can be found in the following article. The WC analysis reveals that ethanol production exhibits strong coherence with the crack ratio, real crack spread, and retail gasoline prices at specific periodicities, particularly in the lower frequency bands. The phase relationships indicate that ethanol production generally leads both the real crack spread and retail gasoline prices by approximately $\pi/2$, while it is mostly in phase with the crack ratio. The wavelet coherence analysis reveals strong long-term relationships between ethanol production and the crack ratio, real crack spread, and retail gasoline prices, particularly from 2016 onwards. These relationships are more pronounced at lower frequencies, indicating that the variables are more aligned over longer periods. The phase analysis suggests that these variables generally move together, with occasional leadership by ethanol production.

6.2.1 Ethanol Production and Crack Ratio

Figure 6.3 shows the WC between ethanol production and crack ratio. The color gradient represents the coherence values, with red indicating high coher-

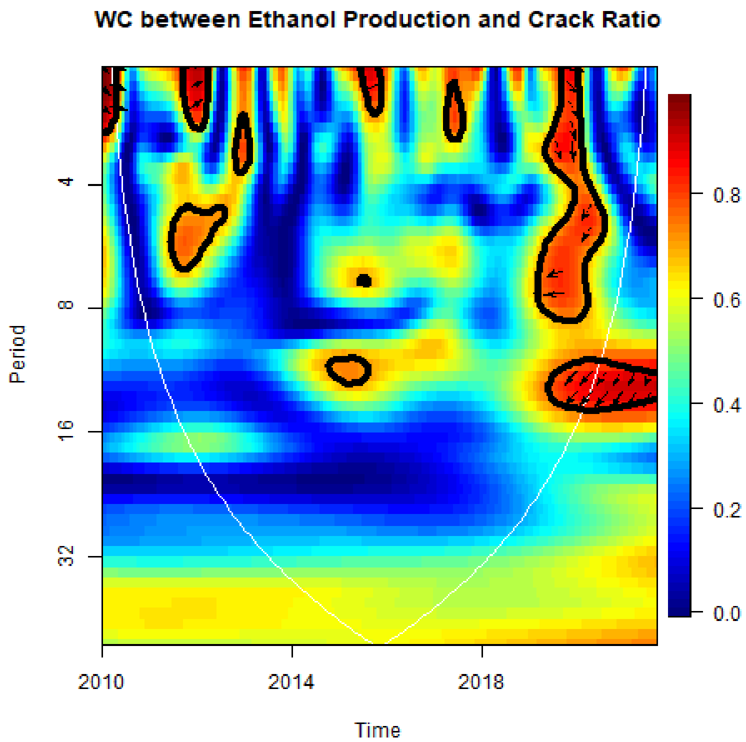

Figure 6.3: Wavelet Coherence between Ethanol Production and Crack Ratio

ence and blue indicating low coherence. The white curve delineates the Cone of Influence (COI), within which the results are more reliable.

From 2016 to 2018, there's a significant coherence at the lower frequencies (around 16 to 32 periods), indicating a strong relationship between ethanol production and the crack ratio during this period.

Some shorter periods (4 to 8 periods) show intermittent high coherence around 2012 and 2014, suggesting spurious correlation at these times.

The analysis reveals significant coherence in the 4- to 8-month period range during multiple intervals, particularly around 2010-2012 and 2016-2018. This suggests a strong relationship between ethanol production and crack ratio at these periodicities. The phase arrows in the high-coherence regions are predominantly pointing to the right, indicating that the ethanol production and crack ratio are generally in phase during these periods. An in-phase relationship implies that increases or decreases in production of ethanol correspond to simultaneous increases or decreases in the crack ratio.

The coherence at lower frequencies (longer periods) in later years might suggest that changes in ethanol production and the crack ratio are more aligned over long-term cycles during recent years.

6.2.2 Ethanol Production and Real Crack Spread

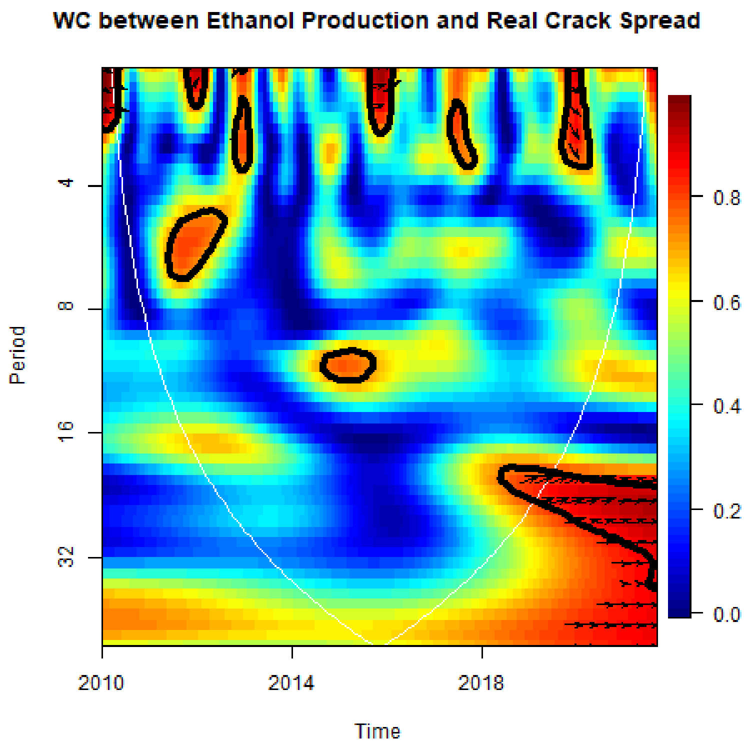

Figure 6.4: Wavelet Coherence between Ethanol Production and Real Crack Spread

Figure 6.4 presents the WC between ethanol production and real crack spread. High coherence is observed in the lower frequency range, particularly around the 16 to 32-month periods, especially from 2016 onwards. This indicates a robust relationship between ethanol production and real crack spread at these lower frequencies (longer periods).

Coherence at the higher frequencies (4 to 8 periods) appears more sporadic but noticeable around 2011, 2013, and 2015.

The phase arrows in the high coherence regions are primarily pointing downwards or slightly to the right. This suggests that ethanol production tends to lead the real crack spread by approximately $\pi/2$ (a quarter cycle). A leading relationship implies that changes in ethanol production precede corresponding changes in the real crack spread by a quarter of the cycle period.

The strong coherence in the recent years suggests a robust long-term relationship between ethanol production and real crack spread, indicating that these variables move together over longer cycles.

6.2.3 Ethanol Production and Retail Gasoline Price

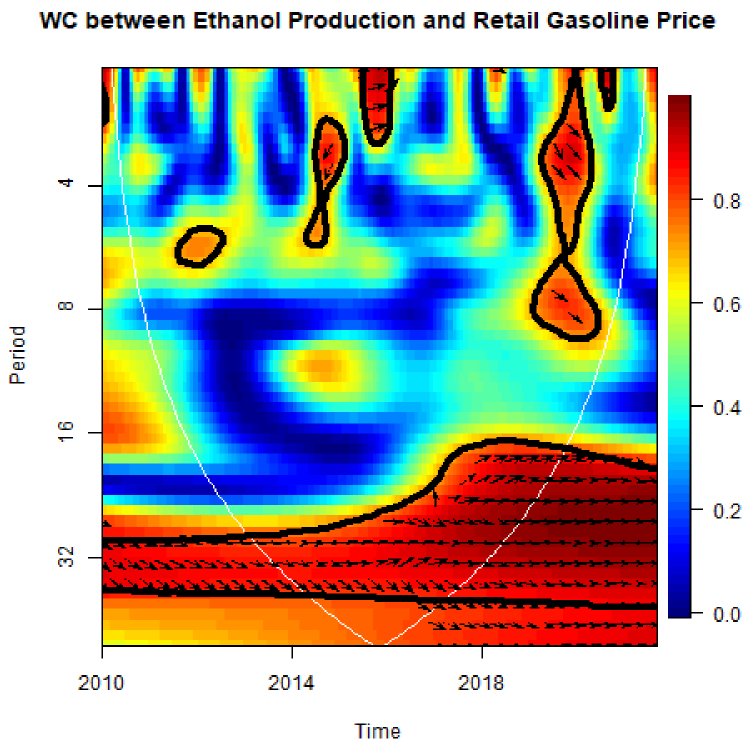

Figure 6.5: Wavelet Coherence between Ethanol Production and Retail Gasoline Price

Figure 6.5 illustrates the WC between ethanol production and retail gasoline price. Significant coherence is evident mainly in the lower frequency range (16- to 32-month periods) throughout the dataset, with intermittent high coherence at higher frequencies (lower periods). These extensive high coherence regions imply a robust long-term relationship between ethanol production and retail gasoline prices, suggesting these variables are closely related over extended periods.

The arrows in the high coherence areas are predominantly pointing upwards or slightly to the left, indicating that ethanol production leads retail gasoline prices by about $\pi/2$. This suggests that changes in ethanol production are followed by corresponding changes in retail gasoline prices after a quarter cycle.

The wavelet coherence analysis reveals that the strongest long-term relationship is between ethanol production and retail gasoline prices, particularly from 2013 onwards. This relationship is most pronounced at lower frequencies, indicating that these variables are more aligned over longer periods. Although there are moderate relationships with the crack ratio and real crack spread, the coherence with retail gasoline prices is the most substantial. Phase analysis supports this by showing that these variables generally move together, with ethanol production occasionally leading retail gasoline prices.

6.2.4 Regionality

In the manner of Du & Hayes, we can take advantage of data gathered across all PADD regional districts to conduct a thorough and nuanced analysis. By utilizing the rich dataset available from these regions, we are able to investigate the complex dynamics and regional variations in the impact of ethanol production on said economic indicators. This approach not only enhances the robustness of our findings but also allows for a detailed understanding of regional differences that might influence national trends. This subsection is set to investigate the regional variations in the impact of ethanol production across the five PADDs. The findings offer insights into whether these impacts are consistent nationwide or if they vary significantly across different regions.

Despite the overall consistency in long-term relationships, some regional variations were notable. PADD 2, which produces by far the most ethanol, displayed strong coherence in both long-term and short-term periods. This suggests that PADD 2 has a particularly significant influence on the observed national trends. The most surprising finding was the uniformity of the long-term relationships across all districts, despite the regional differences in ethanol production volumes and economic contexts.

Crack Ratio

The wavelet coherence analysis between ethanol production and the crack ratio across different PADDs revealed a generally consistent pattern with the national sample, particularly in terms of long-term relationships. Significant coherence was observed in all regions from 2016 to 2019 at lower frequencies (16 to 32 periods), indicating a robust long-term relationship. However, there were some regional variations in short-term coherence (4 to 8 periods), which appeared more sporadic and varied across different PADDs.

Real Crack Spread

Similarly, the analysis of the real crack spread showed consistent long-term coherence with ethanol production across all PADDs, particularly from 2017 to 2019. The phase analysis indicated that ethanol production generally led the real crack spread. This long-term relationship was evident in all regions, although short-term variations were more pronounced in some PADDs compared to others.

Retail Gasoline Prices

The wavelet coherence analysis between ethanol production and retail gasoline prices revealed the strongest and most consistent relationships. Significant coherence was observed in all PADDs from 2016 to 2019 at lower frequencies, indicating a robust long-term relationship. Short-term coherence showed more variability but generally aligned with the national sample's findings.

PADD 1, PADD 3, and PADD 4 showed similar patterns, with strong long-term coherence and sporadic short-term variations. PADD 5, while generally consistent with other districts, displayed slightly more pronounced short-term coherence, indicating regional nuances that might be driven by local economic factors.

The regional analysis of the impact of ethanol production on economic indicators revealed that while there are some short-term variations, the long-term relationships are remarkably consistent across all PADDs. This uniformity suggests that the benefits and effects of ethanol production on economic indicators such as the crack ratio, real crack spread, and retail gasoline prices are broadly similar across different regions in the United States.

PADD 2, with its substantial ethanol production, plays a pivotal role in shaping these national trends. The findings underscore the importance of considering both regional and national contexts in policy-making and economic analysis related to ethanol production and its broader economic impacts.[2]

[2] I provide plots only for PADD2 as focusing on PADD 2 provides a clear illustration of the most significant trends, given its high ethanol production volume. Full plots for each PADD are provided in the Appendix for a detailed comparison.

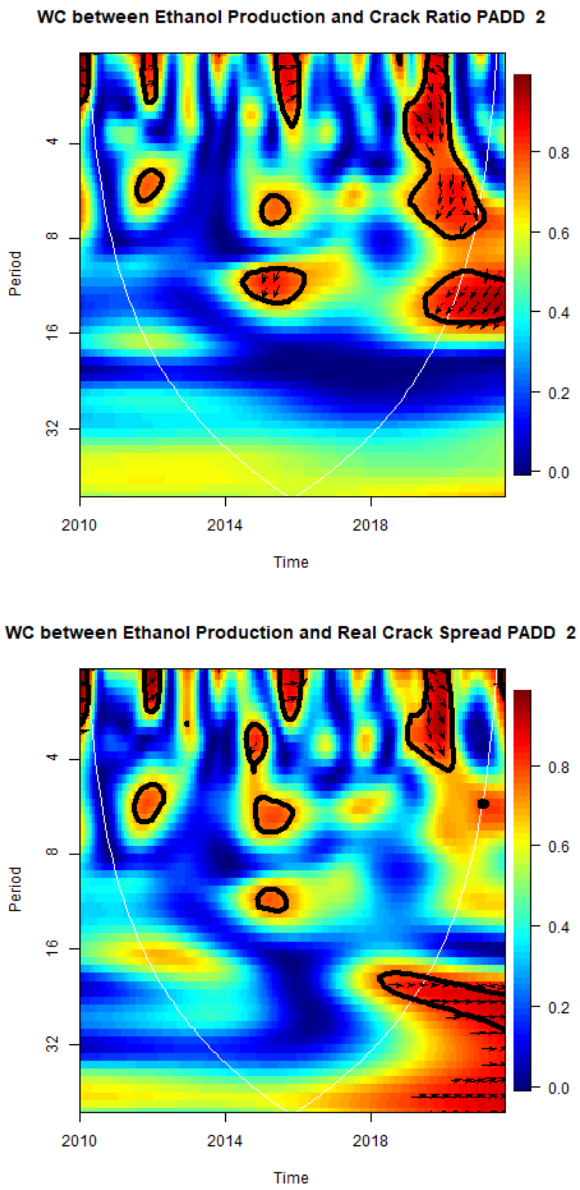

Figure 6.6: Wavelet Coherence between Ethanol Production and CR and CS respectively in PADD2

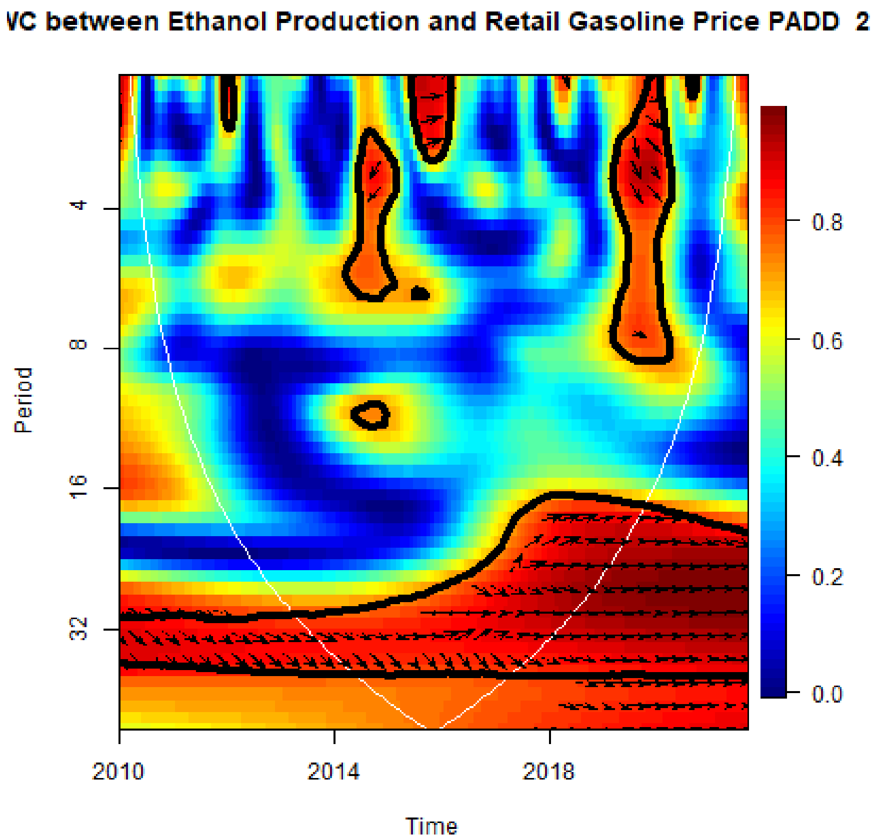

Figure 6.7: Wavelet Coherence between Ethanol Production and Retail Gasoline Prices in PADD2

clearpage

6.2.5 Alternative Energy Commodities

To assess completely the role of ethanol production, it is suitable to put it in context with other energy commodities in play. I included analyzing the impact of oil and natural gas prices on the same economic indicators.

Oil Price

The WC analysis for both the crack ratio and the real crack spread shows similar patterns when correlated with oil prices. Significant coherence is observed at lower frequencies (32 to 64 periods) during the late 1990s, early 2000s, and again from 2007 to 2013. This indicates strong long-term relationships between oil prices and these indicators during these periods. However, the coherence is less pronounced in the recent decade (2015-2020).

In comparison, the relationship between ethanol production and these indicators was notably strong from 2016 to 2019. This suggests that while oil prices historically had a more extended influence on the crack ratio and real crack spread, the influence of ethanol production on these indicators has become more pronounced in recent years.

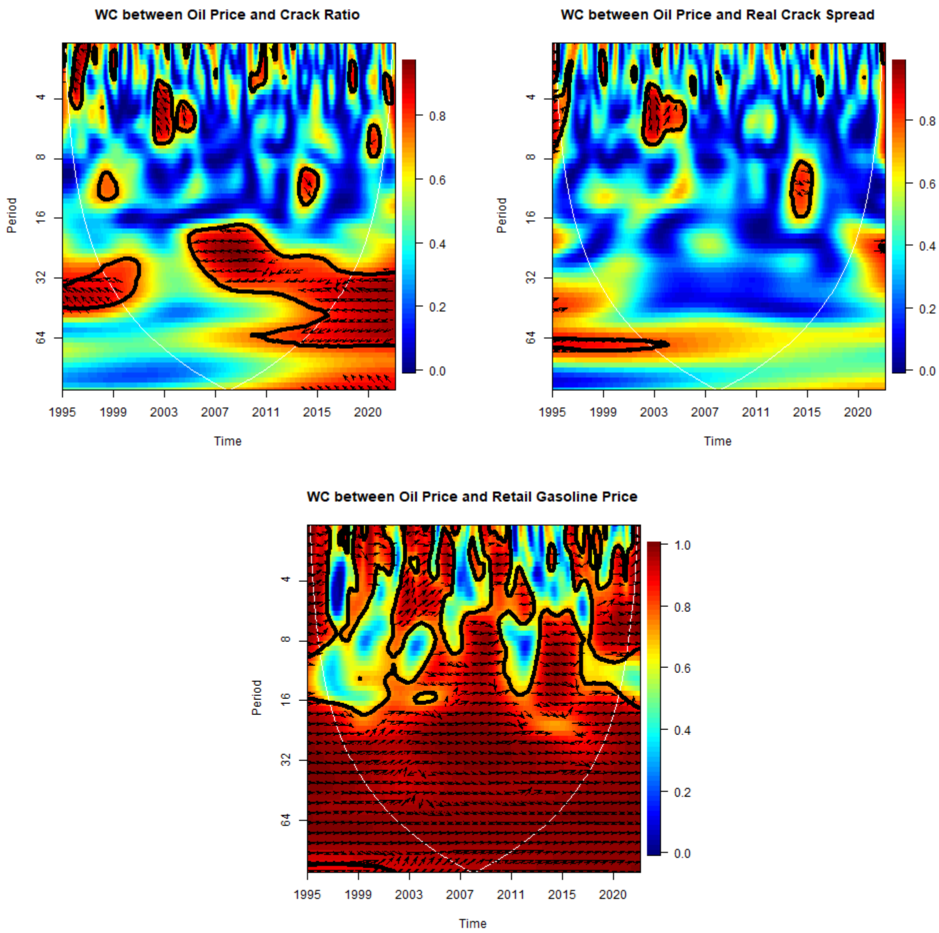

Figure 6.8: Wavelet Coherence between Oil Price

The most striking finding is the enormous and consistent coherence between oil prices and retail gasoline prices. The WC plot shows extensive high coherence across nearly all periods and frequencies from. This robust relationship indicates that oil prices and retail gasoline prices move together closely over both long and short terms. The phase arrows confirm that these two variables are mostly in phase, demonstrating a synchronized movement. This is in stark contrast to the relationship between ethanol production and retail gasoline prices, which, while strong, was primarily observed in the recent decade from 2016 to 2019. The results highlights the dominant and persistent role of oil price in influencing the gasoline prices. This contrasts with the influence of ethanol production, which seems here nearly obsolete.

Natural Gas

I make only short final remark stating, that the influence of natural gas prices on the crack ratio and real crack spread is present but less pronounced and more sporadic compared to the influence of oil prices. This indicates that while natural gas prices do affect these economic indicators, their impact is less consistent over time, but still more significant then that of ethanol production (see plots in Apendix).

6.2.6 Discussion

As said above, the price of gasoline is influenced not only by ethanol production but also by unforeseen events. These events include, but are not limited to, hurricanes, as anticipated by Du & Hayes (2009), as well as the COVID-19 pandemic and the ongoing Russian aggression in Ukraine. Additionally, the price of gasoline is affected by more routine factors, most notably the price of oil. I shown that price of natural gas and more notably price of oil drive the price of gasoline. This again points to the fact that effect of ethanol production is not robust enough to significantly influence said prices on its own.

When assessing the results from wavelet coherence analysis, I again cannot confirm findings of Du & Hayes (2009) that we can attribute direct price effects of ethanol production to retail gasoline price through refiners' margins. If there really was a one-to-one relationship between ethanol production and price of gasoline we would need to see similar plots of these margins and price of gasoline which is not the case.

On the whole, results from wavelet coherence analysis support our model replication colusions about insufficient robustness and flawed theoretical foundation of D&H model concerning direct impact on retail gasoline prices.

Chapter 7

Conclusion

Ethanol plays a vital role in the United States' energy landscape. Its production and use contribute to environmental sustainability, economic growth, and energy security. Corn remains a critical feedstock, while the Renewable Fuel Standard continues to shape the industry's development. As the whole country moves towards more sustainable energy solutions, ethanol will undoubtedly remain a key player. Ethanol, which is produced primarily from biomass such as corn, is crucial for several reasons. It offers a renewable alternative to fossil fuels, and supports domestic economies. Ethanol-blended fuels, such as E10 and E85, are widely used in the transportation sector, reducing dependency on oil imports and promoting energy security.

While ethanol biofuel production in the United States has been championed for its potential to reduce greenhouse gas emissions, enhance energy security, and stimulate rural economies, it is critical to acknowledge that this industry is not without its significant disadvantages. The purported environmental benefits of ethanol have been challenged by recent studies which indicate that the carbon footprint of corn ethanol, when considering fertilizer use and land-use changes, is at least 24% higher than that of regular gasoline.

Health implications are also noteworthy, particularly concerning the use of corn as livestock feed. The predominance of corn in animal diets, which is not naturally suited for many livestock, can lead to digestive issues and increase susceptibility to diseases, necessitating the widespread use of antibiotics. This practice has been linked to the growing problem of antibiotic resistance, posing a significant public health threat. Moreover, overfarming of corn associated with ethanol production necessitates extensive use of nitrogen fertilizers. These fertilizers contribute to nitrogen runoff, contaminating groundwater and surface water, and causing severe environmental issues such as eutrophication with so called "Blue Baby Syndrome".

Socio-economically, the policies supporting ethanol production have led to market distortions. Government subsidies primarily benefit large agricultural producers, leaving smaller farms at a disadvantage. This inequitable distribution of subsidies not only perpetuates economic disparities but also incentivizes unsustainable farming practices aimed at maximizing short-term yields over long-term sustainability.

This thesis aimed to focus purely on the price scope of the issue at hand as ethanol was heralded as factor which makes gasoline cheaper and saves more than a thousand dollars of disposable income to American households. I targeted my thesis' empirical research on ethanol production and its effect on gasoline price through relevant economic indicators of oil producers margins (namely crack spread and crack ratio) and their interconnectedness with price and production of other economic commodities.

In my analysis, I have examined the findings of Du & Hayes (2009) regarding the impact of ethanol production on retail gasoline prices. However, contrary to their results, I have found a surprisingly positive effect instead of a strong negative effect (as high as $1.09 decrease per gallon in the update of Du & Hayes (2011), it regionally climbs up to $1.37). Moreover, taking into consideration the critique provided by Knittel & Smith (2015), I observed a negative effect, but it was statistically insignificant. When considering the crack spread, I found a positive effect that remained consistent.

Overall, my analysis contradicts the initial findings of Du & Hayes (2009), suggesting a different relationship between ethanol production and retail gasoline prices. The critique by Knittel & Smith (2015) appears to be largely accurate, which raises cautiousness and highlights the need for more research and analysis to fully understand the complex dynamics at play.

These dynamics are further underlined by the second part of my empirical research, which I dedicated to wavelet coherence analysis. This approach allows for a nuanced understanding of the time-frequency relationships between ethanol production and various economic indicators, including retail gasoline prices, the crack spread, and the crack ratio.

The wavelet coherence analysis thus provides a deeper insight into the dynamic and evolving nature of these relationships. It highlights the importance of considering both time and frequency domains to fully understand how ethanol production interacts with various economic indicators. The findings suggest that while ethanol production has a significant impact on retail gasoline prices over longer periods, its effect on oil producers' margins (as indicated by the crack spread and crack ratio) is less consistent.

Moreover, the analysis reveals that the correlation between ethanol production and gasoline prices is less significant compared to the relationship between natural gas prices and ethanol production, and even more so when compared to oil prices. This observation underscores the presence of other, more influential factors affecting ethanol production. Consequently, it is recommended that future research should focus on investigating these additional determinants to provide a more comprehensive understanding of role of ethanol in issue at hand.

This thesis offers three primary contributions. First, it provides a comprehensive overview of the debate surrounding Du & Hayes (2009), successfully replicating the study and drawing conclusions based on this replication.

Second, the research question is transposed with its unique aspects of refiners' margin approach and regionally to a model-free approach of wavelet analysis, thereby enriching the discussion and allowing for novel conclusions to be drawn.

Third, the findings are contextualized within a broader perspective, examining aspects of ethanol beyond its impact on prices. Given my skepticism regarding the purported price impact, this thesis may serve as a impulse for policymakers to reassess the Renewable Fuel Standard (RFS). In light of the findings presented, it is advisable to re-evaluate the advantages and disadvantages of the RFS, considering not only its economic implications (because as I have pointed out, they might not be as beneficial as they were previously promoted) but also its broader environmental and social impacts. Future research should continue to explore these dimensions to inform a more nuanced policy framework.

Bibliography

Administration, E. I. (2005): "History of ethanol." *Technical report*, U.S. Department of Energy.

Agency, E. P. (2010): "Renewable fuel standard program (rfs2) regulatory impact analysis." *Technical report*, U.S. Environmental Protection Agency.

Agency, E. P. (2020): "Renewable fuel standard program." *Technical report*, U.S. Environmental Protection Agency.

Association, R. F. (2020): "Fueling a high octane future: 2020 ethanol industry outlook." *Technical report*, Renewable Fuels Association.

Baruník, J. & T. Křehlík (2018): "Measuring the frequency dynamics of financial connectedness and systemic risk." *Journal of Financial Econometrics* **16(2)**: pp. 271–296.

Baum, C., M. Schaffer, & S. Stillman (2007): "Enhanced routines for instrumental variables/gmm estimation and testing. boston college department of economics working paper no. 667."

Bevill, K. (2008): "Building the 'minnesota model'." *Ethanol Producer Magazine* pp. 114–120.

Chen, L., D. Debnath, J. Zhong, K. Ferin, A. VanLoocke, & M. Khanna (2021): "The economic and environmental costs and benefits of the renewable fuel standard." *Environmental Research Letters* **16(3)**: p. 034021.

Drabik, D., P. Ciaian, & J. Pokrivčák (2016): "The effect of ethanol policies on the vertical price transmission in corn and food markets." *Energy Economics* **55**: pp. 189–199.

Du, X. & D. J. Hayes (2009): "The impact of ethanol production on us and regional gasoline markets." *Energy Policy* **37(8)**: pp. 3227–3234.

Du, X. & D. J. Hayes (2011): "The impact of ethanol production on us and regional gasoline markets: an update to may 2009." *Technical report.*

Du, X. & D. J. Hayes (2012): "The impact of ethanol production on us and regional gasoline markets: an update to 2012." *Technical report.*

Farzad Taheripour, Thomas W. Hertel, W. E. T. J. F. B. & D. K. Birur (2010): "Biofuels and their by-products: Global economic and environmental implications." *Biomass and Bioenergy* **34(3)**: pp. 278–289.

de Gorter, H. & D. R. Just (2009): "The economics of a blend mandate for biofuels." *Am. J. Agric. Econ.* **91(3)**: pp. 738–750.

Grinsted, A., J. C. Moore, & S. Jevrejeva (2004): "Application of the cross wavelet transform and wavelet coherence to geophysical time series." *Nonlinear processes in geophysics* **11(5/6)**: pp. 561–566.

Hansen, L. P. (1982): "Large sample properties of generalized method of moments estimators." *Econometrica: Journal of the econometric society* pp. 1029–1054.

He, X., M. Carriquiry, A. Elobeid, D. Hayes, & W. Zhang (2023): "Impacts of the russian-ukraine conflict on global agriculture commodity prices, trade, and cropland reallocation." *Choices* **38(2)**: pp. 1–8.

Hochman, G. & D. Zilberman (2018): "Corn ethanol and US biofuel policy 10 years later: A quantitative assessment." *American Journal of Agricultural Economics* **100(2)**: pp. 570–584.

IEA (2022): "Renewables 2022." `https://www.iea.org/reports/renewables-2022`. License: CC BY 4.0.

Janda, K., E. Michalikova, L. C. S. Rocha, P. Rotella Junior, B. Schererova, & D. Zilberman (2022): "Review of the impact of biofuels on us retail gasoline prices." *Energies* **16(1)**: p. 428.

Kang, S. H., A. K. Tiwari, C. T. Albulescu, & S.-M. Yoon (2019): "Exploring the time-frequency connectedness and network among crude oil and agriculture commodities v1." *Energy Economics* **84**: p. 104543.

Khamphiranon, N. & S. Thammaboosadee (2023): "Examining the correlation between biofuel production and food prices in thailand: a bivariate wavelet coherence analysis approach." In "2023 IEEE PES 15th Asia-Pacific Power and Energy Engineering Conference (APPEEC)," pp. 1–6. IEEE.

Khanna, M., D. Rajagopal, & D. Zilberman (2021): "Lessons learned from us experience with biofuels: Comparing the hype with the evidence." *Review of Environmental Economics and Policy* **15(1)**: pp. 67–86.

Kirwan, B. (2015): "Who benefits from agricultural subsidies?" Accessed: 2024-05-30.

Knittel, C. R. & A. Smith (2015): "Ethanol production and gasoline prices: a spurious correlation." *The Energy Journal* **36(1)**.

Knobeloch, L., B. Salna, A. Hogan, J. Postle, & H. Anderson (2000): "Blue babies and nitrate-contaminated well water." *Environmental health perspectives* **108(7)**: pp. 675–678.

Kristoufek, L., K. Janda, & D. Zilberman (2012a): "Correlations between biofuels and related commodities: A taxonomy perspective." *Available at SSRN 2083435* .

Kristoufek, L., K. Janda, & D. Zilberman (2012b): "Mutual responsiveness of biofuels, fuels and food prices." *Kristoufek, L., K. Janda and D. Zilberman (2012)."Mutual Responsiveness of Biofuels, Fuels and Food Prices", CAMA Working Paper* **38**.

Kristoufek, L., K. Janda, & D. Zilberman (2013): "Non-linear price transmission between biofuels, fuels and food commodities." *CERGE-EI Working Paper Series* **(481)**.

Lark, T. J., N. P. Hendricks, A. Smith, N. Pates, S. A. Spawn-Lee, M. Bougie, E. G. Booth, C. J. Kucharik, & H. K. Gibbs (2022): "Environmental outcomes of the us renewable fuel standard." *Proceedings of the National Academy of Sciences* **119(9)**: p. e2101084119.

Letcher, T. (2020): *Future Energy: Improved, Sustainable and Clean Options for Our Planet.* Elsevier Science.

Lundberg, L., O. C. Sanchez, & J. Zetterholm (2023): "The impact of blending mandates on biofuel consumption, production, emission reductions and fuel prices." *Energy Policy* **183**: p. 113835.

Natanelov, V., A. M. McKenzie, & G. Van Huylenbroeck (2013): "Crude oil–corn–ethanol–nexus: A contextual approach." *Energy Policy* **63**: pp. 504–513.

Pal, D. & S. K. Mitra (2017): "Diesel and soybean price relationship in the usa: evidence from a quantile autoregressive distributed lag model." *Empirical Economics* **52**: pp. 1609–1626.

Raza, S. A., K. Guesmi, F. Belaid, & N. Shah (2022): "Time-frequency causality and connectedness between oil price shocks and the world food prices." *Research in International Business and Finance* **62**: p. 101730.

Rua, A. & L. C. Nunes (2009): "International comovement of stock market returns: A wavelet analysis." *Journal of Empirical Finance* **16(4)**: pp. 632–639.

Rubbaniy, G., A. A. Khalid, & A. Samitas (2021): "Are cryptos safe-haven assets during covid-19? evidence from wavelet coherence analysis." *Emerging Markets Finance and Trade* **57(6)**: pp. 1741–1756.

Schnepf, R. & B. D. Yacobucci (2011): "Renewable fuel standard (rfs): Overview and issues." *Technical report*, Congressional Research Service.

Si, C., Y. Li, & W. Jiang (2023): "Effect of insurance subsidies on agricultural land-use." *International Journal of Environmental Research and Public Health* **20(2)**: p. 1493.

Torrence, C. & G. P. Compo (1998): "A practical guide to wavelet analysis." *Bulletin of the American Meteorological society* **79(1)**: pp. 61–78.

Urbanchuk, J. M. (2012): "Contribution of the ethanol industry to the economy of the united states." *Technical report*, Renewable Fuels Association.

U.S. Department of Justice (2018): "Herfindahl-Hirschman Index." Accessed: 2024-04-19.

U.S. Department of Justice and the Federal Trade Commission (2010): "Horizontal Merger Guidelines." Issued: August 19, 2010.

Vacha, L. & J. Barunik (2012): "Co-movement of energy commodities revisited: Evidence from wavelet coherence analysis." *Energy Economics* **34(1)**: pp. 241–247.

Vacha, L., K. Janda, L. Kristoufek, & D. Zilberman (2013): "Time–frequency dynamics of biofuel–fuel–food system." *Energy Economics* **40**: pp. 233–241.

Wallinga, D. (2020): "Better burgers: Why it's high time the u.s. beef industry kicked its antibiotics habit." The author is grateful for helpful comments from Steven Roach of Food Animal Concerns Trust, Laura Rogers of the Antibiotic Resistance Action Center at George Washington University's Milken School of Public Health, and Lena Brook and Avinash Kar of NRDC.

Whistance, J. & W. Thompson (2010): "How does increased corn-ethanol production affect us natural gas prices?" *Energy Policy* **38(5)**: pp. 2315–2325.

Wu, J. & C. Langpap (2015): "The price and welfare effects of biofuel mandates and subsidies." *Environmental and Resource Economics* **62(1)**: pp. 35–57.

Appendix A

Appendix

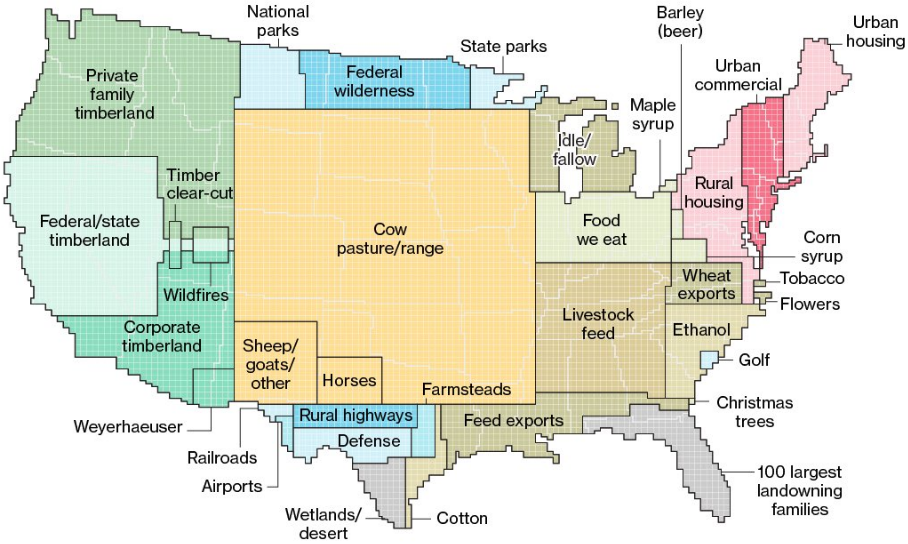

Figure A.1: Contiguous USA Land Usage in 2018.
Source: *Bloomberg Graphics* available at `https://www.bloomberg.com/graphics/2018-us-land-use/#xj4y7vzkg`.

Table A.1: Crack Ratio PADD 1 Results

VARIABLES	(1) Crack Ratio DH	(2) Crack Ratio oil price	(3) Crack Ratio oil price NG price	(4) Crack Ratio oil price NG price lag
U.S. Ethanol Production	-0.0071	-0.0090**	-0.0092**	-0.0063***
	(0.0046)	(0.0036)	(0.0036)	(0.0019)
Real Price of Oil		-0.0030***	-0.0030***	-0.0018***
		(0.0005)	(0.0005)	(0.0003)
Natural Gas Price			-0.0025	-0.0005
			(0.0067)	(0.0034)
Lagged Crack Ratio				0.5376***
				(0.0567)
Gasoline Imports	0.0184*	0.0059	0.0055	0.0052
	(0.0107)	(0.0081)	(0.0082)	(0.0054)
Stock of Oil Reserves	0.0281***	0.0134***	0.0135***	0.0063***
	(0.0047)	(0.0042)	(0.0041)	(0.0024)
Stock of Gasoline Reserves	0.0024	-0.0063***	-0.0063***	-0.0056***
	(0.0023)	(0.0020)	(0.0020)	(0.0012)
Refining Capacity	-0.0582***	-0.0357**	-0.0349**	-0.0184**
	(0.0186)	(0.0145)	(0.0147)	(0.0072)
HHI	-1.0799	-1.7444**	-1.6755**	-0.9743**
	(1.0908)	(0.8333)	(0.8535)	(0.4201)
Hurricane	0.0524	0.0242	0.0222	0.0077
	(0.0364)	(0.0281)	(0.0281)	(0.0199)
January	-0.0706***	0.0065	0.0078	0.0182
	(0.0265)	(0.0230)	(0.0233)	(0.0213)
February	-0.0737**	-0.0143	-0.0139	-0.0043
	(0.0348)	(0.0283)	(0.0284)	(0.0216)
March	-0.0356	0.0222	0.0211	0.0271
	(0.0316)	(0.0264)	(0.0265)	(0.0218)
April	-0.0466	0.0153	0.0119	0.0059
	(0.0363)	(0.0297)	(0.0310)	(0.0229)
May	-0.0112	0.0752***	0.0718**	0.0506**
	(0.0338)	(0.0285)	(0.0297)	(0.0221)
June	-0.0379	0.0297	0.0267	-0.0139
	(0.0333)	(0.0274)	(0.0285)	(0.0222)
July	0.0042	0.0446*	0.0420*	0.0210
	(0.0302)	(0.0243)	(0.0253)	(0.0198)
August	0.0018	0.0297	0.0274	0.0104
	(0.0309)	(0.0249)	(0.0258)	(0.0207)
September	-0.0001	0.0067	0.0042	-0.0209
	(0.0326)	(0.0263)	(0.0273)	(0.0223)
October	-0.0328	-0.0438*	-0.0454*	-0.0589***
	(0.0320)	(0.0253)	(0.0258)	(0.0211)
November	-0.0202	-0.0372*	-0.0386*	-0.0373*
	(0.0251)	(0.0200)	(0.0203)	(0.0202)
Constant	1.7390***	2.7082***	2.6958***	1.5734***
	(0.4614)	(0.3722)	(0.3720)	(0.2178)
Observations	147	147	147	146
R-squared	0.5883	0.7443	0.7449	0.8439

Table A.2: Crack Ratio PADD 2 Results

VARIABLES	(1) Crack Ratio DH	(2) Crack Ratio oil price	(3) Crack Ratio oil price NG price	(4) Crack Ratio oil price NG price lag
U.S. Ethanol Production	0.0006	0.0024	0.0023	-0.0003
	(0.0053)	(0.0043)	(0.0043)	(0.0030)
Real Price of Oil		-0.0029***	-0.0029***	-0.0020***
		(0.0007)	(0.0007)	(0.0005)
Natural Gas Price			-0.0015	-0.0016
			(0.0074)	(0.0051)
Lagged Crack Ratio				0.3789***
				(0.0730)
Gasoline Imports	0.0850	-0.1247	-0.1192	-0.1670
	(0.4668)	(0.3913)	(0.3883)	(0.3007)
Stock of Oil Reserves	0.0044***	0.0017*	0.0016*	0.0008
	(0.0008)	(0.0009)	(0.0009)	(0.0006)
Stock of Gasoline Reserves	-0.0005	-0.0066*	-0.0069*	-0.0051*
	(0.0040)	(0.0035)	(0.0037)	(0.0027)
Refining Capacity	-0.0041	-0.0260	-0.0260	-0.0143
	(0.0220)	(0.0180)	(0.0179)	(0.0120)
HHI	-3.5879	-4.4297**	-4.4799**	-3.2692**
	(2.5375)	(1.9675)	(1.9719)	(1.3119)
Hurricane	-0.0727*	-0.0542*	-0.0546*	-0.0522**
	(0.0373)	(0.0319)	(0.0320)	(0.0259)
January	0.0248	0.0460	0.0481	0.0332
	(0.0332)	(0.0310)	(0.0317)	(0.0314)
February	0.0537	0.0854**	0.0873**	0.0638*
	(0.0406)	(0.0373)	(0.0375)	(0.0328)
March	0.1000***	0.1276***	0.1280***	0.1075***
	(0.0320)	(0.0305)	(0.0304)	(0.0280)
April	0.0843**	0.1082***	0.1072***	0.0607*
	(0.0383)	(0.0348)	(0.0357)	(0.0315)
May	0.1586***	0.1665***	0.1648***	0.1301***
	(0.0345)	(0.0312)	(0.0328)	(0.0291)
June	0.1396***	0.1343***	0.1327***	0.0643*
	(0.0382)	(0.0341)	(0.0357)	(0.0338)
July	0.1418***	0.1283***	0.1263***	0.0742**
	(0.0328)	(0.0297)	(0.0316)	(0.0294)
August	0.1822***	0.1528***	0.1504***	0.1035***
	(0.0327)	(0.0301)	(0.0326)	(0.0299)
September	0.1533***	0.1225***	0.1201***	0.0587*
	(0.0388)	(0.0344)	(0.0371)	(0.0338)
October	0.0949**	0.0518	0.0495	0.0105
	(0.0416)	(0.0373)	(0.0394)	(0.0345)
November	0.0183	-0.0040	-0.0054	-0.0234
	(0.0310)	(0.0285)	(0.0296)	(0.0300)
Constant	1.0886***	2.6332***	2.6703***	1.7840***
	(0.4187)	(0.4830)	(0.5125)	(0.3791)
Observations	147	147	147	146
R-squared	0.6272	0.7062	0.7063	0.7534

Table A.3: Crack Ratio PADD 3 Results

VARIABLES	(1) Crack Ratio DH	(2) Crack Ratio oil price	(3) Crack Ratio oil price NG price	(4) Crack Ratio oil price NG price lag
U.S. Ethanol Production	0.0013	0.0021	0.0017	-0.0012
	(0.0057)	(0.0038)	(0.0036)	(0.0020)
Real Price of Oil		-0.0040***	-0.0038***	-0.0023***
		(0.0006)	(0.0006)	(0.0003)
Natural Gas Price			-0.0102*	-0.0042
			(0.0061)	(0.0033)
Lagged Crack Ratio				0.5357***
				(0.0598)
Gasoline Imports	-0.0162	-0.0263	-0.0170	-0.0270
	(0.0332)	(0.0248)	(0.0241)	(0.0199)
Stock of Oil Reserves	0.0023***	-0.0001	-0.0001	-0.0004
	(0.0006)	(0.0005)	(0.0005)	(0.0003)
Stock of Gasoline Reserves	-0.0033	-0.0031	-0.0034*	-0.0025*
	(0.0027)	(0.0019)	(0.0019)	(0.0013)
Refining Capacity	-0.0147	-0.0222***	-0.0234***	-0.0094**
	(0.0107)	(0.0073)	(0.0069)	(0.0040)
HHI	4.7926*	5.0520***	5.4612***	2.0422*
	(2.7749)	(1.8341)	(1.7227)	(1.0529)
Hurricane	0.0420	0.0302	0.0231	0.0065
	(0.0380)	(0.0276)	(0.0269)	(0.0180)
January	0.0143	0.0372	0.0391*	0.0398*
	(0.0285)	(0.0230)	(0.0228)	(0.0226)
February	0.0054	0.0612*	0.0602*	0.0425*
	(0.0395)	(0.0315)	(0.0307)	(0.0241)
March	0.0293	0.1047***	0.1002***	0.0815***
	(0.0310)	(0.0269)	(0.0267)	(0.0209)
April	0.0321	0.1183***	0.1038***	0.0511**
	(0.0368)	(0.0316)	(0.0322)	(0.0234)
May	0.0592*	0.1363***	0.1233***	0.0714***
	(0.0316)	(0.0277)	(0.0286)	(0.0214)
June	0.0292	0.0987***	0.0843***	0.0224
	(0.0333)	(0.0286)	(0.0293)	(0.0230)
July	0.0467	0.1022***	0.0915***	0.0474**
	(0.0292)	(0.0251)	(0.0258)	(0.0201)
August	0.0536*	0.0902***	0.0801***	0.0375*
	(0.0313)	(0.0257)	(0.0265)	(0.0209)
September	0.0285	0.0691**	0.0578**	0.0058
	(0.0336)	(0.0273)	(0.0280)	(0.0226)
October	-0.0269	0.0246	0.0171	-0.0143
	(0.0309)	(0.0259)	(0.0261)	(0.0217)
November	-0.0376	-0.0023	-0.0078	-0.0234
	(0.0229)	(0.0196)	(0.0197)	(0.0198)
Constant	1.6059***	2.8986***	3.0058***	1.5941***
	(0.5040)	(0.3948)	(0.3768)	(0.2531)
Observations	147	147	147	146
R-squared	0.5630	0.7519	0.7622	0.8474

Table A.4: Crack Ratio PADD 4 Results

VARIABLES	(1) Crack Ratio DH	(2) Crack Ratio oil price	(3) Crack Ratio oil price NG price	(4) Crack Ratio oil price NG price lag
U.S. Ethanol Production	-0.0053	-0.0032	-0.0038	-0.0036
	(0.0088)	(0.0050)	(0.0044)	(0.0034)
Real Price of Oil		-0.0051***	-0.0048***	-0.0035***
		(0.0006)	(0.0005)	(0.0005)
Natural Gas Price			-0.0206**	-0.0170***
			(0.0084)	(0.0064)
Lagged Crack Ratio				0.3215***
				(0.0710)
Gasoline Imports	-11.9267**	-13.5980***	-11.5704**	-9.0864*
	(5.3492)	(4.6266)	(4.7015)	(5.0991)
Stock of Oil Reserves	0.0345***	0.0094	0.0128**	0.0085**
	(0.0094)	(0.0060)	(0.0054)	(0.0043)
Stock of Gasoline Reserves	0.0150	-0.0277	-0.0421**	-0.0427***
	(0.0277)	(0.0190)	(0.0188)	(0.0157)
Refining Capacity	-0.0991	-0.2095**	-0.2885***	-0.2018***
	(0.1815)	(0.0962)	(0.0881)	(0.0681)
HHI	-1.3818	-0.9560	-2.5590	-1.2190
	(4.5577)	(2.3366)	(2.0819)	(1.5439)
Hurricane	-0.0232	-0.0392	-0.0463	-0.0507
	(0.0585)	(0.0415)	(0.0402)	(0.0344)
January	-0.1193**	-0.1320***	-0.0955**	-0.0453
	(0.0537)	(0.0462)	(0.0483)	(0.0484)
February	-0.1067*	-0.1098**	-0.0770	-0.0278
	(0.0569)	(0.0466)	(0.0481)	(0.0482)
March	0.2106***	0.2529***	0.2233***	0.2245***
	(0.0764)	(0.0656)	(0.0663)	(0.0691)
April	0.0020	0.0096	-0.0071	0.0045
	(0.0576)	(0.0478)	(0.0478)	(0.0466)
May	0.1405**	0.1297***	0.1116**	0.1171***
	(0.0552)	(0.0462)	(0.0463)	(0.0448)
June	0.1360**	0.1013**	0.0889*	0.0528
	(0.0550)	(0.0462)	(0.0464)	(0.0461)
July	0.4247***	0.4142***	0.3566***	0.2713***
	(0.1057)	(0.0885)	(0.0909)	(0.0957)
August	0.1841***	0.1232**	0.1158**	0.0979*
	(0.0643)	(0.0545)	(0.0543)	(0.0556)
September	0.8782***	0.9411***	0.8071***	0.6120**
	(0.3083)	(0.2632)	(0.2685)	(0.2899)
October	0.0943**	0.0768**	0.0627*	0.0337
	(0.0410)	(0.0337)	(0.0339)	(0.0354)
November = o,	-	-	-	-
Constant	1.3110	2.9641***	3.5957***	2.5750***
	(0.9630)	(0.5469)	(0.5308)	(0.4588)
Observations	147	147	147	146
R-squared	0.5997	0.7832	0.7949	0.8202

Table A.5: Crack Ratio PADD 5 Results

VARIABLES	(1) Crack Ratio DH	(2) Crack Ratio oil price	(3) Crack Ratio oil price NG price	(4) Crack Ratio oil price NG price lag
U.S. Ethanol Production	-0.0055	-0.0143**	-0.0169***	-0.0122***
	(0.0143)	(0.0066)	(0.0064)	(0.0043)
Real Price of Oil		-0.0067***	-0.0062***	-0.0034***
		(0.0007)	(0.0007)	(0.0006)
Natural Gas Price			-0.0225**	-0.0145**
			(0.0112)	(0.0072)
Lagged Crack Ratio				0.4834***
				(0.0700)
Gasoline Imports	0.1236	0.0229	0.0283	0.0117
	(0.0784)	(0.0413)	(0.0398)	(0.0302)
Stock of Oil Reserves	0.0098	0.0075	0.0043	-0.0011
	(0.0092)	(0.0049)	(0.0047)	(0.0035)
Stock of Gasoline Reserves	-0.0016	-0.0152**	-0.0187**	-0.0192***
	(0.0135)	(0.0076)	(0.0073)	(0.0054)
Refining Capacity	-0.0429	-0.0441	-0.0366	-0.0097
	(0.0599)	(0.0286)	(0.0269)	(0.0179)
HHI	13.7477***	0.9447	0.8414	0.7808
	(4.7892)	(2.5988)	(2.4187)	(1.5105)
Hurricane	0.0455	-0.0074	-0.0260	-0.0194
	(0.0889)	(0.0492)	(0.0478)	(0.0363)
January	-0.0341	0.0075	0.0304	0.0525
	(0.0490)	(0.0346)	(0.0350)	(0.0362)
February	-0.0426	-0.0242	-0.0099	0.0224
	(0.0789)	(0.0466)	(0.0450)	(0.0374)
March	0.0786	0.1152***	0.1127***	0.1206***
	(0.0649)	(0.0431)	(0.0425)	(0.0376)
April	0.0523	0.0549	0.0258	-0.0008
	(0.0882)	(0.0520)	(0.0531)	(0.0415)
May	0.0803	0.1093**	0.0838	0.0655
	(0.0909)	(0.0554)	(0.0560)	(0.0432)
June	0.0251	0.0336	0.0076	-0.0475
	(0.0837)	(0.0519)	(0.0525)	(0.0415)
July	0.0349	0.0662	0.0347	0.0015
	(0.0738)	(0.0485)	(0.0499)	(0.0404)
August	0.0698	0.0679	0.0331	-0.0032
	(0.0724)	(0.0477)	(0.0496)	(0.0411)
September	0.0398	0.0390	0.0021	-0.0302
	(0.0791)	(0.0497)	(0.0515)	(0.0438)
October	0.0133	0.0139	-0.0083	-0.0368
	(0.0726)	(0.0476)	(0.0475)	(0.0402)
November	-0.0168	-0.0183	-0.0316	-0.0417
	(0.0505)	(0.0351)	(0.0350)	(0.0357)
Constant	0.0235	3.2508***	3.5258***	2.1740***
	(1.7134)	(0.8302)	(0.7855)	(0.5445)
Observations	147	147	147	146
R-squared	0.5106	0.8283	0.8385	0.8833

Table A.6: Crack Spread PADD 1 Results

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	-0.0002	-0.0000	0.0009	0.0016	0.0006
	(0.0032)	(0.0045)	(0.0043)	(0.0043)	(0.0024)
Real Price of Oil			0.0016***	0.0013**	0.0005
			(0.0006)	(0.0006)	(0.0003)
Natural Gas Price				0.0082	0.0016
				(0.0079)	(0.0041)
Gasoline Imports	0.0136*	-0.0094	-0.0031	-0.0018	0.0031
	(0.0072)	(0.0110)	(0.0107)	(0.0106)	(0.0070)
Stock of Oil Reserves	0.0112***	0.0037	0.0112**	0.0108**	0.0068**
	(0.0032)	(0.0043)	(0.0047)	(0.0048)	(0.0029)
Stock of Gasoline Reserves	0.0002	-0.0167***	-0.0122***	-0.0123***	-0.0074***
	(0.0015)	(0.0023)	(0.0027)	(0.0027)	(0.0017)
Refining Capacity	-0.0436***	-0.0460***	-0.0575***	-0.0601***	-0.0299***
	(0.0128)	(0.0163)	(0.0158)	(0.0161)	(0.0084)
HHI	-1.8016**	-3.1018***	-2.7630***	-2.9928***	-1.0232**
	(0.7498)	(0.9764)	(0.9292)	(0.9565)	(0.5090)
Hurricane	0.0705***	0.0814**	0.0958**	0.1025***	0.0477*
	(0.0242)	(0.0402)	(0.0388)	(0.0386)	(0.0277)
January	-0.0235	0.0860***	0.0467	0.0423	0.0426
	(0.0165)	(0.0288)	(0.0305)	(0.0307)	(0.0274)
February	-0.0062	0.0936**	0.0633	0.0618	0.0579*
	(0.0221)	(0.0394)	(0.0389)	(0.0387)	(0.0305)
March	0.0142	0.0906**	0.0611	0.0647*	0.0556*
	(0.0201)	(0.0382)	(0.0379)	(0.0378)	(0.0303)
April	0.0078	0.0781*	0.0466	0.0579	0.0255
	(0.0239)	(0.0421)	(0.0418)	(0.0429)	(0.0320)
May	0.0188	0.1443***	0.1003**	0.1115***	0.0612**
	(0.0218)	(0.0379)	(0.0394)	(0.0404)	(0.0295)
June	0.0015	0.0913**	0.0568	0.0669*	0.0079
	(0.0213)	(0.0366)	(0.0376)	(0.0383)	(0.0286)
July	0.0164	0.0759**	0.0553	0.0641*	0.0385
	(0.0192)	(0.0351)	(0.0347)	(0.0352)	(0.0263)
August	0.0120	0.0544	0.0402	0.0478	0.0291
	(0.0201)	(0.0382)	(0.0373)	(0.0376)	(0.0295)
September	0.0114	0.0257	0.0223	0.0306	-0.0010
	(0.0207)	(0.0396)	(0.0381)	(0.0388)	(0.0308)
October	-0.0131	-0.0759**	-0.0703*	-0.0648*	-0.0584*
	(0.0200)	(0.0375)	(0.0360)	(0.0363)	(0.0302)
November	0.0034	-0.0429	-0.0342	-0.0296	-0.0234
	(0.0153)	(0.0275)	(0.0264)	(0.0269)	(0.0260)
Lagged Real Crack Spread					0.5869***
					(0.0642)
Constant	0.8794***	2.5924***	2.0983***	2.1395***	0.9938***
	(0.3171)	(0.4079)	(0.4252)	(0.4273)	(0.2528)
Observations	147	147	147	147	146
R-squared	0.5017	0.5583	0.5938	0.5993	0.7526

Table A.7: Crack Spread PADD 2 Results

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	0.0001	0.0059	0.0046	0.0050	0.0034
	(0.0033)	(0.0064)	(0.0061)	(0.0062)	(0.0035)
Real Price of Oil			0.0021**	0.0022**	0.0010*
			(0.0009)	(0.0010)	(0.0005)
Natural Gas Price				0.0105	0.0044
				(0.0108)	(0.0061)
Gasoline Imports	-0.0382	0.1351	0.2884	0.2502	0.0924
	(0.2914)	(0.5857)	(0.5568)	(0.5548)	(0.3601)
Stock of Oil Reserves	0.0024***	-0.0001	0.0018	0.0023*	0.0013*
	(0.0005)	(0.0009)	(0.0012)	(0.0014)	(0.0007)
Stock of Gasoline Reserves	-0.0032	-0.0185***	-0.0140***	-0.0124**	-0.0084***
	(0.0025)	(0.0050)	(0.0051)	(0.0053)	(0.0032)
Refining Capacity	0.0064	-0.0165	-0.0004	-0.0001	-0.0053
	(0.0135)	(0.0257)	(0.0250)	(0.0254)	(0.0135)
HHI	-2.5825*	-7.6864***	-7.0711***	-6.7248**	-2.4217
	(1.5385)	(2.8860)	(2.6888)	(2.7743)	(1.5295)
Hurricane	0.0040	0.0677	0.0542	0.0575	0.0271
	(0.0232)	(0.0477)	(0.0461)	(0.0457)	(0.0318)
January	0.0174	0.0975**	0.0821**	0.0675	0.0809**
	(0.0201)	(0.0412)	(0.0404)	(0.0416)	(0.0366)
February	0.0494**	0.1871***	0.1640***	0.1506***	0.1640***
	(0.0251)	(0.0520)	(0.0513)	(0.0516)	(0.0400)
March	0.0843***	0.2158***	0.1956***	0.1929***	0.1823***
	(0.0198)	(0.0420)	(0.0420)	(0.0416)	(0.0333)
April	0.0656***	0.1790***	0.1615***	0.1688***	0.1174***
	(0.0240)	(0.0505)	(0.0499)	(0.0506)	(0.0382)
May	0.1000***	0.1998***	0.1941***	0.2061***	0.1601***
	(0.0213)	(0.0453)	(0.0443)	(0.0456)	(0.0340)
June	0.0851***	0.1668***	0.1707***	0.1819***	0.0918**
	(0.0238)	(0.0496)	(0.0480)	(0.0492)	(0.0374)
July	0.0838***	0.1353***	0.1452***	0.1590***	0.0984***
	(0.0202)	(0.0433)	(0.0423)	(0.0441)	(0.0337)
August	0.1070***	0.1507***	0.1721***	0.1889***	0.1385***
	(0.0206)	(0.0444)	(0.0437)	(0.0465)	(0.0368)
September	0.0904***	0.1358***	0.1584***	0.1748***	0.0942**
	(0.0238)	(0.0491)	(0.0476)	(0.0511)	(0.0386)
October	0.0533**	0.0257	0.0573	0.0726	0.0260
	(0.0254)	(0.0520)	(0.0508)	(0.0535)	(0.0411)
November	0.0227	0.0102	0.0264	0.0365	0.0100
	(0.0184)	(0.0369)	(0.0358)	(0.0374)	(0.0345)
Lagged Real Crack Spread					0.5608***
					(0.0665)
Constant	0.1176	2.3528***	1.2238*	0.9679	0.5777
	(0.2560)	(0.4892)	(0.6673)	(0.7249)	(0.3963)
Observations	147	147	147	147	146
R-squared	0.6313	0.5786	0.6094	0.6148	0.7416

Table A.8: Crack Spread PADD 3 Results

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	0.0010	0.0113**	0.0112**	0.0109**	0.0056**
	(0.0036)	(0.0049)	(0.0049)	(0.0048)	(0.0027)
Real Price of Oil			0.0005	0.0006	0.0003
			(0.0008)	(0.0008)	(0.0004)
Natural Gas Price				-0.0068	-0.0041
				(0.0082)	(0.0043)
Gasoline Imports	-0.0134	-0.0205	-0.0192	-0.0129	-0.0341
	(0.0206)	(0.0337)	(0.0336)	(0.0334)	(0.0269)
Stock of Oil Reserves	0.0005	-0.0011**	-0.0008	-0.0008	-0.0001
	(0.0004)	(0.0005)	(0.0007)	(0.0006)	(0.0003)
Stock of Gasoline Reserves	-0.0004	-0.0031	-0.0032	-0.0033	-0.0028
	(0.0017)	(0.0027)	(0.0027)	(0.0027)	(0.0018)
Refining Capacity	-0.0006	-0.0223**	-0.0214**	-0.0221**	-0.0109**
	(0.0068)	(0.0092)	(0.0093)	(0.0091)	(0.0050)
HHI	2.5857	7.9202***	7.8864***	8.1612***	2.8707**
	(1.7573)	(2.3438)	(2.3238)	(2.2497)	(1.4000)
Hurricane	0.0585**	0.1072***	0.1087***	0.1039***	0.0486*
	(0.0238)	(0.0382)	(0.0381)	(0.0382)	(0.0252)
January	0.0134	0.0509*	0.0480	0.0493	0.0720**
	(0.0174)	(0.0303)	(0.0306)	(0.0305)	(0.0290)
February	0.0286	0.1312***	0.1239***	0.1232***	0.1050***
	(0.0243)	(0.0410)	(0.0424)	(0.0419)	(0.0324)
March	0.0641***	0.1752***	0.1653***	0.1623***	0.1174***
	(0.0188)	(0.0349)	(0.0378)	(0.0379)	(0.0290)
April	0.0609***	0.1835***	0.1723***	0.1626***	0.0684**
	(0.0229)	(0.0406)	(0.0441)	(0.0455)	(0.0329)
May	0.0657***	0.1805***	0.1704***	0.1617***	0.0736**
	(0.0195)	(0.0355)	(0.0386)	(0.0404)	(0.0290)
June	0.0487**	0.1433***	0.1343***	0.1246***	0.0377
	(0.0206)	(0.0369)	(0.0393)	(0.0411)	(0.0295)
July	0.0512***	0.1389***	0.1316***	0.1245***	0.0609**
	(0.0179)	(0.0337)	(0.0354)	(0.0370)	(0.0268)
August	0.0545***	0.1311***	0.1264***	0.1196***	0.0608**
	(0.0193)	(0.0368)	(0.0374)	(0.0388)	(0.0293)
September	0.0410**	0.1201***	0.1148***	0.1072***	0.0283
	(0.0205)	(0.0377)	(0.0386)	(0.0399)	(0.0313)
October	0.0116	0.0536	0.0469	0.0419	-0.0105
	(0.0187)	(0.0342)	(0.0356)	(0.0361)	(0.0297)
November	0.0045	0.0347	0.0301	0.0264	-0.0139
	(0.0138)	(0.0249)	(0.0258)	(0.0262)	(0.0252)
Lagged Real Crack Spread					0.6033***
					(0.0645)
Constant	-0.0875	1.4436***	1.2749***	1.3468***	0.7612***
	(0.3195)	(0.4174)	(0.4913)	(0.4816)	(0.2573)
Observations	147	147	147	147	146
R-squared	0.5153	0.5868	0.5897	0.5938	0.7580

Table A.9: Crack Spread PADD 4 Results

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	-0.0022	0.0150**	0.0146**	0.0147**	0.0083**
	(0.0048)	(0.0062)	(0.0060)	(0.0060)	(0.0039)
Real Price of Oil			0.0008	0.0008	0.0006
			(0.0007)	(0.0007)	(0.0004)
Natural Gas Price				0.0030	-0.0074
				(0.0114)	(0.0072)
Gasoline Imports	-14.5643***	-32.4538***	-32.1753***	-32.4688***	-25.6620***
	(3.0251)	(5.2928)	(5.3017)	(5.4092)	(5.6731)
Stock of Oil Reserves	0.0166***	0.0181***	0.0223***	0.0218***	0.0177***
	(0.0051)	(0.0064)	(0.0071)	(0.0073)	(0.0047)
Stock of Gasoline Reserves	0.0034	-0.0553**	-0.0482*	-0.0461*	-0.0586***
	(0.0159)	(0.0244)	(0.0250)	(0.0258)	(0.0187)
Refining Capacity	0.0534	-0.3916***	-0.3732***	-0.3617***	-0.2416***
	(0.0973)	(0.1134)	(0.1084)	(0.1174)	(0.0709)
HHI	2.5945	-0.7816	-0.8526	-0.6205	-0.3590
	(2.4323)	(2.7773)	(2.6238)	(2.7731)	(1.5792)
Hurricane	0.0163	0.0787	0.0814	0.0824	0.0336
	(0.0339)	(0.0545)	(0.0541)	(0.0541)	(0.0408)
January	-0.1650***	-0.3414***	-0.3392***	-0.3445***	-0.1596***
	(0.0320)	(0.0575)	(0.0577)	(0.0609)	(0.0604)
February	-0.1344***	-0.2054***	-0.2049***	-0.2096***	-0.0227
	(0.0330)	(0.0580)	(0.0580)	(0.0605)	(0.0572)
March	0.2221***	0.4836***	0.4766***	0.4809***	0.5043***
	(0.0438)	(0.0770)	(0.0772)	(0.0788)	(0.0763)
April	-0.0354	-0.0762	-0.0774	-0.0750	-0.0351
	(0.0343)	(0.0595)	(0.0596)	(0.0601)	(0.0534)
May	0.0362	0.0158	0.0176	0.0202	0.0447
	(0.0332)	(0.0581)	(0.0584)	(0.0590)	(0.0516)
June	0.0279	-0.0007	0.0051	0.0069	-0.0300
	(0.0326)	(0.0580)	(0.0584)	(0.0585)	(0.0523)
July	0.3667***	0.7349***	0.7367***	0.7450***	0.5698***
	(0.0609)	(0.1041)	(0.1042)	(0.1085)	(0.1072)
August	0.0466	0.0029	0.0130	0.0141	0.0147
	(0.0370)	(0.0648)	(0.0655)	(0.0655)	(0.0612)
September	0.9372***	2.0548***	2.0444***	2.0638***	1.5739***
	(0.1744)	(0.3041)	(0.3042)	(0.3123)	(0.3217)
October	0.0501**	0.0566	0.0595	0.0615	0.0208
	(0.0234)	(0.0399)	(0.0400)	(0.0406)	(0.0394)
Lagged Real Crack Spread					0.5187***
					(0.0682)
November = o,	-	-	-	-	-
Constant	-0.4091	2.3057***	2.0302***	1.9388***	1.3845***
	(0.5161)	(0.6036)	(0.6180)	(0.7071)	(0.4270)
Observations	147	147	147	147	146
R-squared	0.6871	0.6563	0.6615	0.6617	0.7604

Table A.10: Crack Spread PADD 5 Results

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	0.0005	0.0099	0.0114	0.0095	0.0026
	(0.0077)	(0.0082)	(0.0079)	(0.0079)	(0.0041)
Real Price of Oil			0.0011	0.0014*	0.0007*
			(0.0008)	(0.0008)	(0.0004)
Natural Gas Price				-0.0156	-0.0129*
				(0.0139)	(0.0069)
Gasoline Imports	0.1038**	0.0414	0.0581	0.0619	0.0419
	(0.0430)	(0.0514)	(0.0492)	(0.0486)	(0.0315)
Stock of Oil Reserves	0.0042	-0.0005	-0.0001	-0.0023	-0.0077**
	(0.0050)	(0.0060)	(0.0058)	(0.0058)	(0.0035)
Stock of Gasoline Reserves	0.0027	-0.0268***	-0.0245***	-0.0269***	-0.0277***
	(0.0074)	(0.0093)	(0.0091)	(0.0090)	(0.0055)
Refining Capacity	-0.0159	-0.0800**	-0.0797**	-0.0745**	-0.0183
	(0.0326)	(0.0352)	(0.0343)	(0.0334)	(0.0177)
HHI	9.3435***	-0.7664	1.3613	1.2894	0.5262
	(2.6025)	(2.7250)	(3.1282)	(3.0127)	(1.3984)
Hurricane	0.0577	0.0757	0.0845	0.0715	0.0303
	(0.0488)	(0.0601)	(0.0587)	(0.0585)	(0.0377)
January	-0.0236	0.0413	0.0344	0.0503	0.1247***
	(0.0285)	(0.0396)	(0.0394)	(0.0405)	(0.0404)
February	0.0057	0.1242**	0.1211**	0.1311**	0.1836***
	(0.0440)	(0.0554)	(0.0548)	(0.0539)	(0.0404)
March	0.0931***	0.1987***	0.1926***	0.1908***	0.2124***
	(0.0361)	(0.0510)	(0.0505)	(0.0505)	(0.0397)
April	0.0845*	0.1529**	0.1525**	0.1322**	0.0827*
	(0.0487)	(0.0634)	(0.0621)	(0.0647)	(0.0440)
May	0.0956*	0.1910***	0.1862***	0.1684**	0.1408***
	(0.0502)	(0.0675)	(0.0660)	(0.0682)	(0.0453)
June	0.0655	0.1115*	0.1101*	0.0920	0.0061
	(0.0473)	(0.0636)	(0.0623)	(0.0644)	(0.0450)
July	0.0499	0.0900	0.0848	0.0628	0.0200
	(0.0409)	(0.0585)	(0.0573)	(0.0603)	(0.0429)
August	0.0796**	0.0970*	0.0973*	0.0731	0.0321
	(0.0402)	(0.0578)	(0.0567)	(0.0600)	(0.0443)
September	0.0685	0.1207**	0.1208**	0.0951	0.0308
	(0.0438)	(0.0593)	(0.0583)	(0.0617)	(0.0460)
October	0.0627	0.0685	0.0684	0.0529	0.0111
	(0.0409)	(0.0566)	(0.0558)	(0.0568)	(0.0437)
November	0.0325	0.0585	0.0587	0.0494	0.0058
	(0.0293)	(0.0404)	(0.0399)	(0.0404)	(0.0396)
Lagged Real Crack Spread					0.6222***
					(0.0622)
Constant	-1.0102	2.9542***	2.4179**	2.6094***	1.6691***
	(0.9320)	(0.9948)	(0.9963)	(0.9742)	(0.5031)
Observations	147	147	147	147	146
R-squared	0.6170	0.4778	0.4964	0.5069	0.7106

Table A.11: Undeflated Crack Spread Nationwide Results

VARIABLES	(1) Crack Spread DH	(2) Crack Spread oil price	(3) Crack Spread oil price NG price	(4) Crack Spread oil price NG price lag
U.S. Ethanol Production	0.0127**	0.0148***	0.0148**	0.0057***
	(0.0061)	(0.0057)	(0.0059)	(0.0017)
Real Price of Oil		0.0007	0.0007	0.0003
		(0.0004)	(0.0006)	(0.0002)
Natural Gas Price			-0.0000	-0.0017
			(0.0111)	(0.0034)
Lagged Crack Spread				0.7260***
				(0.0513)
Gasoline Imports	-0.0208	-0.0186	-0.0186	-0.0079
	(0.0141)	(0.0134)	(0.0131)	(0.0051)
Stock of Oil Reserves	-0.0002	0.0003	0.0003	0.0002
	(0.0004)	(0.0005)	(0.0005)	(0.0002)
Stock of Gasoline Reserves	-0.0060***	-0.0047**	-0.0047**	-0.0030***
	(0.0012)	(0.0018)	(0.0019)	(0.0009)
Refining Capacity	-0.0125	-0.0150*	-0.0150*	-0.0050**
	(0.0082)	(0.0079)	(0.0080)	(0.0024)
HHI	0.7513	1.0359	1.0359	0.5609**
	(0.6622)	(0.6742)	(0.6728)	(0.2357)
Hurricane	0.0675*	0.0737*	0.0737**	0.0207
	(0.0407)	(0.0398)	(0.0361)	(0.0248)
January	0.0236	0.0201	0.0201	0.0657***
	(0.0220)	(0.0229)	(0.0228)	(0.0248)
February	0.1094***	0.1117***	0.1117***	0.1307***
	(0.0379)	(0.0372)	(0.0372)	(0.0377)
March	0.1597***	0.1560***	0.1560***	0.1615***
	(0.0367)	(0.0370)	(0.0388)	(0.0274)
April	0.1639***	0.1656***	0.1656***	0.1038***
	(0.0338)	(0.0322)	(0.0402)	(0.0216)
May	0.1960***	0.1942***	0.1942***	0.1388***
	(0.0326)	(0.0332)	(0.0394)	(0.0295)
June	0.1558***	0.1559***	0.1559***	0.0649***
	(0.0295)	(0.0294)	(0.0349)	(0.0230)
July	0.1451***	0.1450***	0.1450***	0.0897***
	(0.0356)	(0.0362)	(0.0414)	(0.0285)
August	0.1639***	0.1665***	0.1665***	0.1179***
	(0.0424)	(0.0421)	(0.0479)	(0.0296)
September	0.1610***	0.1663***	0.1663***	0.0782***
	(0.0381)	(0.0381)	(0.0432)	(0.0270)
October	0.0908**	0.0929**	0.0929**	0.0452
	(0.0363)	(0.0368)	(0.0397)	(0.0288)
November	0.0711***	0.0741***	0.0741***	0.0358
	(0.0231)	(0.0227)	(0.0238)	(0.0227)
PADD 2	0.2696**	0.3237***	0.3237***	0.1127**
	(0.1218)	(0.1246)	(0.1249)	(0.0456)
PADD 3	0.9790**	1.0601***	1.0601***	0.3957***
	(0.4193)	(0.3910)	(0.3892)	(0.1221)
PADD 4	-0.2384**	-0.1414	-0.1414	-0.1096*
	(0.1174)	(0.1464)	(0.1422)	(0.0583)
PADD 5	0.2081*	0.2875**	0.2874**	0.0518
	(0.1232)	(0.1441)	(0.1463)	(0.0486)
Constant	0.3168	0.0631	0.0632	-0.0237
	(0.2902)	(0.3330)	(0.3202)	(0.1209)
Observations	735	735	735	730
R-squared	0.5174	0.5248	0.5248	0.7726

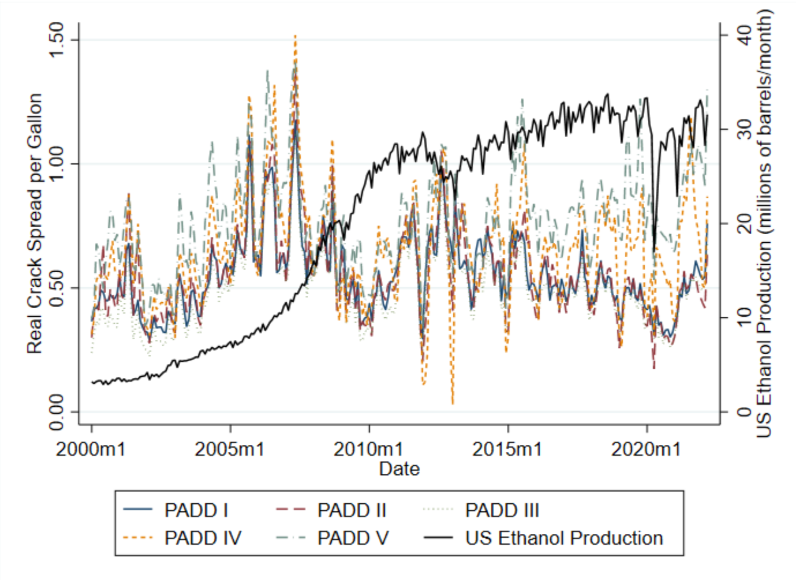

Figure A.2: Real Crack Spread

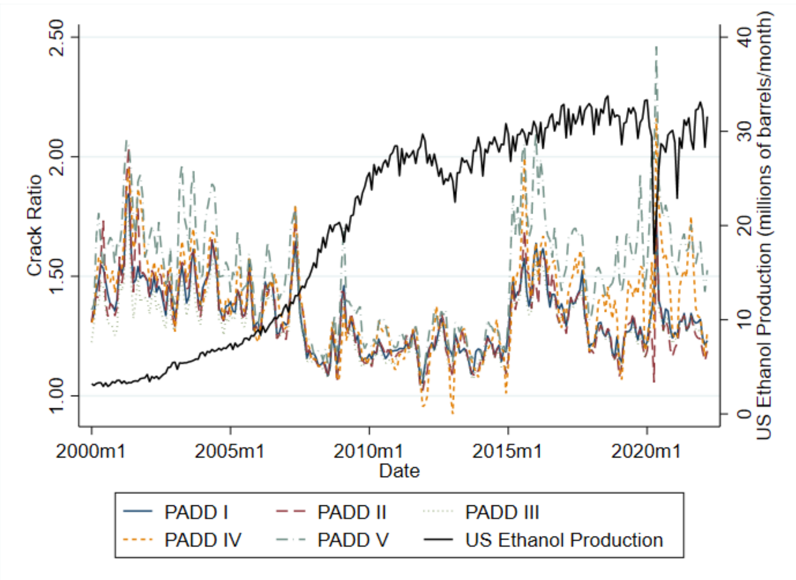

Figure A.3: Crack Ratio

Table A.12: Crack Spread Results 2001-2012

VARIABLES	(1) Real Crack Spread DH	(2) Real Crack Spread w/ CPI	(3) Real Crack Spread w/ CPI oil price	(4) Real Crack Spread w/ CPI oil price NG price	(5) Real Crack Spread w/CPI oil price NG price lag
U.S. Ethanol Production	-0.0039***	-0.0054***	-0.0158***	-0.0078***	-0.0036
	(0.0005)	(0.0015)	(0.0022)	(0.0028)	(0.0023)
Real Price of Oil			0.0037***	0.0019**	0.0008
			(0.0007)	(0.0008)	(0.0006)
Natural Gas Price				0.0250***	0.0048
				(0.0061)	(0.0056)
Gasoline Imports	-0.0040***	-0.0080***	-0.0090***	-0.0092***	-0.0034**
	(0.0007)	(0.0021)	(0.0019)	(0.0018)	(0.0014)
Stock of Oil Reserves	0.0011***	-0.0008	0.0015***	0.0017***	0.0001
	(0.0003)	(0.0006)	(0.0006)	(0.0006)	(0.0004)
Stock of Gasoline Reserves	-0.0004	-0.0167***	-0.0118***	-0.0091***	-0.0072***
	(0.0010)	(0.0031)	(0.0028)	(0.0024)	(0.0018)
PADD Refining Capacity	0.0039***	0.0425***	0.0280***	0.0227***	0.0104***
	(0.0012)	(0.0042)	(0.0038)	(0.0036)	(0.0023)
Hurricane	0.0082	0.4834***	0.4163***	0.2831***	0.2225***
	(0.0135)	(0.0333)	(0.0325)	(0.0438)	(0.0778)
January	0.0043	0.0619	0.0561	0.0496	0.0804***
	(0.0150)	(0.0410)	(0.0431)	(0.0339)	(0.0247)
February	0.0207	0.0884**	0.0662	0.0811**	0.0981***
	(0.0156)	(0.0420)	(0.0417)	(0.0363)	(0.0237)
March	0.0417***	0.1460***	0.1234***	0.1403***	0.1361***
	(0.0138)	(0.0510)	(0.0439)	(0.0391)	(0.0333)
April	0.0661***	0.2199***	0.1768***	0.2138***	0.1575***
	(0.0157)	(0.0607)	(0.0556)	(0.0521)	(0.0334)
May	0.0790***	0.2717***	0.2292***	0.2567***	0.1464***
	(0.0202)	(0.0740)	(0.0683)	(0.0656)	(0.0358)
June	0.0611***	0.2093***	0.1557***	0.1885***	0.0537**
	(0.0176)	(0.0608)	(0.0552)	(0.0540)	(0.0252)
July	0.0447***	0.1469***	0.0973*	0.1315***	0.0399
	(0.0156)	(0.0566)	(0.0498)	(0.0490)	(0.0292)
August	0.0611***	0.1532***	0.1200**	0.1663***	0.1015***
	(0.0161)	(0.0586)	(0.0519)	(0.0482)	(0.0317)
September	0.0708***	0.1314**	0.1084**	0.1693***	0.0811**
	(0.0183)	(0.0515)	(0.0440)	(0.0410)	(0.0396)
October	0.0564***	0.0614	0.0526	0.1027***	0.0063
	(0.0177)	(0.0415)	(0.0396)	(0.0354)	(0.0285)
November	0.0156	0.0432	0.0317	0.0487*	-0.0060
	(0.0118)	(0.0433)	(0.0379)	(0.0287)	(0.0381)
Lagged Real Crack Spread					0.6837***
					(0.0578)
PADD II	-0.1546***	-0.7205***	-0.6270***	-0.5501***	-0.2236***
	(0.0273)	(0.0950)	(0.0889)	(0.0879)	(0.0512)
PADD III	-0.4189***	-2.0063***	-1.6737***	-1.4632***	-0.5228***
	(0.0648)	(0.2377)	(0.2167)	(0.2170)	(0.1220)
PADD IV	0.0028	-0.5314***	-0.3932***	-0.2991***	-0.2973***
	(0.0416)	(0.1343)	(0.1220)	(0.1086)	(0.0817)
PADD V	-0.0674*	-0.7410***	-0.5682***	-0.4561***	-0.2797***
	(0.0360)	(0.1227)	(0.1148)	(0.1067)	(0.0684)
Constant	0.2161***	1.0847***	0.8061***	0.5399***	0.3759***
	(0.0457)	(0.1486)	(0.1355)	(0.1304)	(0.1033)
Observations	660	660	660	660	660
R-squared	0.4775	0.4623	0.5693	0.5963	0.8068

Table A.13: Crack Ratio Results 2001-2012

VARIABLES	(1) Crack Ratio DH	(2) Crack Ratio oil price	(3) Crack Ratio oil price NG price	(4) Crack Ratio oil price NG price lag
U.S. Ethanol Production	-0.0170***	-0.0092***	-0.0099***	-0.0023
	(0.0010)	(0.0012)	(0.0019)	(0.0018)
Real Price of Oil		-0.0028***	-0.0026***	-0.0013***
		(0.0003)	(0.0005)	(0.0004)
Natural Gas Price			-0.0020	0.0020
			(0.0041)	(0.0036)
Lagged Crack Ratio				0.6294***
				(0.0613)
Gasoline Imports	-0.0064***	-0.0056***	-0.0056***	-0.0023***
	(0.0012)	(0.0010)	(0.0010)	(0.0008)
Stock of Oil Reserves	0.0024***	0.0006	0.0006	0.0000
	(0.0006)	(0.0004)	(0.0004)	(0.0003)
Stock of Gasoline Reserves	0.0014	-0.0023	-0.0025	-0.0045***
	(0.0019)	(0.0017)	(0.0016)	(0.0011)
PADD Refining Capacity	-0.0008	0.0100***	0.0105***	0.0058***
	(0.0027)	(0.0025)	(0.0024)	(0.0018)
Hurricane	0.0779***	0.1281***	0.1390***	0.0718
	(0.0272)	(0.0247)	(0.0313)	(0.0516)
January	0.0286	0.0330	0.0335	0.0556***
	(0.0314)	(0.0238)	(0.0238)	(0.0190)
February	0.0302	0.0468**	0.0456**	0.0559***
	(0.0332)	(0.0229)	(0.0224)	(0.0154)
March	0.0933***	0.1102***	0.1088***	0.0865***
	(0.0300)	(0.0248)	(0.0243)	(0.0248)
April	0.1422***	0.1744***	0.1714***	0.1226***
	(0.0417)	(0.0368)	(0.0372)	(0.0277)
May	0.1749***	0.2067***	0.2044***	0.1108***
	(0.0479)	(0.0444)	(0.0443)	(0.0259)
June	0.1140***	0.1541***	0.1514***	0.0432**
	(0.0346)	(0.0297)	(0.0298)	(0.0214)
July	0.0753***	0.1124***	0.1096***	0.0297
	(0.0277)	(0.0235)	(0.0226)	(0.0185)
August	0.0882***	0.1130***	0.1092***	0.0594**
	(0.0298)	(0.0267)	(0.0258)	(0.0251)
September	0.0886**	0.1058***	0.1008***	0.0634**
	(0.0374)	(0.0356)	(0.0351)	(0.0269)
October	0.0491	0.0557**	0.0516**	0.0017
	(0.0300)	(0.0254)	(0.0239)	(0.0184)
November	0.0175	0.0261	0.0247	0.0022
	(0.0265)	(0.0260)	(0.0252)	(0.0227)
PADD II	-0.1753***	-0.2452***	-0.2515***	-0.1293***
	(0.0528)	(0.0468)	(0.0449)	(0.0371)
PADD III	-0.4310***	-0.6794***	-0.6967***	-0.2891***
	(0.1308)	(0.1180)	(0.1148)	(0.0970)
PADD IV	0.0359	-0.0673	-0.0750	-0.1971***
	(0.0842)	(0.0742)	(0.0680)	(0.0497)
PADD V	0.0216	-0.1075*	-0.1167*	-0.1512***
	(0.0693)	(0.0651)	(0.0599)	(0.0445)
Constant	1.4562***	1.6644***	1.6862***	0.7814***
	(0.0903)	(0.0840)	(0.0713)	(0.1085)
Observations	660	660	660	660
R-squared	0.6858	0.7650	0.7652	0.8576

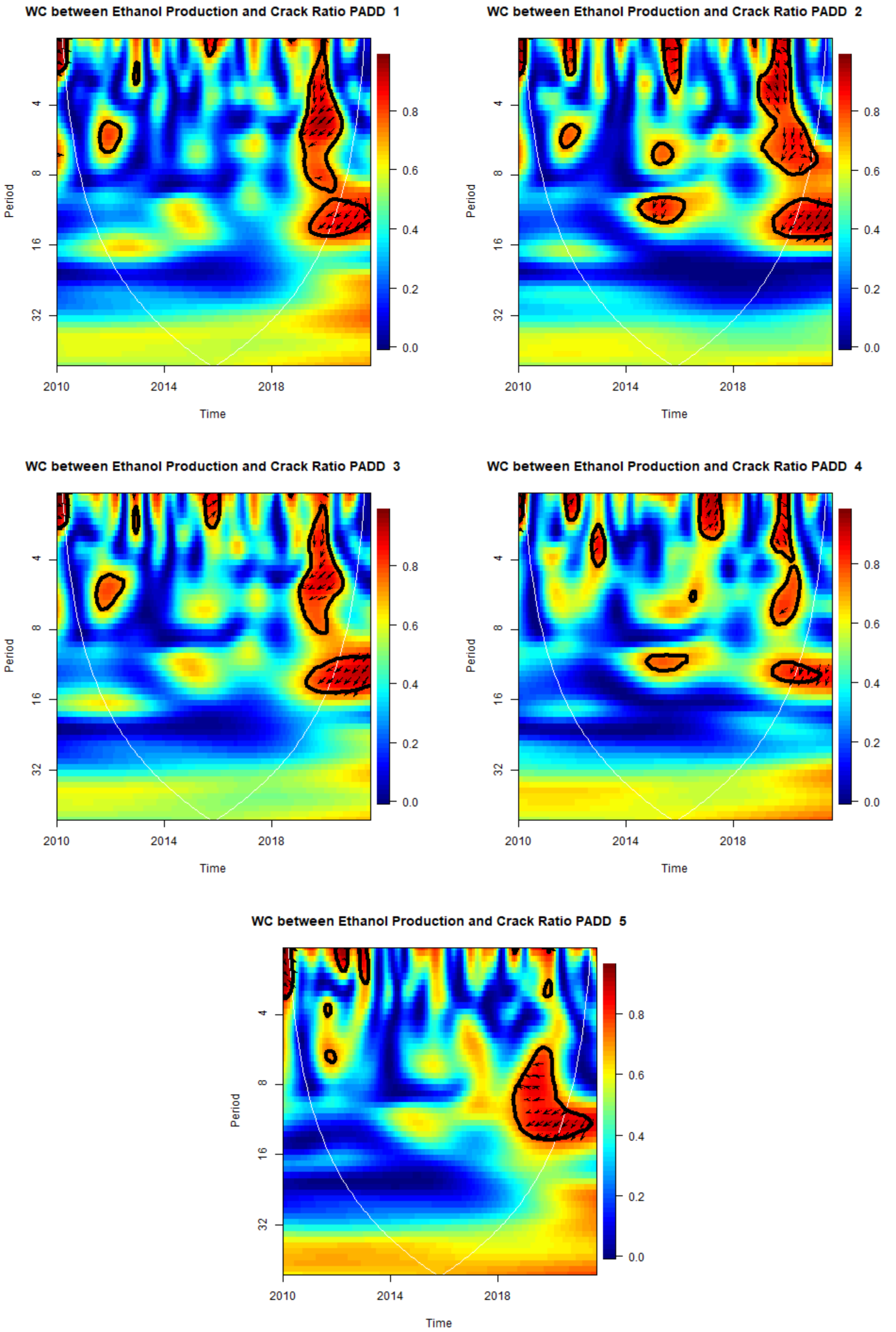

Figure A.4: Wavelet Coherence between Ethanol Production and Crack Ratio across PADDs

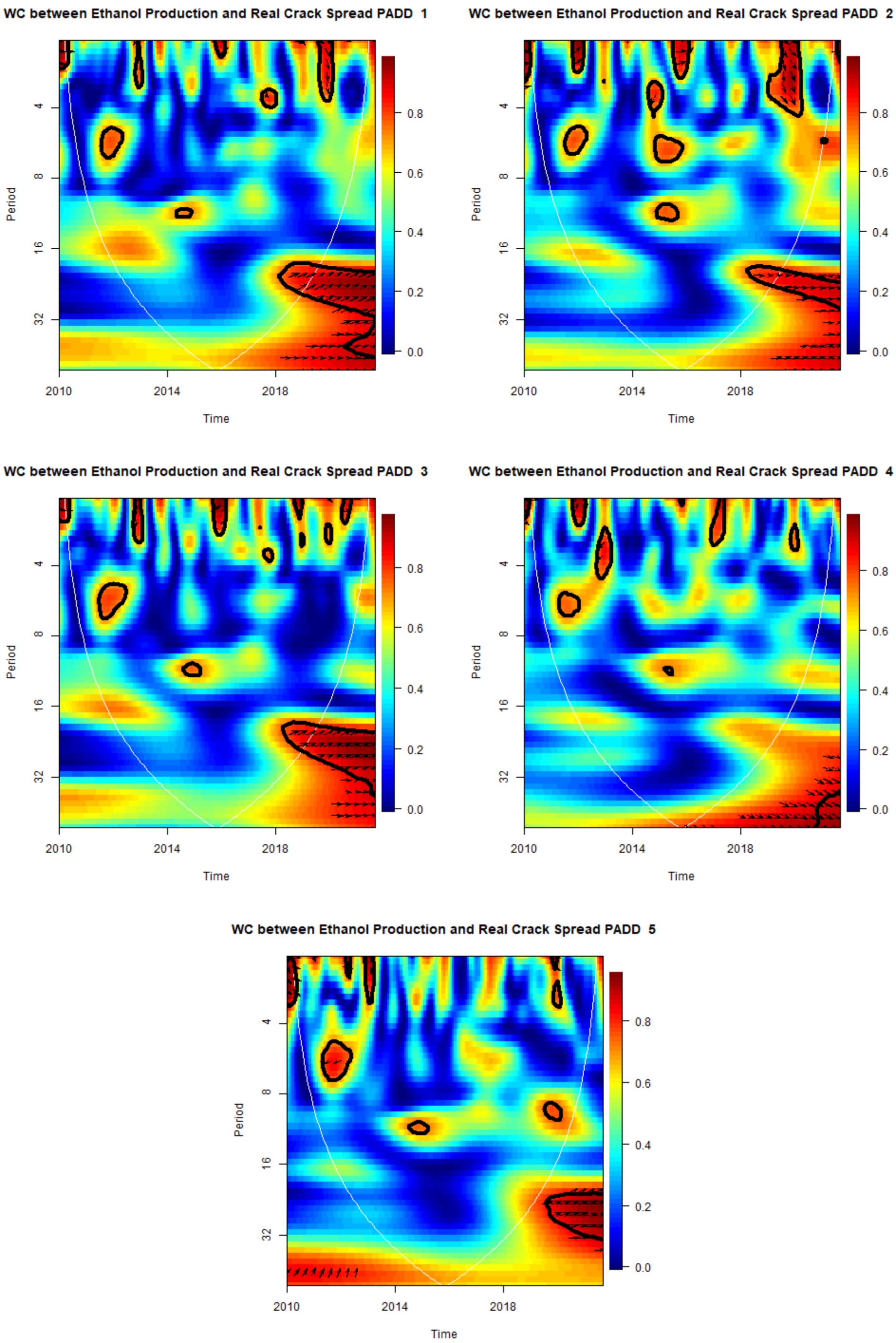

Figure A.5: Wavelet Coherence between Ethanol Production and Real Crack Spread across PADDs

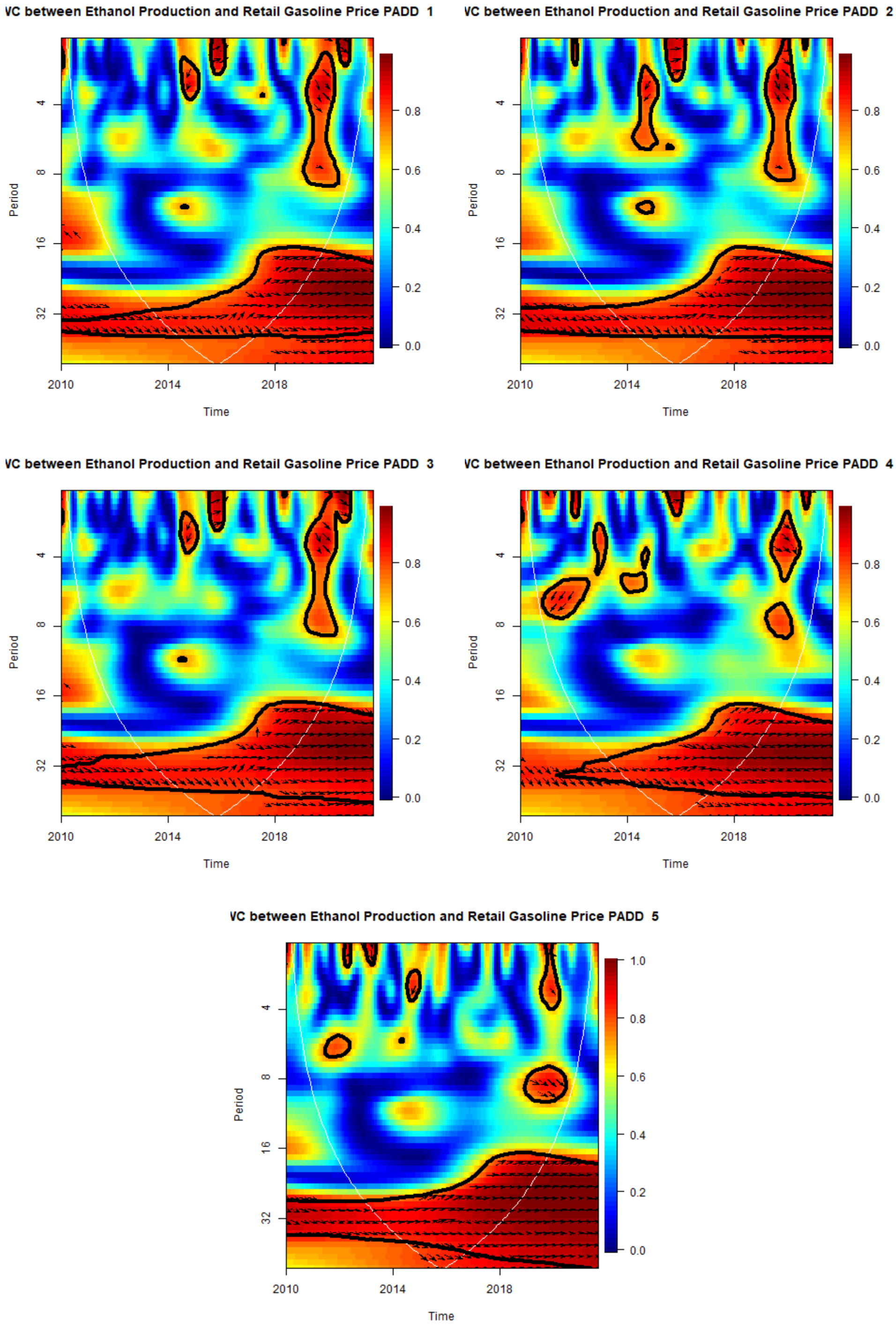

Figure A.6: Wavelet Coherence between Ethanol Production and Retail Gasoline Prices across PADDs

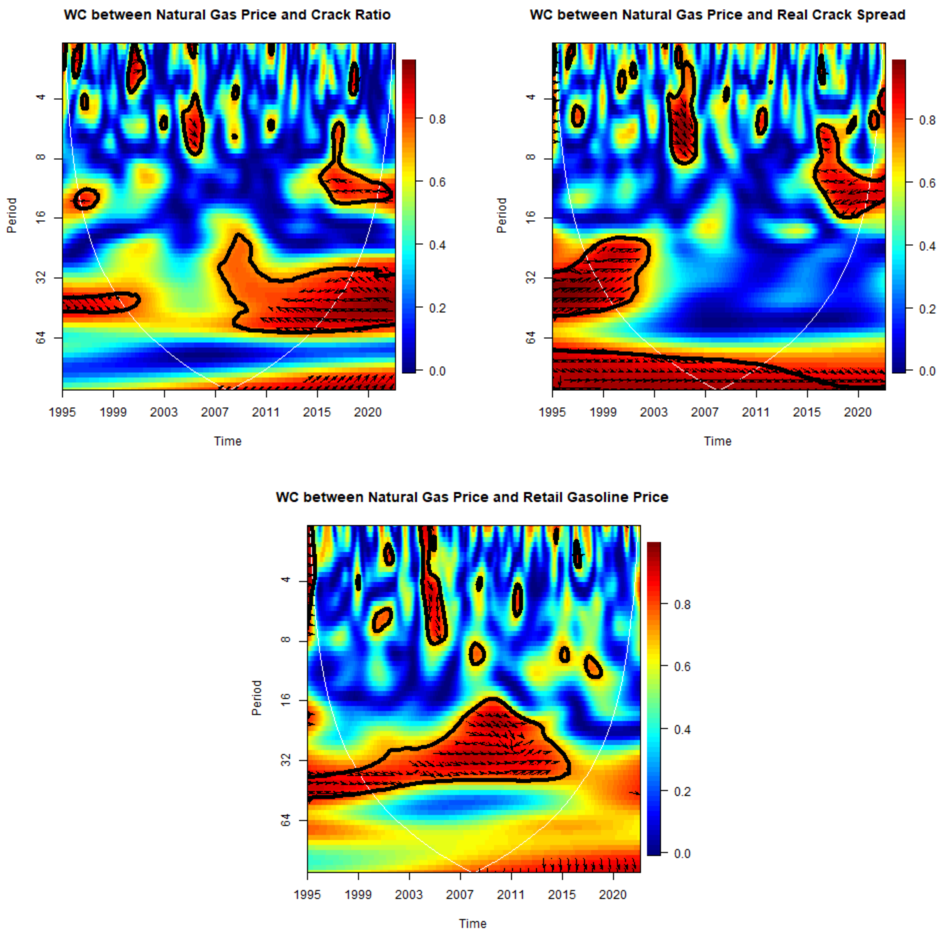

Figure A.7: Wavelet Coherence between Natural Gas Price