# THE COMPLEX STRUCTURE OF THE U.S. BIOFUEL MANDATE AND IMPLICATIONS FOR WORLD BIOFUEL AND GRAIN/OILSEED PRICES

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ABSTRACT

The Renewable Fuel Standard has helped to increase the amount of biofuels consumed in the United States while also contributing to increased grain/oilseed price volatility. The nested structure created values biofuels differently based on arbitrary characteristics. Biodiesel has been an important biofuel for blenders dealing with mandate compliance in both 2011 and 2013. In 2011, increased sugarcane ethanol prices forced increased biodiesel demand and hence prices, resulting in biodiesel exceeding its mandate for the first time and competing for the remainder of the advanced biofuel mandate. Similarly, in 2013 excess biodiesel was utilized to help breach the ethanol blend wall causing RIN prices to converge. In both years it caused short term excess biodiesel plant profit as they took advantage of higher prices while input costs were not increased as rapidly.

BIOGRAPHICAL SKETCH

Justin Shepherd was born February 13, 1988 in Moosomin, Saskatchewan. Justin grew up on a mixed cattle, cash crop, and forage farm and was always extensively interested in agriculture and the family farm. He is still involved on planning and working on the family farm when the opportunity arises. He graduated from McNaughton High School in 2006. Despite an early university experience with engineering, Justin found his way back to agriculture and graduated with great distinction with the degree of Bachelor of Science in Agribusiness from the University of Saskatchewan in 2012.

In his free time, Justin enjoys coaching and playing hockey, reading, farming, and going on drives checking crops. Justin will earn his Master of Science in Applied Economics and Management from Cornell University in August, 2014. After his graduation, Justin plans to move to Boulder, Colorado to begin a career as an agricultural analyst with DHF Team, continue to be involved in his family farm, and begin collecting antique trucks and tractors.

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I am extremely lucky to have been able to work with a fellow Canadian in Dr. Harry de Gorter, who was my committee chairman. I thank Harry for taking me on as his student and the stirring conversations debating biofuel policies. I have learned an incredible amount that I will directly translate into my new role in a commercial research operation while hopefully being able to receive his insights for many more years.  My committee members also includes Dr. David Just, thank you for helping me to grasp econometrics and providing technical analysis out of my capacity.

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# CHAPTER 1

# INTRODUCTION

## *Statement of the Problem*

The purpose of this paper is to provide a basic framework for understanding U.S. biofuel mandates under the rubric of the Renewable Fuel Standard (RFS) which are extremely complicated and widely misunderstood by the public and economists who study them. We explain simply how the nested structure creates interactions between mandates and the various biofuels used for compliance, essentially creating a handbook on how to understand the mandates and what interactions have occurred and what is likely to again. Additionally, the RFS is directly responsible for emerging world biofuel trade patterns and impacts how domestic blenders bid up biofuels and crop inputs that are used in production. While many economists view the RFS as a consumption mandate, we clearly show that a blend mandate is the proper way to model them and show how the blend wall only came into effect in 2013 and how blenders avoided the cliff.

The nested structure of the U.S. mandate also has implications for corn-ethanol and corn prices, and trade in both ethanol (including two-way trade with Brazil) and biodiesel. So prices of both biofuels and three main feed stocks: corn, soybean and canola oil, and sugarcane (and hence sugar) are being affected by the way in which the complex U.S. RFS mandate works. And the primary driver since early 2013 has been the ethanol blend wall in the United States and more recently, the uncertainty in the EPA's final ruling for 2014 (which at the time of writing, has still not been resolved), both having implications for the way forward in 2014 and beyond. But the volatility of grain-oilseed prices have been greatly impacted by this mandate structure in

2011 and now again since 2013 so using accepted price prediction models by de Gorter, Drabik, and Timilsina (2013) we will try to unravel why they do not always work as intended.

***Organization of Thesis***

This thesis is broken into 3 chapters to help the reader build up their understanding of the Renewable Fuel Standard and how it impacts different fuel markets and how they are economically modelled. We begin in Chapter 2 by briefly reviewing the Environmental Protection Agency (EPA) rulemaking regarding the RFS and how different biofuels are classified within the mandates. We will show how the four mandate categories interact and the particular spill over pathways that exist. In addition, the EPA is required to implement the annual quantities for each of the four mandates defined above by specifying blend ratios for the amount of renewable fuel blended with each of gasoline and diesel. We look at different methods of calculating ethanol and biodiesel blend ratios and the confusion that stems from the RFS structure. We also look at how renewable identification numbers (RINs) are utilized for compliance of each blender's RFS obligations and their multiplication factors that can lead to certain biofuels being preferred.

Chapter 3 considers why 2013 is an important time period for reaching the 10 percent ethanol limit in gasoline (i.e., the blend wall) resulting from the RFS and how the market accordingly priced RINs. We start by building a simplified model of the blend wall according to conventional research and the opportunities for expanding research in this area moving forward. While the simple blend wall does not fully explain the complexities of the RFS, it is an important starting point to see how economists differ on how it can and will be breached. Finally, we show how the nested structure that was explained in Chapter 2 allows the blend wall to be breached by biofuel blenders by using their least cost method utilizing several paths of compliance.

In Chapter 4, we are able to bring together all the understanding of the blend wall and RFS to help explain model errors in established price prediction models. It is important to first explain the advanced biofuel mandate interactions between biodiesel and Brazilian sugarcane ethanol during 2011 where the nested structure of the RFS occurs for the first time. Understanding this time period is vital moving forward to 2013 when the blend wall occurs and the interaction that now encompasses biodiesel and corn ethanol in the renewable fuel gap. These interactions show up in market prices of biofuels as it drives demand resulting in RIN prices converging. The interactions are not necessarily a bad thing[1], it just shows that the RFS is working as designed.

Understanding the Renewable Fuel Standard in the United States is an important first step in understanding how biofuels are chosen by fuel blenders to be utilized in the nations fuel supply. This paper took a very complex government program and attempted to simplify it into an easy to use guide and help explain past model errors.

[1] Clearly biofuel prices are increased due to the RFS increasing demand for biofuels, but as a policy goal of increasing biofuel consumption in the U.S. it is inevitable that this is the case.

# CHAPTER 2

# EXPLAINING THE COMPLEX STRUCTURE OF THE U.S. BIOFUEL MANDATES

### ***Overview of the Mandate Structure***

U.S. biofuel mandates under the rubric of the Renewable Fuel Standard (hereafter the RFS) are extremely complicated.[2] Four broad categories of biofuel mandates are specified: biomass based diesel (BBD), cellulosic biofuels, advanced biofuels, and total renewable fuel. Each category is defined by two criteria: biomass based diesel (mostly biodiesel from vegetable oils and animal fats) *versus* not (mostly ethanol)[3], and a minimum level of greenhouse gas (GHG) emissions reduction relative to the fossil fuel (gasoline or diesel) it is assumed to replace.[4] For example, corn ethanol only qualifies for the total renewable fuel mandate and is required to reduce GHG emissions 20 percent relative to gasoline.

These alternative biofuels are to be blended with either gasoline or diesel. The first two categories (BBD and cellulosic) are nested within the advanced biofuel mandate, with the latter nested within the total renewable fuel standard. All listed biofuels qualify for the overall total renewable fuel mandate. In governing the mandated use of alternative renewable fuels, EISA 2007 establishes the annual volumes of each of these alternative renewable fuels that must be

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[2] The RFS is under the Clean Air Act Section 211 (o) as amended by the Energy Independence and Security Act (EISA) of 2007 (EISA, 2007).
[3] We assume in this paper that all biofuels are used in transportation. Biogas, cellulosic biodiesel (heating oil) and naphtha are not used in transportation but their levels to date have been minuscule and so can be ignored.
[4] Biofuels themselves are net zero as recognized by the IPCC (2008) (the GHGs absorbed in growing the crop are emitted in burning the fuel – see de Gorter and Just (2008) for a comprehensive discussion). But GHGs are emitted in the production and distribution of biofuels from field to fuel tank, as measured by "life-cycle accounting".

blended with either gasoline or diesel. Eligible biofuels are not just biodiesel and ethanol, but also include renewable diesel, naphtha, biobutanol, biogas, and biogasoline.

This chapter is outlined as follows. We begin by briefly reviewing the Environmental Protection Agency (EPA) rulemaking regarding the RFS and how different biofuels are classified within the mandates. We will show how the four mandate categories interact and the particular spill over pathways that exist. In addition, the EPA is required to implement the annual quantities for each of the four mandates defined above by specifying blend ratios for the amount of renewable fuel blended with each of gasoline and diesel. We also look at how renewable identification numbers (RINs) are utilized for compliance of each blender's RFS obligations and their multiplication factors that can lead to certain biofuels being preferred. Finally, we consider why 2013 is an important time period for reaching the 10 percent ethanol limit in gasoline (i.e., the blend wall) resulting from the RFS and how the market accordingly priced RINs.

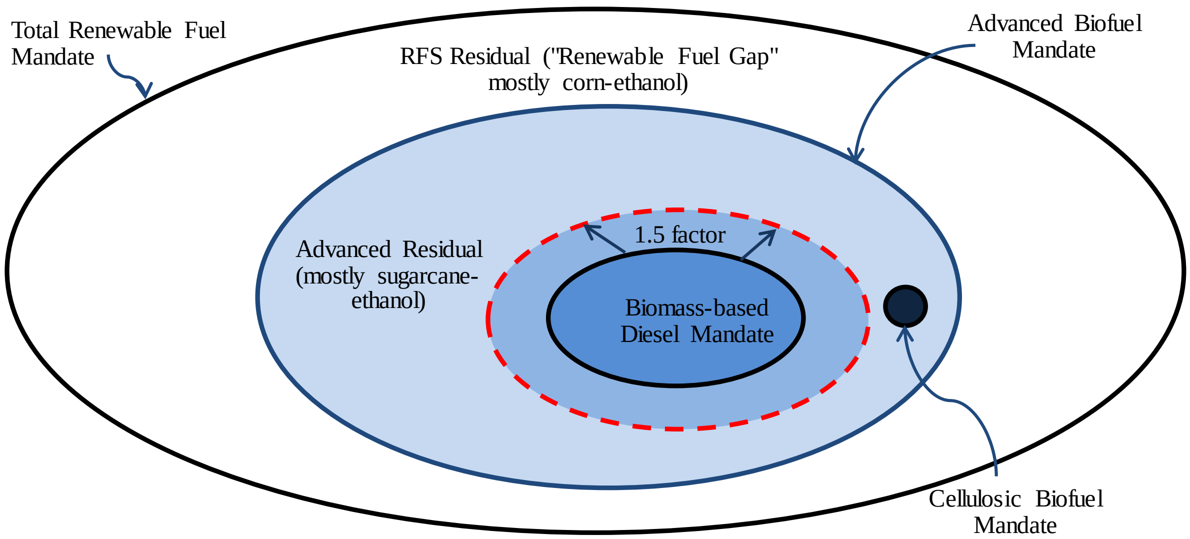
***The General Structure of U.S. Biofuel Mandates***

The structure of the RFS is remarkably complex with nested mandates based on GHG emission reductions and source or type of biofuel. Each mandate is a specific volume of a biofuel for each year. Figure 2.1 is a heuristic summary of the total renewable fuel standard.[5] The total renewable fuel mandate includes all possible types of domestically consumed biofuels and requires a minimum 20 percent reduction in GHG emission. Within the total renewable fuel mandate, there is an advanced biofuel mandate that requires a minimum 50 percent reduction in GHG emissions. The advanced mandate has two specific mandates within it: a biomass-based diesel (BBD) mandate,[6] and cellulosic biofuels (not only ethanol and biodiesel but also cellulosic

[5] Circle size is not representative of biofuel volume produced in that category.
[6] There are two types of biodiesel that need to be defined that fall under the biomass-based diesel mandate. Biodiesel is made from trans-esterification while renewable diesel is made by at least three other processes and it includes recycled vegetable oils and animal fats. Unlike biodiesel, renewable diesel has

gasoline and cellulosic diesel).[7] But cellulosic biofuels require a 60 percent saving in GHG emissions.

**Figure 2.1. The Nested Structure of the RFS up to 2010**




Source: Derived from various EPA RIN generation data (http://www.epa.gov/otaq/fuels/rfsdata/2010emts.htm)

Once each of the inner mandates for advanced biofuels are satisfied in Figure 2.1, any spillover or ‘overage’ can compete with other advanced biofuels without explicit mandates (e.g., sugarcane ethanol from Brazil is the major type of biofuel that fills the advanced mandate outside the biofuels qualifying for each of the two inner mandates) to fill the residual of the advanced biofuel mandate.[8] As soon as the advanced mandate is filled, advanced biofuel ‘overage’ starts counting towards the total renewable fuel mandate. The difference between the advanced biofuels mandate and the total renewable fuel mandate is known as the ‘renewable fuel

the same chemical properties as diesel and its equivalence values vary between 1.5 and 1.7. Through the remainder of the paper biodiesel will refer to all types of biodiesel including renewable diesel.

[7] The entire circle includes every biofuel within it. If a gallon of biodiesel is blended, it counts towards the BBD mandate, but also to the advanced biofuel and total renewable fuel mandates (but with a multiplier of 1.5 to the latter two mandates – we discuss this later).

[8] Sugarcane ethanol is also vital for meeting California’s Low Carbon Fuel Standard (LCFS) so even if the advanced biofuel standard was met with biodiesel, sugarcane ethanol would still be imported to help fulfil the LCFS.

gap' which can be filled with any biofuel that meets the 20 percent GHG reduction threshold (Meyer, Schmidhuber, & Barreiro-Hurle, 2013).

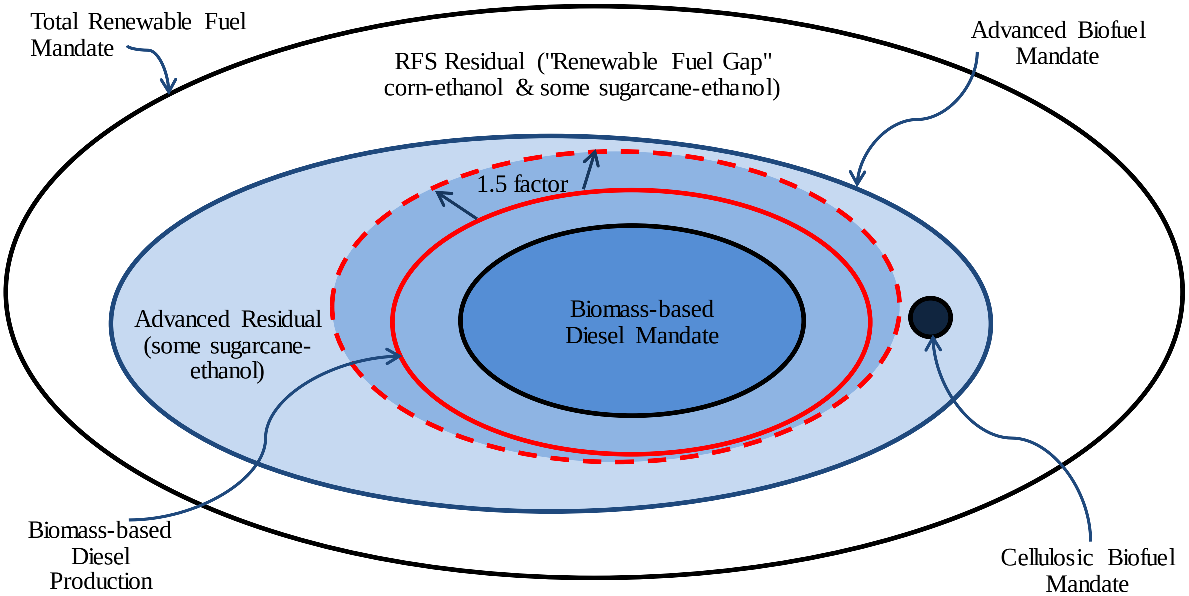
All biofuels currently being consumed in the United States are therefore advanced except for corn ethanol and other extremely low amounts of biofuels like some non-ester renewable diesel that reduces less than 50 percent GHG (and even some BBD). There are really only three "explicit" mandates in the United States: that for BBD, cellulosic biofuels and total renewable fuel. In other words, if cellulosic biofuel consumption went beyond the total renewable fuel mandate, the BBD mandate is the only other mandate that has to be filled regardless (and vice-versa). While no other type of biofuel can meet this category, cellulosic biofuels could, in principle, meet the entire total renewable fuel standard if at least the mandate was met for BBD. There is no corn ethanol mandate per se – it qualifies for the renewable fuel gap as the residual represented by the green area in Figure 2.1 although even that can in theory be filled by 'overage' of any advanced biofuel. However, prior to 2013, only corn ethanol has been counted towards the renewable fuel gap and Figure 2.1 allows easy understanding of blenders RFS compliance in the United States.[9]

Although corn ethanol had the renewable fuel gap easily filled until 2013, it does not mean that within the advanced biofuel mandate that there were no interactions. Figure 2.2 shows how blenders complied with the RFS during 2011 and 2012 as the BBD mandate was exceeded for the first time and created spillover into the advanced residual gap. We will show in this and later chapters how biofuel policy and world biofuel prices created the opportunity for blenders to choose between importing Brazilian sugarcane ethanol and domestic biodiesel. Even though

[9] There have been minor amounts of other biofuels that did not meet GHG emissions reduction requirements for the other mandates to count under the total renewable fuel standard.

BBD was competing with sugarcane ethanol for the advanced residual, there was no significant spillover into the renewable fuel gap and competing with corn ethanol.

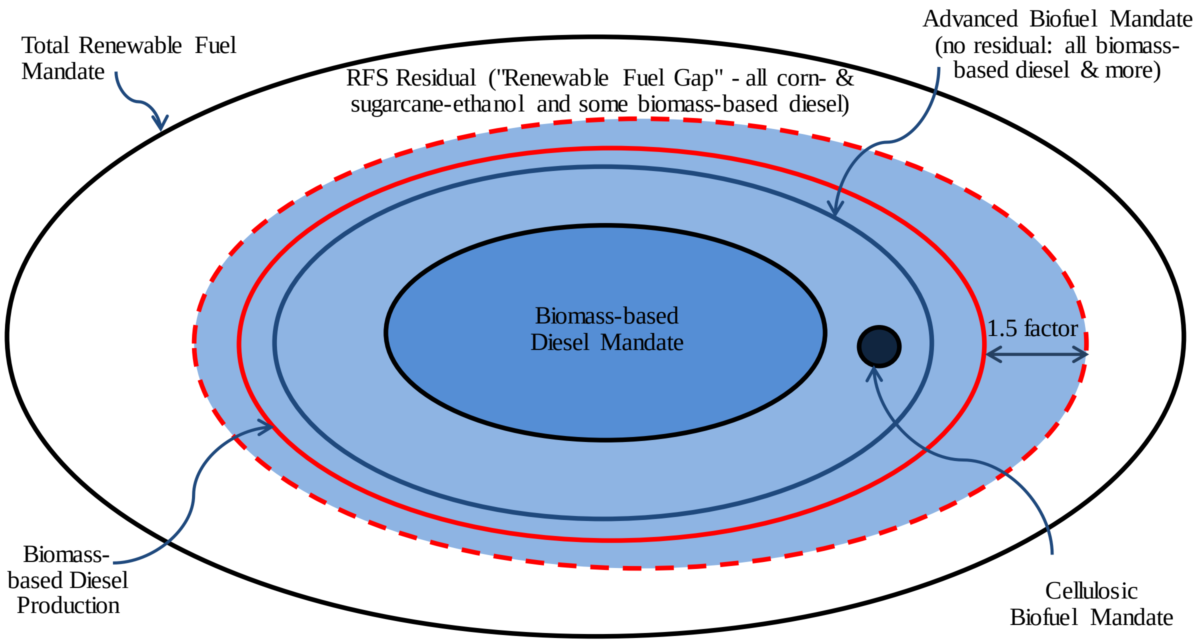
**Figure 2.2. The Nested Structure of the RFS during 2011/2012**




Source: Derived from EPA RIN generation data (http://www.epa.gov/otaq/fuels/rfsdata/2012emts.htm)

But beginning in 2013 advanced biofuel overage spilled into the total renewable fuel mandate as shown in Figure 2.3, displacing corn ethanol, which is instead mostly exported. The figure shows that BBD filled the entire advanced mandate alone and pushed sugarcane ethanol into the renewable fuel gap. This occurred because of the ethanol "blend wall" where cars are limited to a maximum blend ratio of 10 percent. The economics of the blend wall is an issue we take up in greater detail in the next chapter but the impact of spillage was to equalize RIN prices. But first we have to explain more details of the mandates like the types of biofuels and the GHG emissions reduction requirements, the ethanol equivalence factors associated with each biofuel as everything is measured in terms of ethanol equivalent gallons, and the categories of "renewable identification numbers" (RINs) that are used to ensure compliance of the mandates (Cornell University Law School, 2013a). To this we now turn, step by step.

**Figure 2.3. The Nested Structure of the RFS during 2013**




Source: Derived from EPA RIN generation data (http://www.epa.gov/otaq/fuels/rfsdata/2013emts.htm)

The different biofuels that fall under each mandate are shown in Table 2.1. The first column lists most of the biofuel types that are being counted towards the RFS. BBD can be ester-based diesel (e.g., from soybean oil) or non-ester renewable diesel (e.g., from cellulosic feedstock's) which can be used as a transportation fuel, a transportation fuel additive, heating oil, or as a jet fuel (Schnepf & Yacobucci, 2013).[10] Cellulosic biofuels can produce biodiesel and biogasoline from feedstocks such as corn stover, miscanthus, switch grass, forest residues, or short rotation woody crops. Advanced biofuels require GHG reduction of 50 percent as shown in column 2 of Table 2.1 and includes overage from cellulosic and BBD as well as sugarcane ethanol, naphtha, biobutanol, and biogas. Any biofuel that qualifies with 20 percent GHG reduction fits under the total renewable fuel standard, which is mainly corn ethanol.

[10] Consequently, when calculating the blend ratio for motor fuels later, the data has to be adjusted to account for consumption outside motor fuels.

It is important to realize that depending on plant production methods and inputs used, biofuels may count towards different mandates.[11] For example, certain plants producing non-ester renewable diesel can only count towards the advanced mandate or the total renewable fuel mandate (e.g., using coal as a conversion source) (Schnepf & Yacobucci, 2013).

Table 2.1. Classifying Biofuels

| *Biofuel Type* | *GHG Reduction*[a] | *Equivalence Value* | *RIN Category*[b] |
|---|---|---|---|
| Biomass-based diesel (BBD) Mandate | 50% | | D4 |
| Biodiesel | | 1 (1.5)[c] | |
| Non-ester renewable diesel | | 1 (1.5-1.7)[c] | |
| Cellulosic Biofuel Mandate | 60% | | |
| Biogasoline | | 1.5 | D3 |
| Biodiesel | | 1.7 | D7 |
| Advanced Biofuel Mandate | 50% | | D5 |
| Sugarcane ethanol | | 1 | |
| Naphtha | | 1.5 | |
| Biobutanol | | 1.3 | |
| Biogas | | 1 | |
| Renewable Fuel Gap[d] | 20% | | D6 |
| Corn Ethanol | | 1 | |

[a] Biofuels within each mandate must reduce GHG by that amount over diesel or gasoline.
[b] Renewable identification numbers (RINs) are the EPAs compliance categories and will be discussed later in the chapter.
[c] Numbers in parentheses reflect equivalence values for the advanced and total renewable fuels mandates.
[d] Calculated by subtracting the advanced mandate from the total renewable mandate.
Source: Adapted from EISA 2007

The third column of Table 2.1 gives the ethanol equivalence value attributed to each gallon of biofuel consumed for each type of biofuel. The EPA requires each gallon of biofuel to be defined in terms of an ethanol equivalent gallon, where the equivalence value differs from 1 to reflect differential energy content (EPA, 2013). Ethanol has an equivalence value of 1

[11] Grandfathered plants that were built before December 19, 2007 are exempt from the 20 percent lifecycle GHG threshold requirement. However, any new expansion at existing plants must achieve the 20 percent reduction threshold (Schnepf & Yacobucci, 2013).

regardless of the feedstock source (e.g., corn or sugarcane) even though it can apply to different mandates. The EPA creates equivalence values for biofuels based on the different energy content compared to ethanol and the type of inputs (e.g., proportion of renewable feedstock and energy conversion source) (EPA, 2013).[12]

As we showed above, the BBD mandate is composed of both biodiesel and non-ester renewable diesel although we refer to the overall category as BBD. The BBD standard is the only mandate given in actual volume; not in ethanol equivalence terms. This means a gallon of BBD counts differently towards its own mandate compared to the remainder of the advanced biofuel mandate and the renewable fuel gap (Cornell University Law School, 2013b). Ester-based biodiesel has an equivalence value of 1 towards its own mandate but 1.5 towards the advanced and total renewable fuel mandates. Non-ester renewable diesel has an equivalence value of 1 to the BBD mandate and a range between 1.5 and 1.7 for the advanced mandate, depending on the how it was produced: the type of feedstock (e.g., soybean oil or palm oil) or fuel used in its production (e.g., natural gas or coal). This means that even when ester-based biodiesel (non-ester renewable diesel) is blended exactly at the mandated volume it will actually generate 1.5 (1.5-1.7) times the compliance volume towards the advanced and total renewable mandate, respectively.[13]

Within the cellulosic biofuel mandate, biogasoline and biodiesel have equivalence values of 1.5 and 1.7, respectively. This means each gallon of cellulosic biogasoline counts 1.5 times towards the cellulosic mandate, the advanced biofuel mandate and the total renewable fuel standard. It is important to note that cellulosic biodiesel blended under the cellulosic biofuel mandate does not count towards the BBD mandate. By 2022, 16 billion gallons (BG) of

[12] http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf
[13] This manifests itself as a Renewable Identification Number to be discussed later.

cellulosic biofuels are required and since that is in ethanol equivalent, if the entire amount was biogasoline,[14] the actual volume needed would be 10.67 BG (EISA, 2007).

The annual required consumption for each mandate from 2007 to 2022 is given in Table 2.2 as mandated by EISA (EISA, 2007). For example, in 2022, the total volume of biofuels mandated in ethanol equivalent gallons is 36 BG. The renewable fuel gap includes corn ethanol and is capped in 2015 at 15 BG. BBD was originally intended to be at least 1 BG but it was revised upwards in 2013 to 1.28 BG due to biodiesel production capacity exceeding this level by 500 million ethanol equivalent gallons. The major source of growth in biofuels was expected to come from cellulosic biofuels (16 BG in 2022). This appears to have been optimistic at best and the issues associated with not filling the cellulosic mandate will be discussed in the next sections. The discussion on the EPA adjusting the yearly volumes will take place in a later chapter but for now we will assume the schedule is identical as that laid out in Table 2.2.

[14] Mandated Volume (16 BG) divided by Equivalence Factor (1.5 for bio-gasoline) equals 10.67 BG actual gallons

Table 2.2. The Mandated Volumes as originally created by EISA 2007

| *Year* | *Advanced Biofuel* | *Cellulosic Biofuel*[a] | *Biomass-based Diesel* | *Other Advanced*[c] | *Renewable Fuel Gap* | *Total RFS* |
|---|---|---|---|---|---|---|
| 2008 | 0 | 0 | 0 | 0 | 9 | 9 |
| 2009 | 0.6 | 0 | 0.5 | 0.1 | 10.5 | 11.10 |
| 2010 | 0.95 | 0 | 0.65 | 0.2 | 12 | 12.95 |
| 2011 | 1.35 | 0.25 | 0.8 | 0.3 | 12.6 | 13.95 |
| 2012 | 2 | 0.5 | 1 | 0.5 | 13.2 | 15.2 |
| 2013 | 2.75 | 1 | 1.28[b] | 0.75 | 13.8 | 16.55 |
| 2014 | 3.75 | 1.75 | 1.28 | 1 | 14.4 | 18.15 |
| 2015 | 5.50 | 3 | 1.28 | 1.5 | 15 | 20.5 |
| 2016 | 7.25 | 4.25 | 1.28 | 2 | 15 | 22.25 |
| 2017 | 9 | 5.5 | 1.28 | 2.5 | 15 | 24 |
| 2018 | 11 | 7 | 1.28 | 3 | 15 | 26 |
| 2019 | 13 | 8.5 | 1.28 | 3.5 | 15 | 28 |
| 2020 | 15 | 10.5 | 1.28 | 3.5 | 15 | 30 |
| 2021 | 18 | 13.5 | 1.28 | 3.5 | 15 | 33 |
| 2022 | 21 | 16 | 1.28 | 4 | 15 | 36 |

All volumes are in billion gallons
[a] Cellulosic biofuels have essentially been adjusted to zero each year up to 2014.
[b] BBD was adjusted to 1.28BG for the 2013 year.
[c] Calculated as difference between advanced biofuel and the sum of BBD and cellulosic biofuels.
Source: EISA 2007

A final way to look at how biofuels meet their respective mandates is shown in Table 2.3 which demonstrates for 2013 the mandated volumes that must be met and the actual RIN generated volumes that can be used to comply with the RFS. The mandated column assumes that all explicit mandates are met and not exceeded. If there is cellulosic biofuel or BBD overage, it will count towards the advanced biofuel gap and compete predominantly with sugarcane ethanol. As stated earlier, BBD will automatically have overage because the BBD mandate has to be met in actual gallons while it is given a 1.5 equivalence factor. For example, if the BBD mandate is 1 BG, at least 0.5 BG[15] will automatically count as overage for the advanced biofuels mandate as shown. Provided there is no advanced spillover, corn ethanol will fill the entire renewable fuel

[15] Due to the range of 1.5-1.7 equivalence different BBD products carry.

gap of 13.8 BG. The mandated volumes are of course only theoretical. To the actual volume generated column we now must turn.

Table 2.3. Mandates versus Outcomes for 2013

| | *Mandated (EISA 2007)* | *Actual* |
|---|---|---|
| Cellulosic Biofuels Mandate | 1 | 0.014 |
| Biomass-based Diesel Mandate[a] | 1 | 1.28 |
| Advanced Biofuel Mandate[b] | 2.75 | 2.75 |
| Cellulosic biofuel | 1 | 0.014 |
| Biomass-based diesel (1.5-1.7) | 1.5 | 2.68 |
| Other advanced biofuel[c] | 0.25 | 0.777 |
| *Total Advanced Overage* | 0 | 0.707 |
| Renewable Fuel Gap[d] | 13.8 | 13.8 |
| Advanced Overage | 0 | 0.707 |
| Corn Ethanol[e] | 13.8 | 13.08 |
| Total RFS Mandate[f] | 16.55 | 16.537 |
| Ethanol | | 13.55 |
| Biodiesel | | 3.06 |

[a] The mandated amount of biomass-based diesel is in actual or 'wet' gallons. Biomass-based diesel counts 1.5 to 1.7 times actual gallons towards the remainder of the mandates.
[b] Advanced biofuels is renewable fuel (other than ethanol derived from corn starch) that is derived from renewable biomass, and achieves a minimum 50 percent reduction of GHG emissions relative to gasoline or diesel it is assumed to replace. .
[c] This includes imported sugarcane ethanol, bio-butanol, renewable diesel, and other advanced biofuels. For 2013, Brazilian sugarcane ethanol was 0.457 billion gallons and most of the remainder (0.32 billion gallons) is imported renewable diesel.
[d] The renewable fuel gap is the difference between the total RFS and the advanced biofuel mandate.
[e] There is no corn ethanol mandate. Corn ethanol can only fill the residual of the renewable fuel gap which in theory can be filled by any advanced biofuel. However, up to 2013, corn ethanol has been the only biofuel counted towards the renewable fuel gap except for minute amounts of biodiesel, for example.
[f] Renewable fuel is any biofuel blended that achieves a minimum GHG reduction of 20 percent.
Source: EISA 2007; EPA (2014)

The actual volume shows how a stark contrast to the original EISA 2007 legislation. Cellulosic biofuels were expected to produce one billion gallons in 2013, but the actual mandate was revised downwards to just 14 million gallons. The major effect this has is increasing the burden on BBD and sugarcane ethanol to meet the advanced residual as the EPA did not lower the overall advanced mandate down by the corresponding 986 million gallons. What happened was large increases in BBD production and imports as well as steady imports of sugarcane ethanol causing over 700 million gallons to spill over into the renewable fuel gap for the first time and displace corn ethanol which was instead exported.

The importance of the equivalence values will be discussed in greater detail in a later section that will introduce Renewable Identification Numbers (RINs) which keep track of each gallon of biofuel blended in the United States. Additionally, although we have looked at the original structure of the RFS, each year the EPA has the ability to adjust the mandates volumes.[16] While we have tried to explain the U.S. mandate structure in as simple form as possible until now, we must now introduce these other complexities.

***How the Renewable Fuel Standard is actually implemented***

The question naturally becomes how does the federal government (the EPA in this case) implement a mandate that specifies particular quantities of renewable fuel to be consumed each year? Is it implemented as a consumption mandate (as most economists model the U.S. mandate)[17] rather than as a blend mandate, as in all other countries? If so, how do individual fuel blenders coordinate amongst themselves through the year to achieve a fixed quantity target each year? What incentive does each company have to ensure the mandate is met and how does the EPA ensure compliance?

The answer is the EPA implements the U.S. consumption mandate as a blend mandate by specifying percentage standards for BBD, cellulosic, advanced biofuels and total renewable fuel. While most economists have modelled the RFS as a fixed quantity for each of ethanol and

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[16] For more information on their ability to adjust mandates, refer to Appendix 1.
[17] See for example Lapan and Moschini (2012), Cui et al. (2011), Babcock (2102), Abbott (2012), Tyner and Viteri (2011) and Hertel and Beckman (2012), just to name a few examples.

biodiesel this is not the case as we will show. Compliance is ensured through the system of renewable identification numbers (RINs). So the purpose of this section of the chapter is to explain the exact process of implementing the RFS: the establishment of percentage standards (blend mandate) and how the compliance mechanism of RINs work.

Annual EPA volumes are given in Table 2.4 and are also called Renewable Volume Obligations (RVOs). The EPA has adjusted the cellulosic mandate down each year as supplies were not forthcoming but they did not change the total renewable fuel standard or advanced mandate. This implicitly increased the advanced mandate by 0.1, 0.25, 0.5, and 1 BG in 2010, 2011, 2012, and 2013, respectively. Hence, through 2013, although cellulosic mandates declined relative to that specified by the EISA, the volumes for the advanced mandate were maintained as in the EISA 2007 and so was informally filled by greater volumes of BBD and Brazilian sugarcane ethanol. In 2013, the BBD mandate in 2013 was formally increased from 1 BG to 1.28 BG. However, in 2014, the EPA recommended (for the first time ever) a reduction in the total renewable mandate rather than having advanced biofuels (mostly BBD and Brazilian sugarcane ethanol) pick up the slack (EPA, 2013a). The 2014 mandated volumes are still being debated and may revert to the total renewable volumes as set out in the 2007 EISA.

Table 2.4 Volume Used to Determine Percentage Standards (BG)

| | *2008* | *2009* | *2010* | *2011* | *2012* | *2013* | *2014*[a] |
|---|---|---|---|---|---|---|---|
| Cellulosic | - | - | 0.0065 | 0.0065 | 0.01 | 0.014 | 0.017 |
| Biomass-based Diesel[b] | - | 0.5 | 0.65[c] | 0.8 | 1 | 1.28 | 1.28 |
| Advanced Biofuel | - | 0.6 | 0.95 | 1.35 | 2 | 2.75 | 2.2 |
| Total Renewable Fuel | 9 | 11.1 | 12.95 | 13.95 | 15.2 | 16.55 | 15.21 |

[a] Ranges were provided for 2014 by the EPA, these are the average volumes to calculate percentage standards.
[b] Biomass-based diesel volumes are in actual ‘wet’ gallons.
[c] The EPA combined BBD compliance volumes for 2009 and 2010 to give blenders time to build capacity.
Source: adapted from various EPA Regulatory Announcements

The EPA then alters the projected volumes depending on whether territories (e.g., Hawaii and Alaska) opt in or not for each year. In addition, they also can reduce the projected motor gasoline and motor diesel that is produced by exempt small refineries and refiners (EPA, 2013). There is a profound lack of consistency in the yearly regulatory announcements provided by the EPA and the necessary forecast data provided in Federal Register Notices. Each year's percentage standards needs be calculated separately with the specific adjustments for that year. A complete listing of the equations and information the EPA requires to create the blend standards is provided in Appendix 2 and the forecast data is provided in Appendix 3.

After determining the annual volumes of each mandate, the EPA publishes percentage standards for each mandate (the ratio of each mandated volume to total forecast gasoline and diesel consumption (excluding renewable gasoline[18] and renewable diesel[19]) from the Energy Information Agency (EIA) in November prior to each calendar year. The result of the complicated yearly calculations is the only other accessible data the EPA furnishes and is given in Table 2.5: the percentage standards for cellulosic, BBD, advanced biofuels and total renewable fuel. Hence, the numerator is the renewable fuel volume as given in Table 2.4 and the denominator is the same in each case: total forecast gasoline and diesel consumption (excluding any renewable fuel and adjustments as discussed earlier). Additionally, the numerator for BBDs percentage standard is multiplied by 1.5 to account for its mandate being provided in ethanol equivalence values. Now that these percentages are calculated, each individual has to calculate for themselves how much of each biofuel mandate is to be blended with gasoline versus diesel. To this we now turn.

[18] Any renewable fuel that is projected to be blended into gasoline. It is made up predominantly of corn and sugarcane ethanol (>99.99%), with trace amounts of biobutanol and cellulosic biogasoline.
[19] Any renewable fuel (i.e., biomass-based diesel, non-ester renewable diesel) projected to be blended into diesel

Table 2.5 EPA Mandated Percentage Standards

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|
| Cellulosic | - | - | 0.004% | 0.003% | 0.006% | 0.008% | 0.01% |
| Biomass-based Diesel | - | - | 1.1%[a] | 0.69% | 0.91% | 1.12% | 1.16% |
| Advanced Biofuel | - | - | 0.61% | 0.78% | 1.21% | 1.60% | 1.33% |
| Total Renewable Fuel | 7.76% | 10.21% | 8.25% | 8.01% | 9.23% | 9.63% | 9.20% |

[a] While there was a proposed volume for BBD in 2009, they had not yet developed the percentage standards for any category other than total renewable fuel. Blenders were allowed to combine 2009 and 2010 to build capacity and were allowed to double count 2009's BBD compliance volume towards the overall 1.1 percent total renewable fuel standard.

Source: adopted from various EPA Regulatory Announcements

It is important to determine blend mandate ratios for BBD and ethanol as a ratio of total motor diesel consumption (diesel and BBD) and total motor gasoline consumption (gasoline and ethanol). This measure is the appropriate way to model the economics of blend mandates (de Gorter and Just, 2009) and is the exact definition of when the blend wall becomes an issue, in other words, regular cars are limited to 10 percent ethanol blend as defined by the second measure specified. The blend requirement published by the EPA is not useful directly: one requires the breakdown between biofuels blended with diesel versus gasoline, and we cannot model the economics of mandates or analyze the blend wall without having these modified blend ratios with total specific fuels in each of the denominators. Therefore we completely ignore the EPAs E/G distinction and calculate our own.

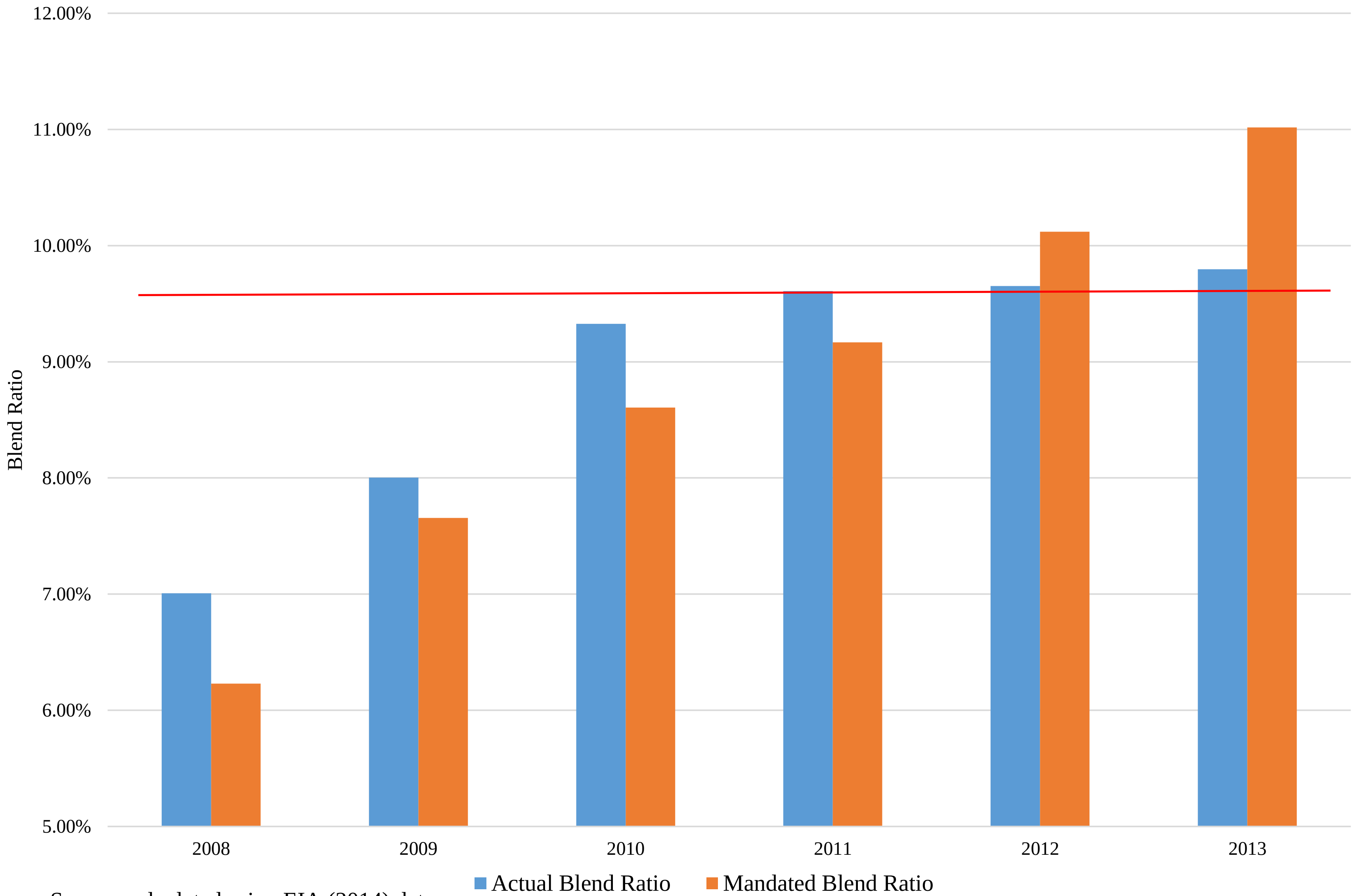
After completing all of these complex steps as described until now, we can now come up with mandated versus actual blend ratios for each year in the United States. These are shown in Figure 2.4 and is for the first time calculated. The mandated blend ratio assumes that BBD meets its own mandate while the renewable fuel gap is filled with corn ethanol and the advanced residual is filled with sugarcane ethanol as blenders have traditionally done. This results in a significantly higher blend ratio relative to the blender choice ratio during 2013 although they are close in previous years. One reason for the high mandated blend ratio is during close examination of the EPA's forecast data we realize the forecasted total renewable fuel volume is 16.55 BG and the EIA forecasts total renewable fuels to be blended with gasoline and diesel of 15.16 BG, for a gap of nearly 1.4 BG. The gap is closed with small amounts of biofuels like naphtha and biogas that are not blended into conventional motor fuels.[20] The gap is important for blenders because if they operate as the past with no changes, we expect the gap to be filled with corn ethanol and the blend ratio to equal the mandated blend ratio (i.e., simple assumptions here, no stored RINs being used, etc).

The actual ethanol blend ratio has been relatively constant since 2010 around 9.5% of ethanol in total motor gasoline. This graph will become even more important as we move into modeling the blend wall in chapter 3 and will be further discussed there. For now, understanding how to calculate the mandated blend wall is sufficient.

Despite the fact that biodiesel does not have an impending blend wall, it is still necessary to have the proper blend ratio to model the economics of a blend mandate. Hence, the comparisons of the two blend ratios for biodiesel as shown in Figure 2.5. Determining the biodiesel blend ratios does not take into account the 1.5 equivalence factor. The equivalence factor adjustment compares the energy content of biodiesel relative to ethanol, therefore using actual gallons makes more sense in calculating the ratio of biodiesel in diesel. Biodiesel has not reached 2.5 percent of motor diesel consumption in the United States as of 2013.

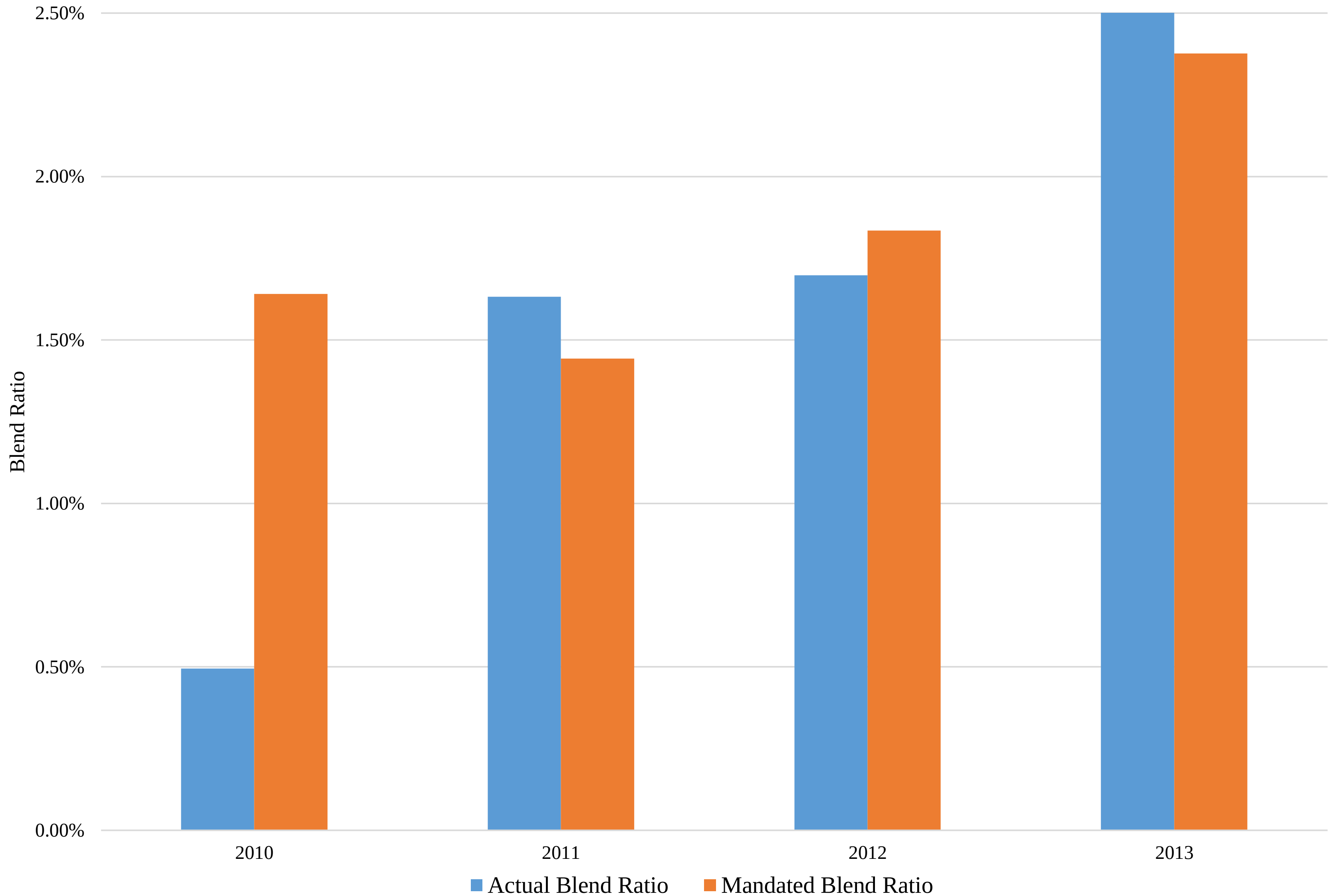
[20] Total of less than 30 million gallons ethanol equivalence

Figure 2.4. Ethanol Blend Ratios




Source: calculated using EIA (2014) data

Figure 2.5. Biodiesel Blend Ratio




Source: Calculated using EIA (2014) data

Whether the actual quantity of each biofuel is above or below mandated volumes for the year is not important. What is important is that the blender fulfills their blend ratio complying with the percentage standard ethanol over pure gasoline and biodiesel over pure diesel. If actual gasoline consumption is half the forecast, it is possible that total ethanol used is half (can be higher if mandate is not binding or blenders want to store RINs for the following year, only possible by going over the mandated volume – see discussion in next section). This is an important distinction that shows the mandate is manifested as a blend mandate, not a consumption mandate. Chapter 3 will further explain blend ratio calculation issues and determine ratios using actual ethanol and motor gasoline consumption.

***Deciphering Renewable Identification Numbers***

Obligated parties to the RFS comply in the least cost manner available by blending biofuels and using renewable identification numbers (RINs) that ensure they fulfil the mandated blend requirement of the RFS. Every gallon of biofuel in the United States has at least one unique RIN that is assigned to it and is separated at the end of the supply chain when it is blended with gasoline or diesel (McPhail, Westcot, Lutman, 2011). The RINs are then submitted to the EPA as proof of compliance with the RFS. If a blender exceeds its mandate, it has the ability to keep the excess RINs for compliance in the next year or sold to other blenders.

Due to the RFS being calculated in ethanol equivalent gallons, RIN prices are in dollar-per-gallon-of-ethanol equivalent.[21] Each RIN type has a D Code as shown in the final column of Table 2.1 based on fuel type and GHG reduction amount. Cellulosic biofuels generate D3 (biogasoline) or D7 (biodiesel) RINs based on fuel type which both qualify for the cellulosic biofuels mandate although due to relatively small amounts being consumed the remaining

[21] Even BBD RINs are on the market in ethanol equivalence.

discussion in this thesis will not delve into such details.[22] The BBD mandate requires D4 RINs for compliance and can be filled with both biomass-based diesel and qualifying non-ester renewable diesel and requires GHG reduction of 50 percent. Other advanced biofuels outside of BBD such as sugarcane ethanol, naphtha, and biogas generate D5 RINs.[23] Corn ethanol only qualifies under the D6 category where GHG emission reductions are required to be a minimum of 20 percent for new plants being built (Schnepf & Yacobucci, 2013).

RIN demand comes from parties bound to the RFS who find it less expensive to buy separated RINs than to obtain them by purchasing and blending biofuel. RIN supply can come from obligated parties who blend more biofuels than required, and thus have more RINs than needed for compliance, or from non-obligated parties. Blenders value RINs as the price required to not have to blend that gallon of biofuel or to blend excess amounts. According to that principal, as RIN prices increase it reflects the incremental cost of not blending that biofuel or anticipating future compliance regulations.

Biofuel producers are allowed flexibility under RFS to build up a surplus of RINs by producing or purchasing more than their specific obligation and are allowed to carry a maximum

[22] An important point in the cellulosic category is that in any year that EPA waives any part of the cellulosic RFS, blenders have an option to buy their way out of blending instead of actually blending (U.S. Congress, 2007; and Tyner, 2010). To buy out of blending, obligated parties must purchase a credit from the EPA plus purchase an advance biofuels RIN. The price for the credit in 2013 is $0.42/gal., and the November 20, 2013, price of an advanced biofuel Renewable Fuel Identification Numbers (RIN) was $0.21/gal. Thus, the total cost of buying out of the RFS obligation would be $0.63/gal. Converting that to gasoline equivalent, assuming it would be valued on an energy basis, would make it $0.95/gal. As of November 20, 2013, wholesale gasoline was $2.66/gal., so the maximum one would pay for cellulosic biofuel is $3.61/gal gasoline equivalent. At present, there is no cellulosic biofuel available for that price. The consequence of this “off ramp” is that the cellulosic part of the RFS may not really be a binding mandate. Through the waiving of the cellulosic mandate, it is essentially creating additional mandates on BBD and advanced (sugarcane ethanol).

[23] The EPA has grandfather clauses allowing plants who utilize different production methods and feed stocks to qualify for specific mandates. There are volumes of non-ester renewable diesel that qualify for D4, D5, or D6 RINs depending usually on feed stocks going into production.

of 20% forward to the next year to help meet future compliance (Yacobucci, 2013). Blenders can also carry a deficit into a following year provided they make up the deficit by purchasing RINs or producing more biofuel to equalize their debts. Carrying over RINs is an important ability to meet future requirements depending on blender forecasts for profitability and blend ratios. Banked RINs can impact RIN prices if there are surpluses or shortages of RINs due to blender's expectations. Corn ethanol has traditionally generated the largest amount of carry over RINs due to other biofuels capacity catching up the mandates.

The conventional literature regarding RINs and the mandate structure focus on the individuality of each mandate and the relative lack of interactions between them (Thompson, Meyer, & Westhoff, 2009).[24] A constant feature is RIN prices are determined within each mandate and fuel market and it greatly simplifies how to understand it. While this literature has been often been accurate and explains prices at certain times, in a new era of interacting RINs this literature must be further explored and deciphered.[25]

The D6 RIN (the majority of volume comes from corn ethanol) price is the opportunity cost to blenders to make up the difference between the market price of gasoline, $P_G$, and the consumer demanded price of ethanol, $P_E$ plus the ethanol tax credit when in effect, $t_c$. The D6 RIN price only has value in theory if $P_E$ is greater than $P_G$ (Babcock, 2012). Using ethanol as an example, Equation 2.1 calculates what the D6 RIN price, $P_{D6}$ should theoretically be according to its blending margin.

$$P_{D6} = P_G - P_E + t_c \tag{2.1}$$

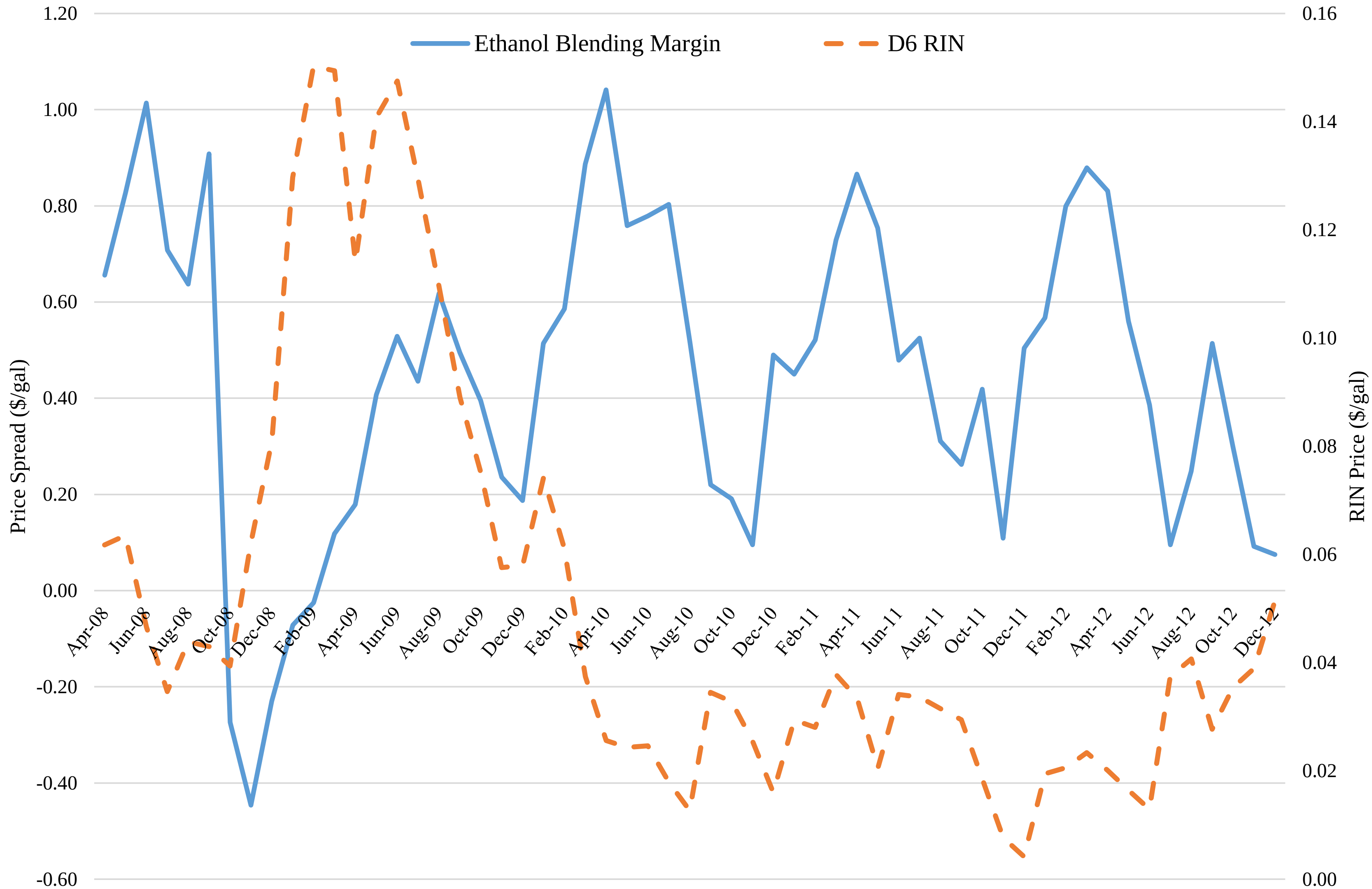
[24] (Irwin and Good, 2009) recognize the blend ratio for gasoline in 2013 exceeds the blend wall and implicitly forces blenders to use BBD to help reach their obligations. In addition, equalizing RIN prices show the tightly binding blend wall issues.
[25] D4 and D6 RIN prices are currently equal to each other.

Additionally, theory states that this RIN price applies to each gallon of biofuel produced, regardless if it is the first or the last produced during a calendar year and is paid to blenders who are willing to exceed their mandates and sell those excess RINs (Thompson, Meyer, & Westhoff, 2009).

Market data provides evidence of Equation 2.1 being accurate in the years leading up to 2013 and is reported in Figure 2.6. An initial glance at the figure reveals an inverse relationship between the D6 RIN price and ethanol gasoline price spread which makes sense according to economic theory. Ethanol can potentially become market competitive when gasoline is priced higher and results in D6 RINs having no value.[26] When the price of ethanol is priced higher than gasoline, blenders value D6 RINs to help recoup losses from exceeding their mandates as seen during early 2009. While loses to blenders reached nearly $0.20 per gallon, RIN values increased to $0.15 showing the theory works well. At the end of 2012 D6 RIN prices are less than 6 cents as blenders still value RINs for their intrinsic value, mainly they have value in the options future sense and are tradable. In addition, blenders in remote areas of the U.S. without easy access to ethanol supply will pay other blenders to exceed their obligations creating RIN demand.

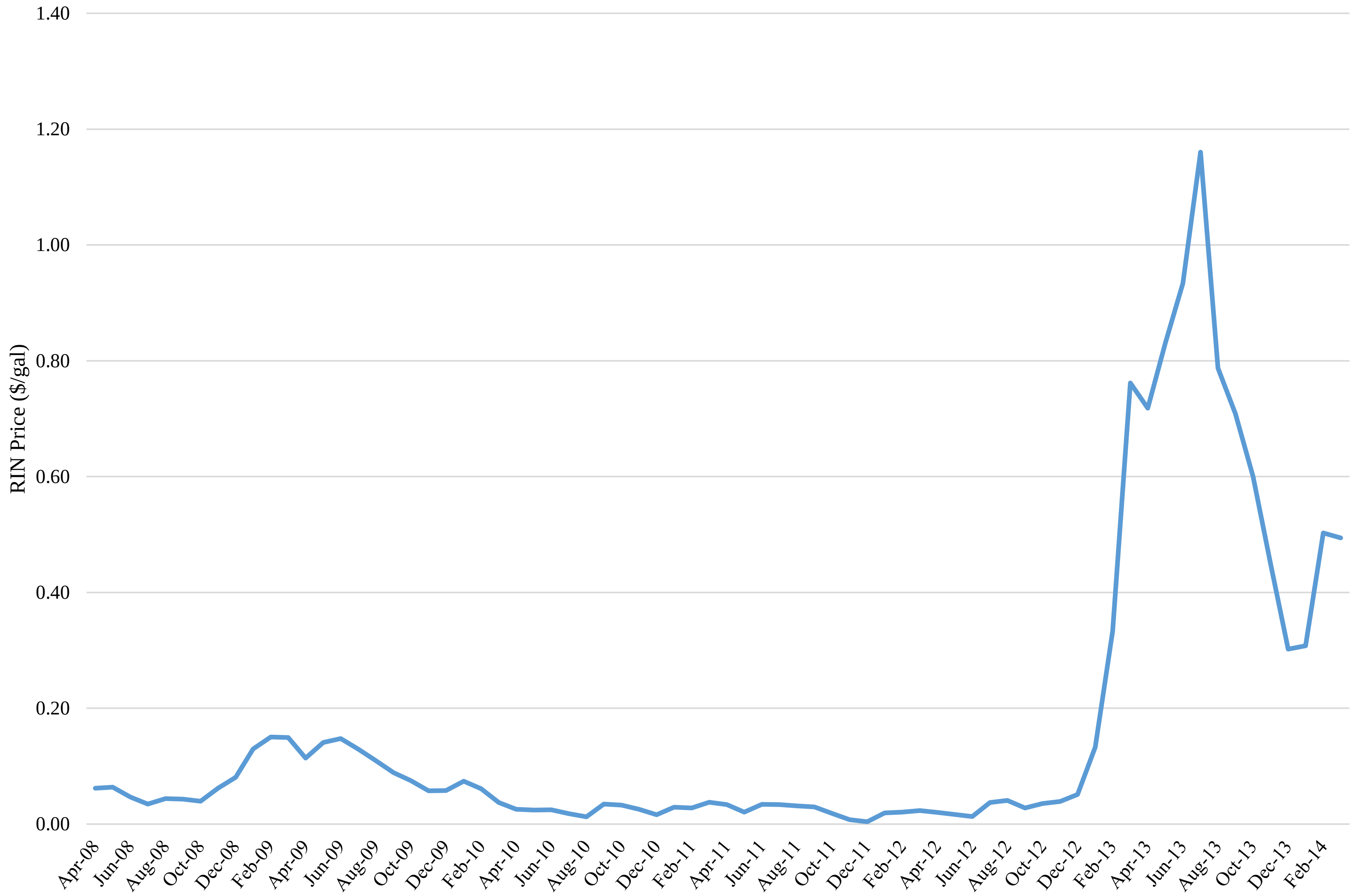
[26] Introduces a new issue, a gallon of ethanol only contains ~70% of energy relative to gasoline so the price of ethanol must reflect energy differential.

Figure 2.6. Pre 2013 D6 RIN Prices versus Equation 2.1



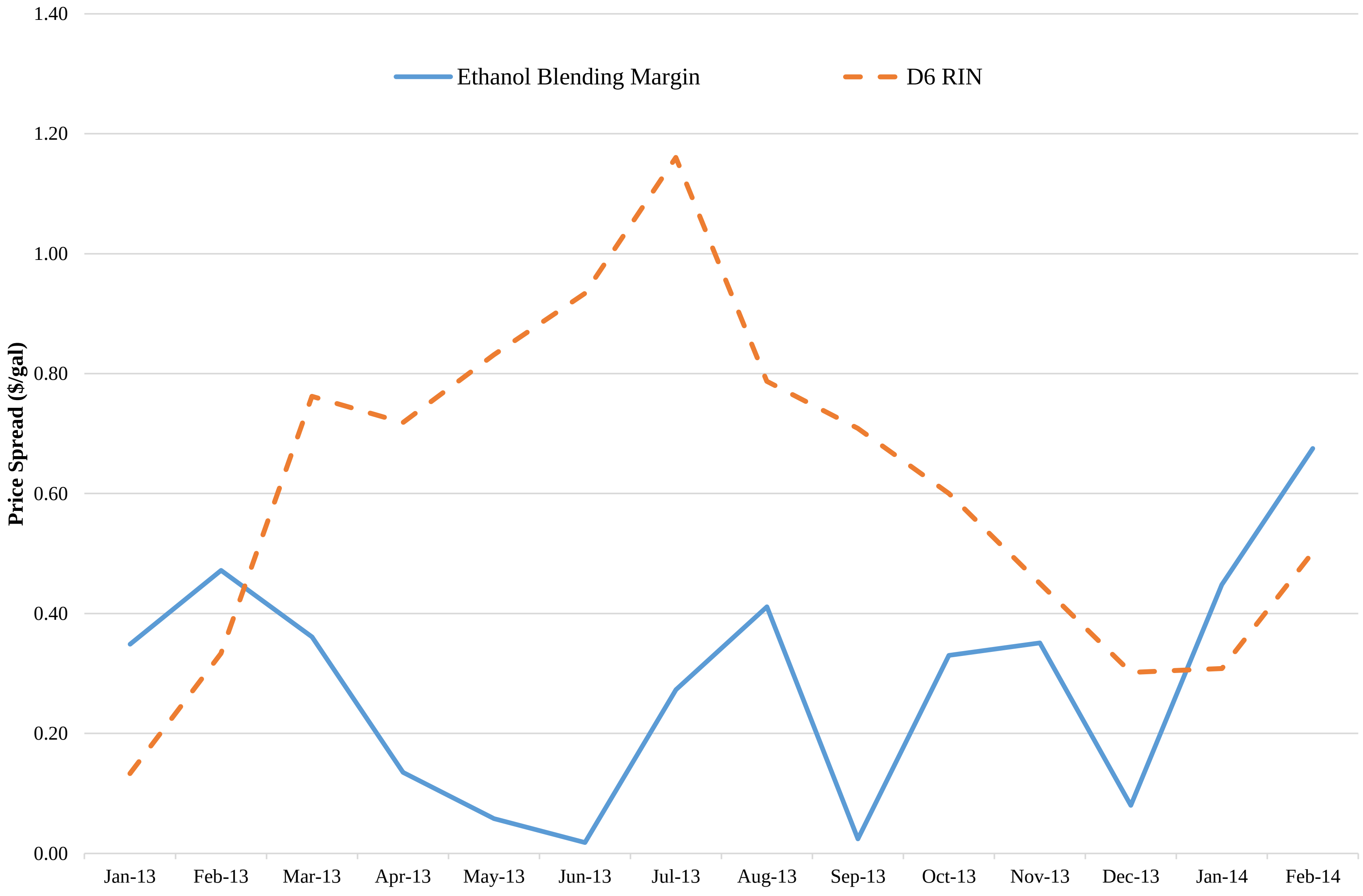

Source: OPIS (2014)

Figure 2.7. Corn Ethanol D6 RIN Price: What Changes in 2013?




Source: OPIS (2014)

Figure 2.8. 2013's New Era of D6 RIN Prices




Source: OPIS (2014)

While this ethanol formula and theory holds relatively true for a long period, a fundamental shift occurs in 2013 in the whole fuel market. Figure 2.7 shows the drastic shift in 2013 as D6 prices start to climb rapidly even though the underlying fundamental market theory, the price of gasoline minus ethanol, has not changed. Figure 2.8 provides evidence of a new era for D6 RIN prices as the blending margin never becomes negative for ethanol blenders even though prices climb to nearly $1.20 per RIN. Clearly, there are some sort of new interactions within the RFS structure and fuel markets that has not been experienced until 2013. So far we have just considered D6 RINs and now introduce RINs that impact the RFS with a multiplication factor and can count over several mandates.

The equation for determining biodiesel D4 RIN prices is similar to the ethanol equation introduced earlier, the D4 RIN price,$P_{D4}$, is equal to the price of diesel, $P_D$ minus the price of biodiesel, $P_B$ with a tax credit $t_c$ added in. The tax credit in biodiesel has played an important part in inducing blenders to use it. The tax credit increases blenders demand to pay for biodiesel by the exact amount of the tax credit $t_c$ (Babcock, 2011).

$$P_{D4} = -1 * \left(\frac{P_D - P_B + t_c}{1.5}\right) \tag{2.2}$$

Because prices in the numerator of Equation 2.3 are per actual biodiesel gallons and $P_{D4}$ is given in per ethanol equivalent, the entire term must be divided by its 1.5 equivalent factor to calculate the true D4 RIN value on the market and multiplied by negative one to make comparisons easier (Babcock, Moreira, & Peng, 2013).[27]

[27] This is assuming the majority of BBD comes from ester based biodiesel with equivalence value of 1.5.

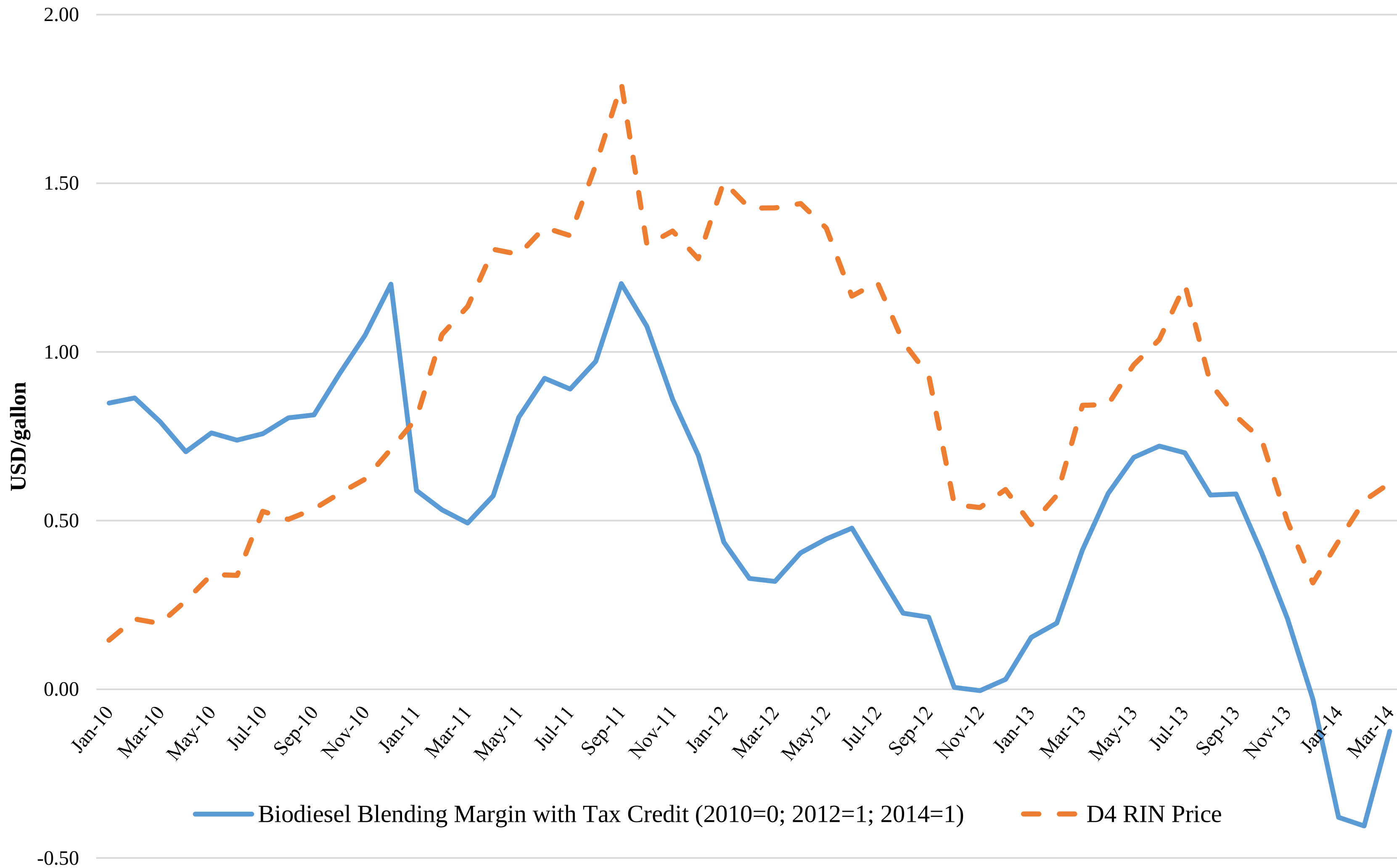
Equation 2.2 is used for the formula in Figure 2.9 which does a good job of predicting the BBD RIN price, $P_{D4}$, for the years in question. In 2010, blenders were without the tax credit and so $t_c$was equal to zero in the formula. The year 2011 had the tax credit in effect and was equal to 1. Again in there was no tax credit in 2012 and blenders went the entire year without it. Evidence from the D4 formula shows that when tax credit is left in the formula for 2012 it predicts very accurately (Babcock, 2011). This means producers anticipated the re-enactment of the tax credit with reasonable certainty and for 2014 re-occurs. We assume that the tax credit will be reinstated and blenders anticipate that. The consistent gap of D4 RIN prices exceeding the model is explained as intrinsic value, the value of time in the futures market means they will consistently exceed what the model predicts due to the potential to have more value in the future (Irwin, 2013). While ethanol D6 RINs have been sharply affected in 2013, D4 RINs continue to be determined by their respective blend margin. This issue is very important and will be explained in later chapters.

When RIN prices are reported, they are provided in ethanol equivalent values because of how blenders must comply with their RFS obligations. Figure 2.10 provides data on the three main categories of RINs that are traded according to market prices: biodiesel (D4), advanced (D5), and ethanol (D6) (OPIS, 2014). According to economic theory, biodiesel (D4) RINs must be worth at least the value of D5 and D6 RINs because it can meet both non-cellulosic advanced and overall mandates. Traditionally D4 has traded at a large price premium over other RINs due to biodiesels large price discrepancy relative to diesel as blenders need incentives to blend excess amounts. Advanced D5 RINs have traded in the middle range of D4 and D6 and this makes economic sense as they can meet both advanced and the total renewable fuels mandate. The final category, D6 RINs, have traditionally been extremely low priced and typically used entirely by corn ethanol as explained earlier. Figure 2.10 shows that substantial price spreads that existed in RIN markets until 2013 when the markets converge for the first time. The fact that they have converged and have been strongly correlated since the start of 2013 and into 2014 is very important and will be the focus of the remainder of the thesis.

This chapter has summarized the very complicated and convoluted Renewable Fuel Standard that is administered by the Environmental Protection Agency. The lack of consistency in EPA information that is released causes a lot of improper economics to be done. This chapter serves to cut through the dense shroud and provide an easy to understand explanation of how the nested structure allows for multiple compliance pathways for blenders. In addition, the nested structure allows biofuel spillovers into other mandates and therefore RINs equalizing is not shocking but what it tells the market is extremely important. Another important distinction is showing the proper way to model the RFS as a blend mandate and not a consumption mandate as many other economists view it. Finally we explain RINs and how historically they have been priced significantly differently although 2013 a market shifting dynamic occurred.

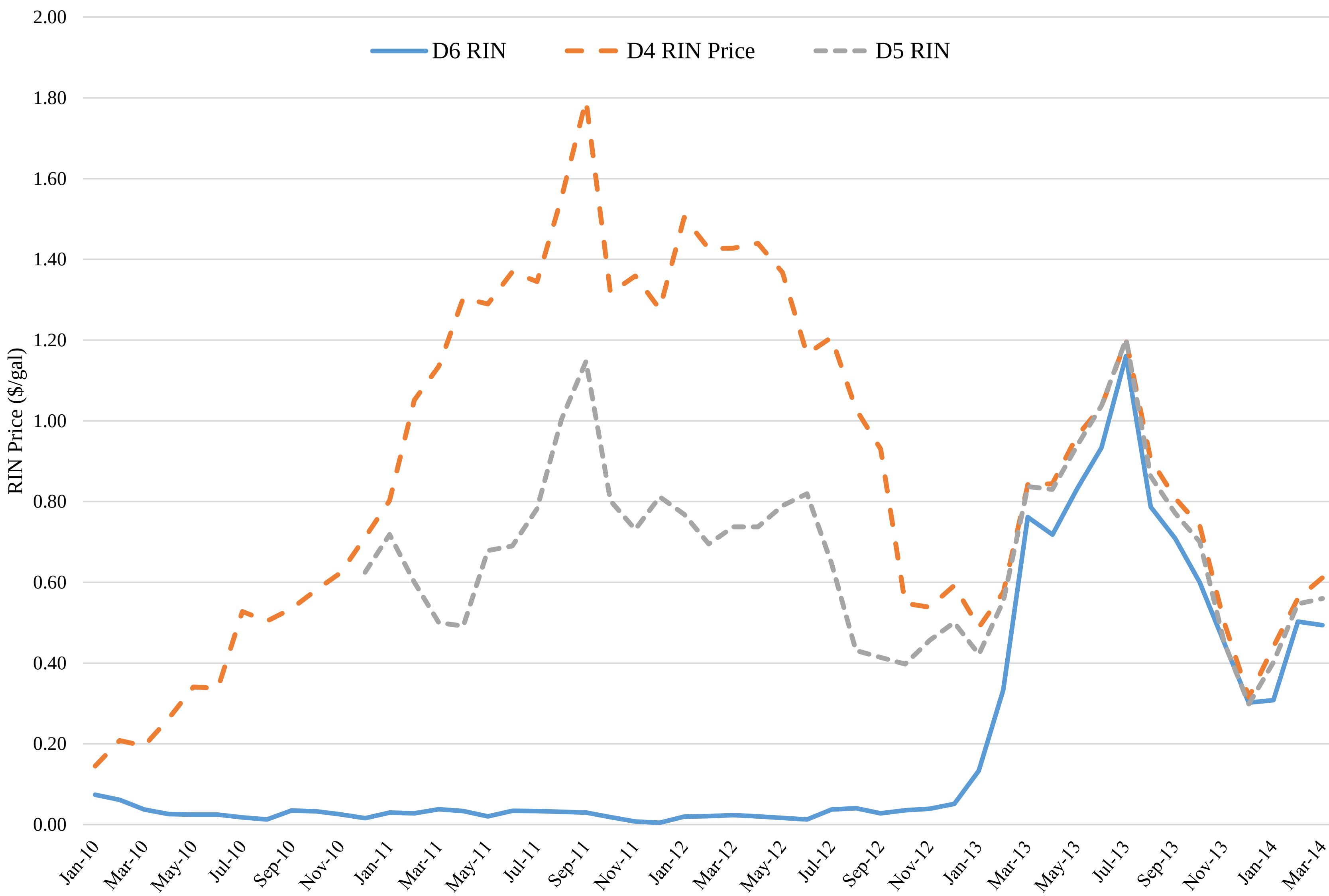
During the year 2013 many firsts occurred in the biofuels markets. This paper will now determine what is happening with RIN prices and how ethanol and biodiesel markets begin to interact. As RIN prices have equalized it has led to many unforeseen effects of biofuel usage and impending costs to American fuel consumers. The mandate interaction takes place because of the E10 blend wall which will be explained in the next chapter to which we now turn.

Figure 2.9. Biodiesel Blending Margin Net of Blenders' Tax Credit and D4 Biodiesel RINs Price




Source: OPIS (2014)

# Figure 2.10. Historical RIN Prices




Source: OPIS (2014)

# CHAPTER 3

# THE ECONOMICS OF THE BLEND WALL

## *A Simple Model of the Blend Wall*

The 'blend wall' refers to potential engine damage that can occur in vehicles when using gasoline blends with greater than 10 percent ethanol.[28] Prior to 2013, the required blend for ethanol was very close too or less than 10 percent, but in 2013 the mandated blend ratio was at 11.07 percent, causing the blend wall to become an issue.[29] Provided blenders did not want to breach the this 1.4 billion gallon shortfall between the total renewable fuel volume and forecasted ethanol and biodiesel consumption as described in Chapter 2 for 2013 with ethanol it would necessitate additional biofuel blending (non-ethanol) or using stored RINs (de Gorter, Drabik, & Just, 2013). Historically, corn ethanol has filled the majority of the renewable fuel gap and if this is what happened in 2013, the blend ratio of ethanol would have been approached the calculated mandate ratio. Ethanol production during 2013 was still strong but excess ethanol production that could not be consumed domestically was exported (not counted towards the RFS) (Meyer & Paulson, 2013). But we will show there are multiple ways the blend wall can be overcome.

Some economists consider an average of 9 percent to be the effective blend ratio maximum across all areas and seasons (Tyner and Viteri, 2010; Tyner, 2009; Tyner, Dooley, Hurt, & Quear, 2008). According to this theory, the blend wall has been in effect since 2009 although Figure 2.3 clearly illustrates actual ethanol blend ratios were 9.33%, 9.61%, 9.66%, and

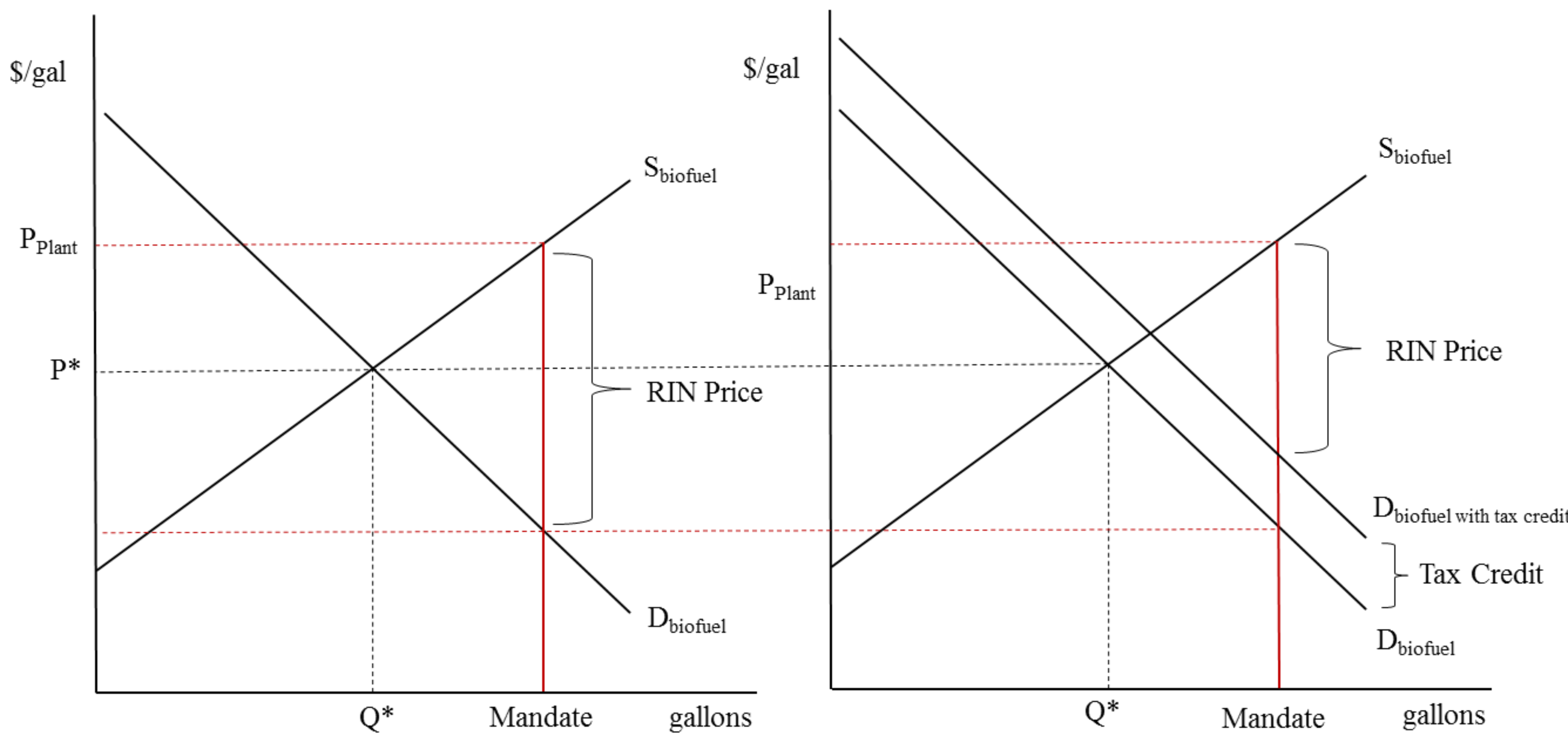
[28] The remainder of the paper will assume blend ratios use formula (E/E+G) as used by de Gorter and Just, 2009.
[29] As calculated in Chapter 2 using EIA and EPA forecasts.

9.77% in 2010, 2011, 2012, and 2013, respectively. Comparing the actual blend ratios to the mandated illustrates the large gap between what blenders have traditionally done and 2013. So why didn't D6 RIN prices skyrocket earlier then 2013 as shown in Chapter 2 if the blend wall was actually binding before? The nested mandate structure of the U.S. RFS allows blenders to use biofuels that are higher up the mandate structure (e.g., BBD or sugarcane ethanol) to push corn ethanol out of the renewable fuel gap. We show that blenders utilized increased amounts of biodiesel to help breach the blend wall. But first, we give a simple model of the blend wall to motivate the discussion.

The simplest economic thought on RINs can be represented in a supply and demand graph in Figure 3.1 showing how conventional literature determines their respective prices.[30] If the mandate is binding, there will be more biofuel produced for a higher cost than consumers will pay as shown in the left-hand panel (Babcock, 2012). The mandate enforces a certain amount of biofuel that must be produced over and above what a free market demands ($P^*$, $Q^*$). The price difference between the supply and demand curves at the mandated amount is known as the RIN price (Thompson, Meyer, & Westhoff, 2009) (Babcock, 2012). Consumers are price sensitive and unwilling to purchase biofuels for more than the market price of gasoline or diesel.[31] The right-hand panel considers when a tax credit exists and shifts blender's willingness to pay up by the amount of the tax credit.

[30] While ethanol does not have an explicit mandate, it can be implied that one essentially exists as advanced biofuels cannot currently fill the entire renewable fuel gap.
[31] In addition, the difference in mileage between gasoline and diesel, and ethanol and biodiesel, respectively, must be taken into account.

Figure 3.1. Conventional Literature determining the RIN Price on a Binding Mandate




Source: based on Thompson et al., 2009

Let us make it clear from the outset: RINs are not a maximum like a production quota or cap & trade permits. Rather, the ethanol mandate is a minimum blend ratio (RINs have value only for the ethanol blended beyond the required minimum). If a firm blends less than the minimum, it does not free up a RIN (unlike with a production quota or cap & trade permit system). For a production quota or cap & trade permits, their value is on the total quotas or permits. The economics are very different. A RIN is freed up only if you blend above the minimum required. That RIN can be sold to some firm who blends less than the minimum (otherwise, the RIN has no value). Of course, the RIN can be stored and sold later but same concept; it is just that the buyer of the RIN is going under the blend requirement in some other time period. If a firm buys a RIN to blend less than the minimum required, some other firm had to have blended more than the minimum to generate that RIN in the first place.

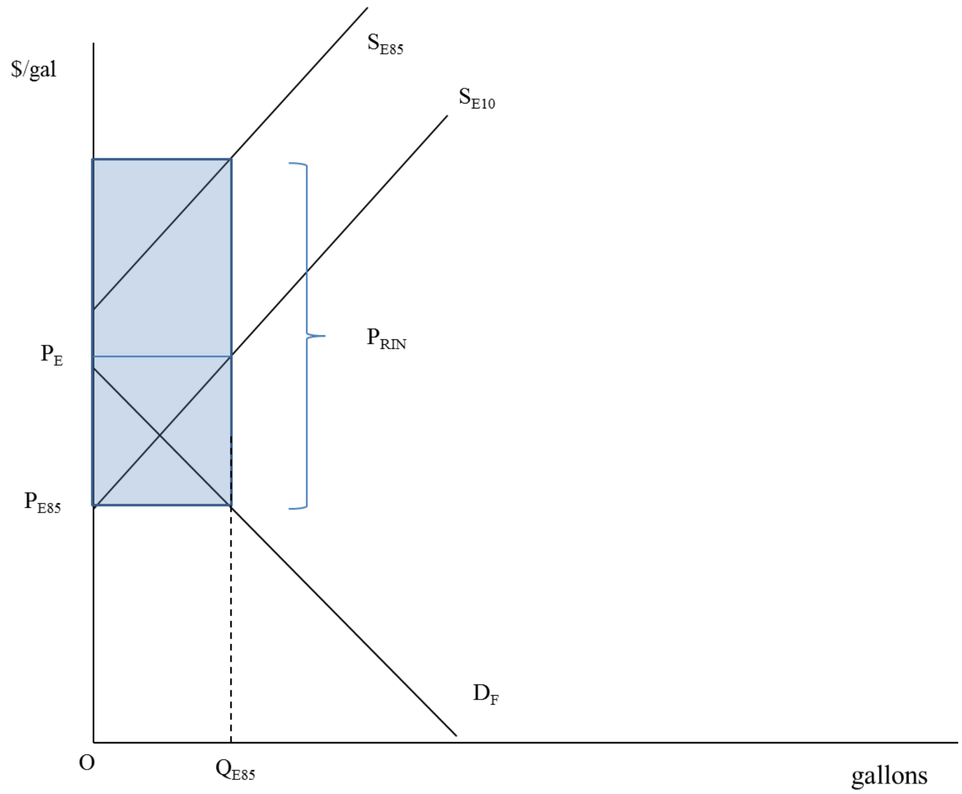
A RIN is required for every gallon of ethanol blended with gasoline as proof to the EPA you are blending the minimum required (and these RINs are forfeited or "retired" to the EPA – they are not kept and sold on the free market). The RIN has an opportunity cost only if the firm blends more than the minimum required (when it does not have to be forfeited to the EPA and so the firm has a "free" RIN to be sold now, later or used later). So the RIN price reflects the cost of compliance: differential costs of each firm to meet the minimum blend requirement. The more homogenous the cost structures, the lower the price of RINs (and the fewer traded presumably, independent of speculators).

To understand the basic economics of a blend wall, let us begin with a very simplified world where there is only corn ethanol and E85 is the only way to breach the blend wall. When the blend wall is reached (less than 10 percent but that is irrelevant in this simplified analysis), the value of a D6 RIN has to increase to pay E85 producers and consumers to increase E85 supply (infrastructure of E85 stations, increased cost of marketing, etc.) and demand (increase the number of flex cars, more fuel per flex car). [32] High D6 RIN prices reflect blender's willingness to pay others to exceed their obligated volumes. In this way, the aggregate blend ratio is satisfied. According to theoretical determination of D6 RIN prices, the underlying fundamental is the price spread of gasoline and ethanol; although in 2013 the price of gasoline is at a significant premium to ethanol and D6 RIN values should only have intrinsic value (approximately 1-4 cents).[33]

High D6 RIN prices mean consumers of fuel (E10) pay the cost (e.g., in form of higher priced E10 Fuel) to have ethanol produced above 10 percent consumed by flex fuel vehicles using E85. The D6 RIN prices mostly reflect the costs of having to sell ethanol outside the established E10 market. In order to induce more E85 sales (incl. more E85 stations and flex cars) consumers require a 75¢/gal discount just to get E85 mile equivalence to E10 (Babcock & Pouliot, 2013).[34] The result for consumers using E85 is less miles travelled per gallon, filling up more often, and a relatively low amount of stations equipped for sale. Babcock also finds that to get flex fuel vehicles owners to choose E85 a further discount of 15 percent is required over the equalized cost per mile travelled (2013). Most of these stations are located in the Midwest where the majority of ethanol is produced and unsurprisingly where the lowest E85 prices are.[35]

[32] Approximately 3 percent of vehicle fleet in the U.S. are flex fuel (EIA, 2014).
[33] E85 ranges from 30-70 percent ethanol depending on seasonal variation in fuel specifications, we use a miles equivalence factor of 0.799 for pricing E85 relative to E10. It other words it means the price of E10 must be discounted approximately 20% to reach an equivalent E85 price.
[34] According to EIA the current national average gasoline price is $3.547 per gallon, hence a discount of $0.717 is currently needed to reach energy equivalence of E85 relative to E10. Therefore, if E85 is priced at $2.83 per gallon, it is equal to E10 on a miles equivalent basis.
[35] Nationally only 2 percent of all retail stations offer E85 (EIA, 2014)

Figure 3.2. E85 RIN Market

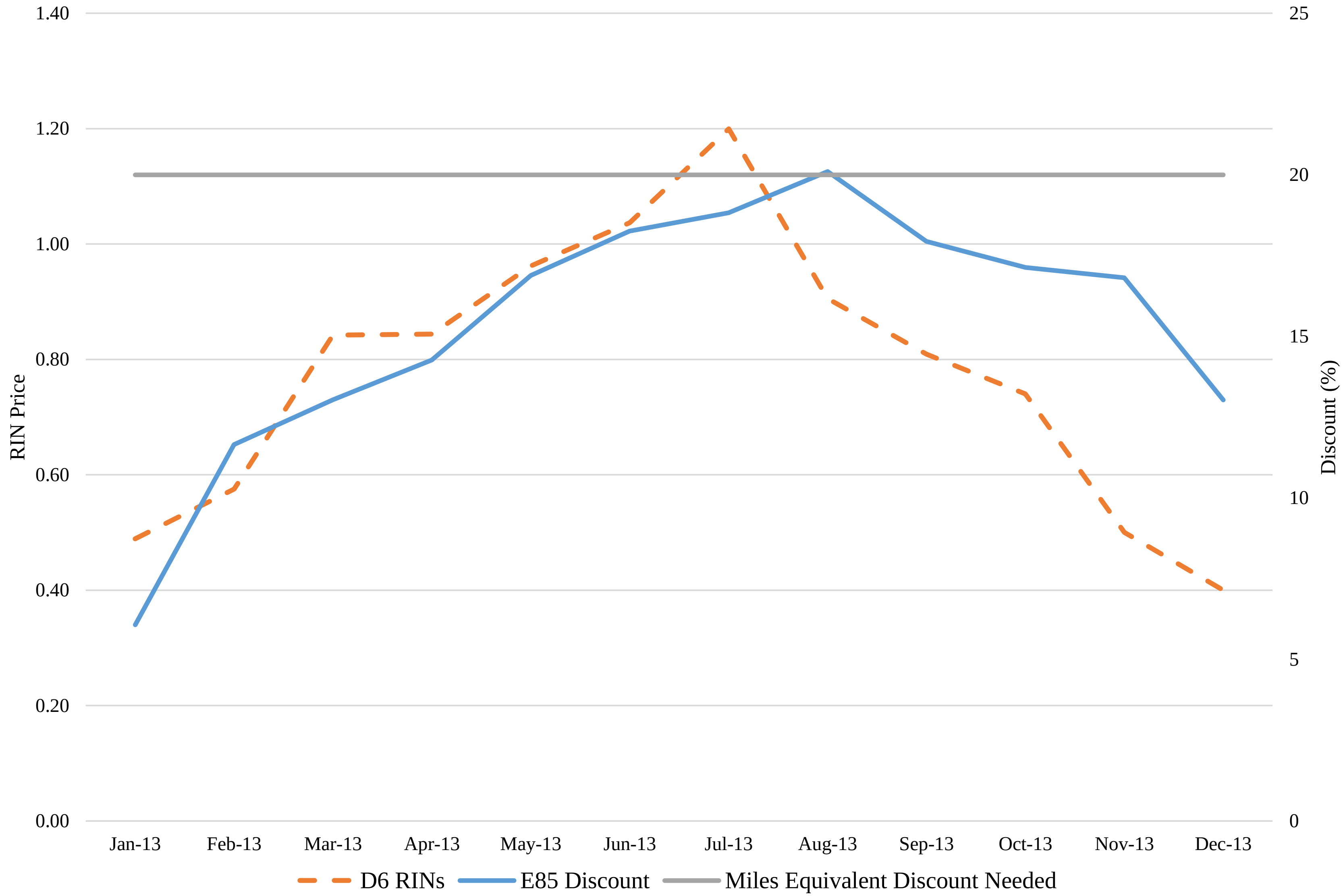



The blend wall is a special case as it represents a maximum for E10 cars but the required blend is greater than 10 percent. The RIN price now reflects the same underlying relative compliance cost between firms except this time it includes the differential costs of E10 versus E85; some have no capacity to sell E85 so differential costs between firms are now higher (plus part of RIN price to induce more E85 sales so existing E85 cars have to buy more (and higher ethanol to gasoline ratios), more E85 cars have to be sold and more E85 stations have to be built. Because E85 contains more ethanol than E10 it generates more RINs for the blender who is able to pass along price discounts and E85 becomes relatively cheaper to E10. Figure 3.2 exhibits the simple model of the blend wall using higher blends of ethanol to breach the blend wall. If there is no blend wall, $P_{RIN}$ will be equal to the distance between fuel demand and E10 supply to induce excess consumption over the free market. When the blend wall becomes a constraint for blenders, a higher RIN price is needed to increase supply of E85. In this model, the D6 RIN price is a tax on E10 to help subsidize an increase in the supply and demand for E85, perhaps even providing a discount to consumers for E85 on a miles per gallon basis. Essentially, high D6 RIN prices are supposed to induce consumers to buy E85 at a discount in order to be adopted in greater volumes and help to breach the blend wall.

As shown in the previous chapter, the price of D6 RINs start to immediately increase in January 2013 (see Figure 2.10). Blenders buy excess D6 RINs to avoid blending additional ethanol over their E10 blend limit. The discount of E85 relative to E10 is shown in Figure 3.3 versus the price of D6 RINs for 2013. Because the blend wall is binding for 2013, the D6 RIN price should be positively correlated with the price discount of E85 relative to E10 because the higher the RIN price, the more blenders can discount E85 and increase consumption. They track very closely allowing E85 to be discounted until August when RIN prices fall substantially more than the E85 discount. When the RIN price falls, blenders are not able to tax E10 to subsidize E85 price discounts to maintain the 20 percent discount necessary for miles equivalence to occur. If the blend wall is still in effect why does the D6 RIN price fall so quickly and drastically? To this we now turn.

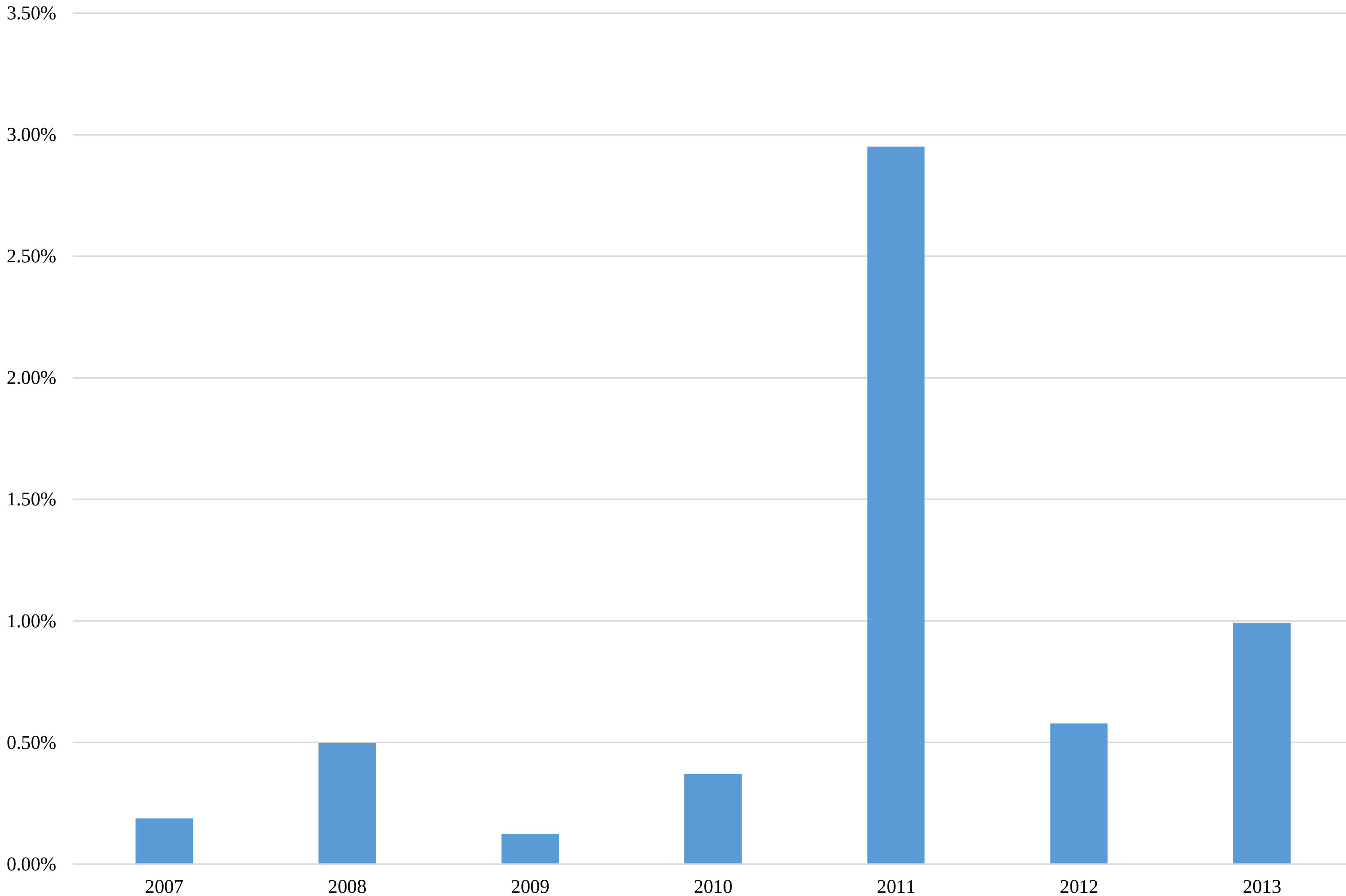
Collecting accurate up to data on the consumption of E85 in the United States is very tricky. Certain states with high consumption like Minnesota and Iowa keep track of statewide consumption reasonably well. Nationally, the EIA releases data but are currently waiting to release more accurate survey yearly results from 2012. Babcock and Pouliot calculated that 500 million gallons of E85 capacity exists within the U.S (2013). Figure 3.4 shows an approximate EIA consumption data for E85 since 2007. Overall, the amount of ethanol being blended as E85 is very small relative still to overall ethanol consumption, less than 1 percent.

Figure 3.3. 2013 E85 Discount versus D6 RIN Prices




Source: OPIS, calculated

Figure 3.4. E85 Consumption relative to Total Ethanol Consumption




Source: EIA

If we continue to assume ethanol is capable of breaching the blend wall with only E85 price discounts, than we would assume D6 RIN prices to stay high according to equation 2.1 in Chapter 2 because gasoline is still priced at a premium relative to ethanol. As discussed further in Chapter 2, D6 RINs cannot be valued at more than a D4 RIN or else a rational blender would switch to the lower cost option immediately. What this means is that biodiesel D4 RINs set the margin with respect to the ability to discount E85 with higher valued D6 RINs (Irwin. 2013). This is a very important distinction to make because it brings the roles of mandates and multiplicative factors even more strongly into the conversation. Essentially, D4 RINs continue along their blend margin and implicitly set the amount of discount that E85 consumers can receive. While acknowledged by Good and Irwin, there needs to be more research and analysis on the impact that biodiesel now holds over ethanol with a binding blend wall and what this means into the future if the ethanol mandate is expanded (2013). While most economists agree the RIN market is influenced by prices of its inputs (i.e., gasoline and ethanol), the RIN market could start to influence what biofuels are blended and how they are used with respect to the RFS. It could potentially start to push up its RINs in order to pay for more E85, causing the price of biodiesel to increase as well but more research is needed.

The formal analysis of Figure 3.2 assumes that D6 RINs are the only way to breach the blend wall by inducing consumers to use more ethanol by lowering the price of E85. There are several ways around the blend wall. Blenders have the option of using banked RINs or borrowing RINs from the future. There were 2.5 BG of RINs carried into 2013, which was more than enough to eliminate the excess ethanol that needs to be sold.(EPA, 2014) However, blenders may have felt 2014 to have even tighter blending constraints, so it was likely only RINs that expired in 2013 were used (stored RINs have a 24-month shelf life). Increased E15 and E85 sales are possible as the EPA recently approved E15 for cars manufactured after 2001, but the market has not grown very much due to higher supply costs and customer resistance. Lowering the price of ethanol with higher value RINs could reduce or eliminate the amount of E0 sales. Another option is to increase the use of drop-in biobutanol which can go to E13 and each gallon counts 1.3 towards mandate (de Gorter, Drabik, & Just, 2013).

Up to now in this chapter we have just considered what is going on within the corn ethanol market and the renewable fuel gap. We understand higher D6 RIN price are needed to subsidize E85 and help breach the blend wall for consumption of ethanol. According to Tyner and Vitera, they argue that the blend wall became an issue in 2010 when the actual blend ratio exceeded 9% for the first time although the market did not react in any way to show this is the case. Data in Figure 2.4 would empirically show the blend wall is closer to 9.5 percent as it has been fairly consistent for the last 4 years. The blend wall was finally reached due to increasing mandates for 2013 which forced blenders to breach the blend wall and meet their RFS obligations though another compliance pathway.

***How the Nested Mandate Structure of the RFS helped Breach the Blend Wall***

Within the RFS nested structure, advanced biofuels have the opportunity to displace ethanol provided it is cost efficient (e.g., lowest compliance cost) for blenders. The advanced biofuel mandate is composed of BBD, cellulosic, and other advanced biofuels (mostly Brazilian sugarcane ethanol) as described earlier in Chapter 2. Sugarcane ethanol imports have been vital in filling the remainder of the advanced mandates obligations. During 2013, blenders began to use biodiesel (domestic production and imports) overage to meet the additional 1.4 BG above the ethanol blend wall which is EPA RIN generation, not actual consumption. RIN generation means some RINs can be kept for future year’s compliance if blenders exceed their mandates although

D6 RIN generation would be expected to be much higher if blenders are utilizing higher blends of ethanol instead of another pathway. Biodiesel generated approximately 750 million ethanol equivalent RINs above its mandate during 2013 and on its own nearly met the advanced mandate. When combined with sugarcane ethanol and other advanced biofuels it resulted in over 700 million advanced RINs able to spill over into the renewable fuel gap to compete with corn ethanol. There has been spill over RIN generation previously although RIN prices did not equalize until 2013. This is further proof of mandate interactions and the blend wall not being realized until then. We can now separate out the two main competitors for the renewable fuel gap for 2013, first by discussing Brazilian sugarcane ethanol and lastly biomass-based diesel.

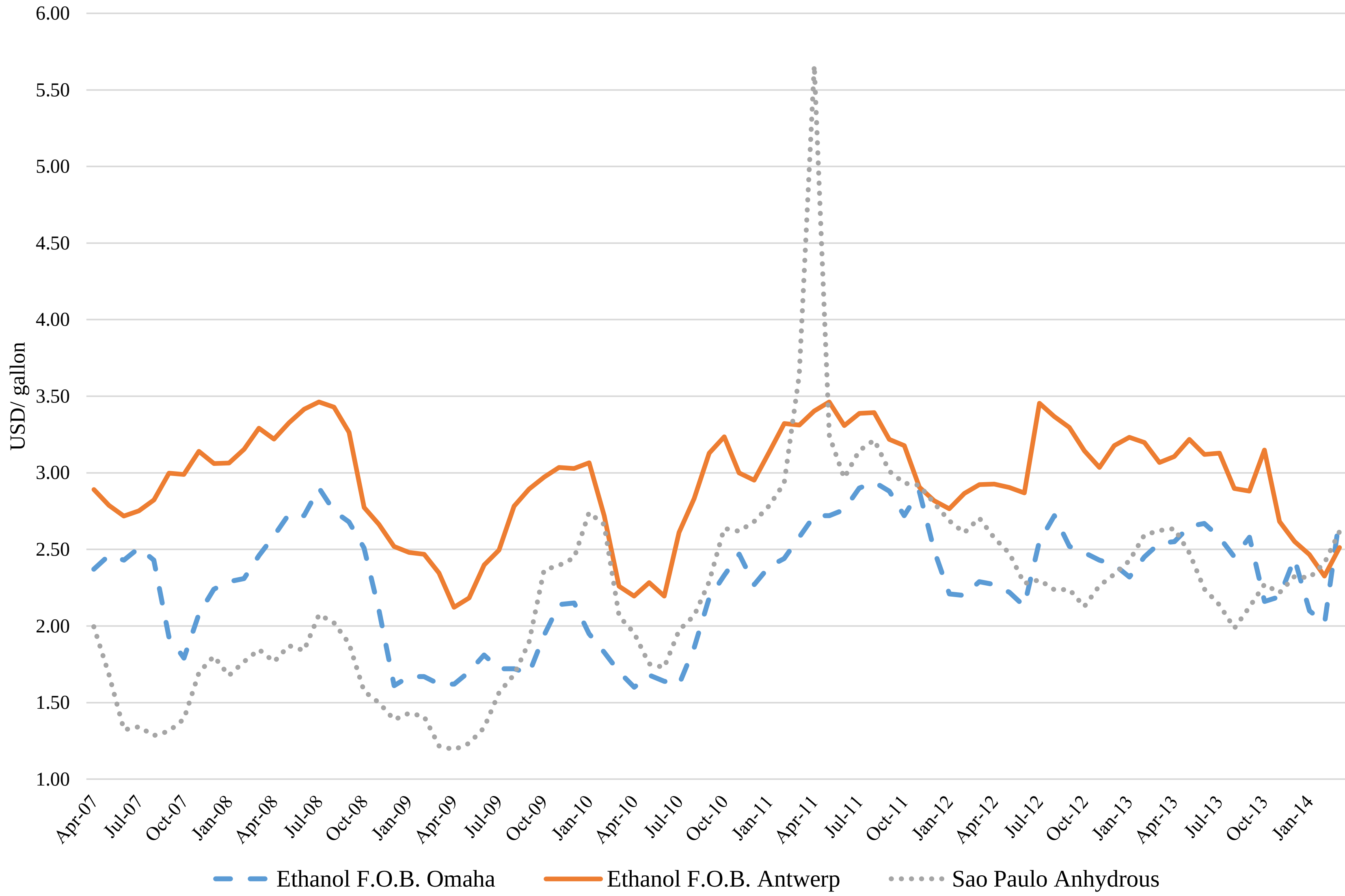
Importing Brazilian sugarcane ethanol enables blenders another potential compliance pathway primarily for meeting their advanced biofuel RFS obligations. Sugarcane ethanol qualifies as D5 advanced RINs but is physically identical to corn ethanol when blended with gasoline. The EPA's differentiation of the classification of these two identical products is due entirely to their classification of GHG reduction. The importance of this is realized when blenders try to breach the blend wall with sugarcane ethanol, which is blended at the exact same limitations as corn ethanol. The RFS mandate structure has induced intra-industry ethanol trade between the United States and Brazil on an unprecedented scale and therefore is a waste of resources as they are identical products (Meyers et al., 2013).[36] Another important impact is the price difference of sugarcane relative to corn ethanol. If the price of ethanol in the U.S. rises substantially it will impact consumption of ethanol and use of biofuels. According to Meyer et al the net result of the ethanol intra-industry trade is higher Brazilian ethanol prices, higher

[36] Bilateral trade of ethanol between the U.S. and Brazil started to develop in 2010 due to uncoordinated environmental policy between the two countries and has resulted in substantial quantities of ethanol crossing paths on the ocean (Meyers et al, 2013)

conventional ethanol prices in the U.S., and additional transportation costs. Intra industry ethanol trade between the U.S. and Brazil is increasing ethanol costs in both countries while increasing GHG from transportation.

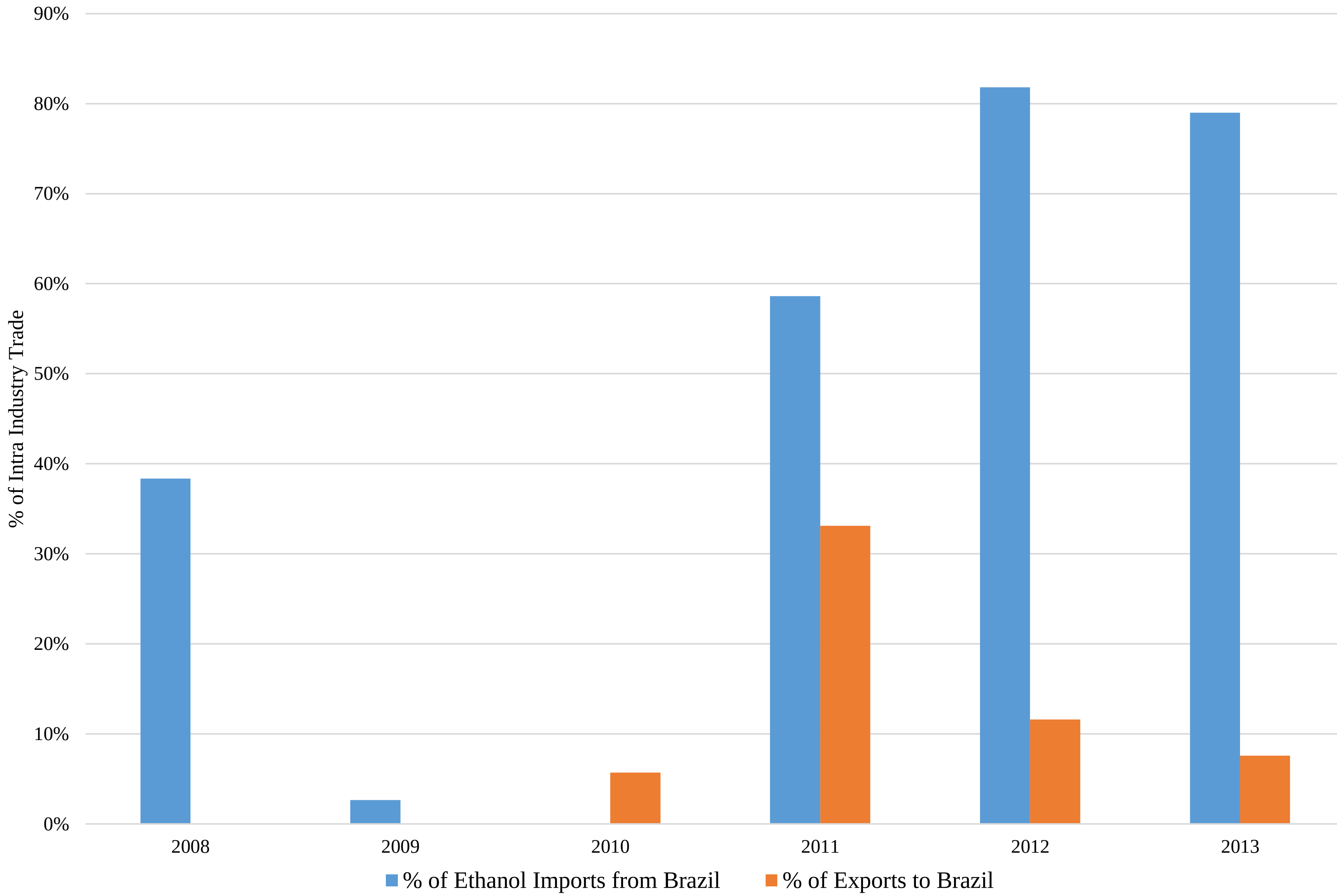
In Figure 3.5, world ethanol prices are shown for Omaha, Antwerp, and Sao Paulo in USD per gallon. While European prices have been priced at a premium relative to the other two, in late 2010 into early 2011 Brazil experienced a rapid run up in anhydrous prices due to production issues. The result was zero imports of ethanol from Brazil in 2010 and took until the end of 2011 for imports to begin again and therefore was unable to help fill the residual of the advanced mandate. As Figure 3.6 shows, nearly 60% of ethanol imports during 2011 still came from Brazil as blenders required a certain volume to help fill the residual of the advanced mandate during that year. Looking at RIN prices during this time both D5 and D6 spike as the cost of advanced biofuels became prohibitively expensive. This fact will become very important in helping to show why model prediction error occurs in Chapter 4 and referring back to Figure 2.2 shows the lack of sugarcane ethanol required BBD to expand past its mandate for the first time in 2011. The price effect depends on elasticities of supply and demand in both countries as well as market prices of fossil fuels and inputs into biofuel production which are impacted by policies in both countries.

# Figure 3.5. World Ethanol Prices



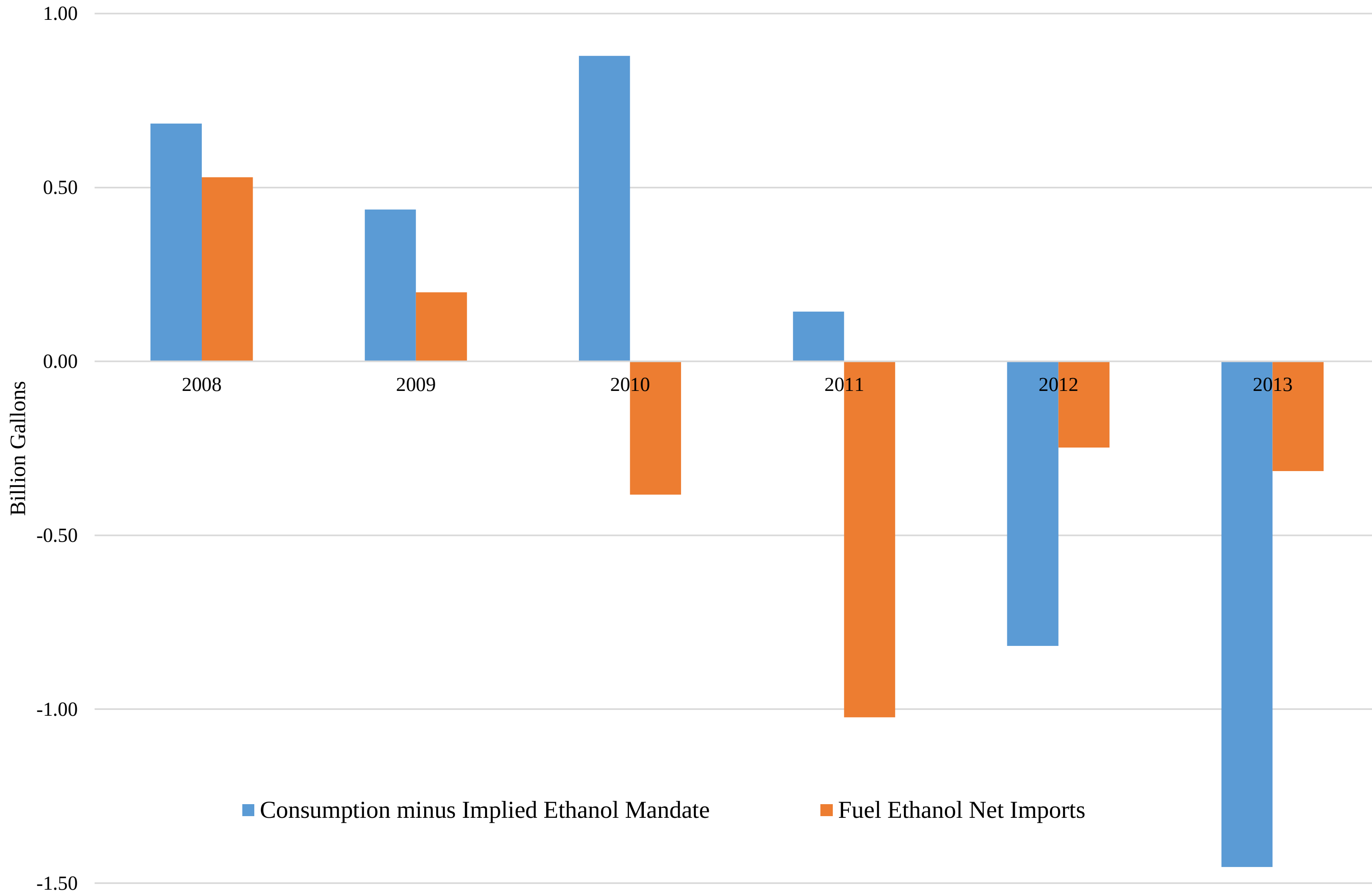

Source: EIA

Figure 3.6. U.S. - Brazil Ethanol Trade




Source: EIA

Figure 3.7. Ethanol Consumption versus Net Ethanol Imports




Source: EIA

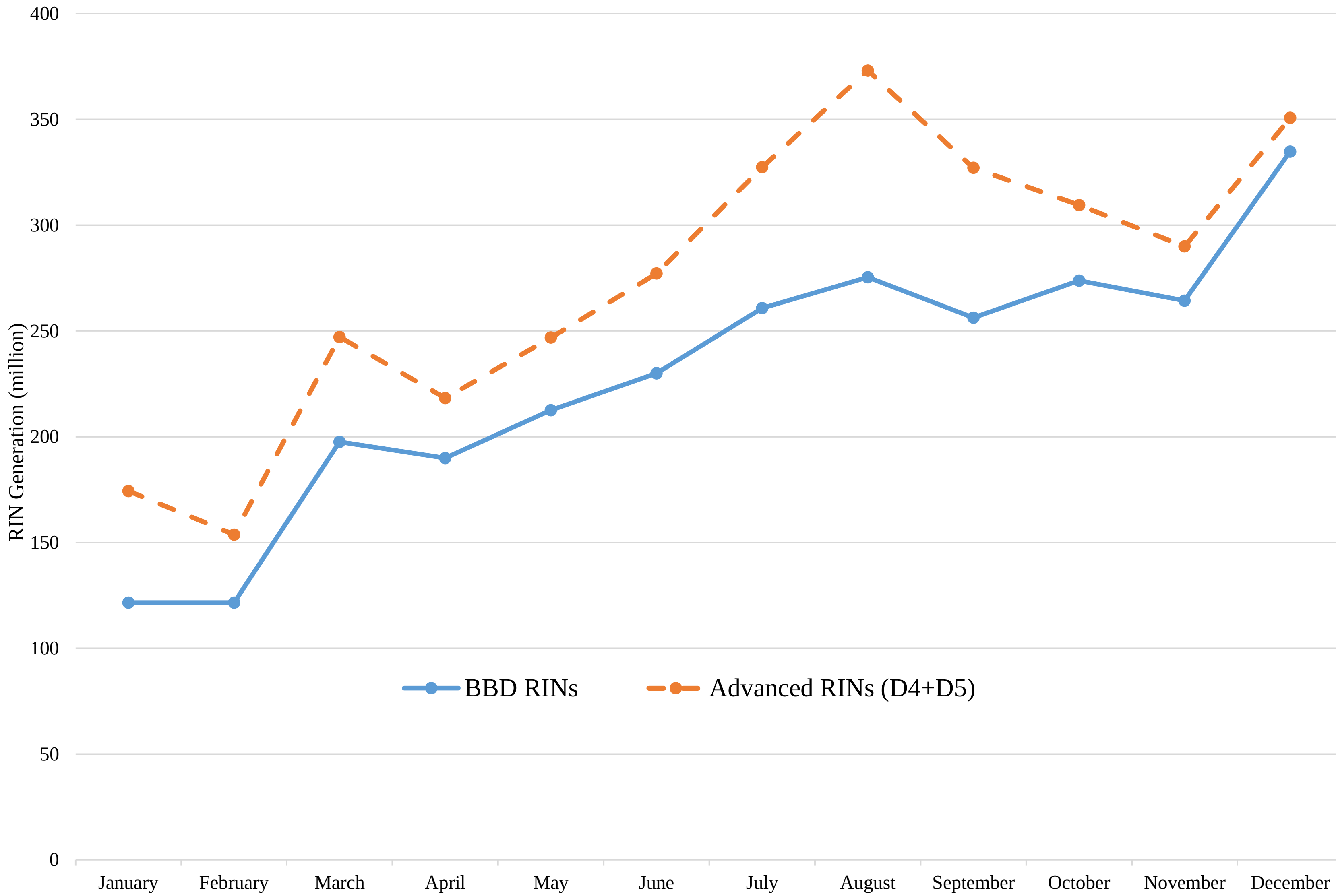
Importing Brazilian sugarcane does not make sense for economic reasons but it will continue to occur due to sugarcane ethanol being nested higher than corn ethanol in the RFS. In Figure 3.6 it shows since 2011 over 60 percent and since 2012 80 percent, of all ethanol imports have come from Brazil into the United States to count for the RFS and LCFS in California. Due to the ethanol consumption constraints in the U.S. resulting from the blend wall and over 450 million RINs of sugarcane ethanol, this means less corn ethanol can be consumed and instead must be exported in 2013. The result of the RFS nested mandate structure means domestic corn ethanol producers must export excess ethanol while more expensive homogenous products are imported and consumed by American gasoline users instead. EISA 2007 states the amount of advanced biofuels is to continue increasing so sugarcane ethanol will be counted on to help fill it while actively contributing to problems such as the blend wall. Essentially, corn and sugarcane ethanol are interchangeable and with a binding blend wall, blenders can use either product up the blend limit of roughly 9.5 percent but then again must switch to another biofuel (biodiesel) or use stored RINs.

But for 2013, BBD nearly fills the entire advanced mandate on its own as shown in Figure 2.3. This means BBD and sugarcane ethanol spill into the renewable fuel gap and displace corn ethanol due to the nested structure which is shown by the dotted black line expanding advanced biofuels. Because BBD has (for all purposes) met the advanced mandate, the side effect of importing sugarcane ethanol has is displacing corn ethanol from being consumed domestically in the United States. As shown in Figure 3.7 the United States has transitioned from a net exporter of ethanol in 2009 to a net importer ever since. This result is primarily due to the Renewable Fuel Standard and how the EPA has chosen to categorize certain types of ethanol. Until 2011 the U.S. consumed more ethanol than was mandated as we described earlier. Starting in 2012, the total RFS continued to increase as well as not waiving the cellulosic mandate put pressure on BBD as the only viable commercial biofuel to start filling parts of the advanced residual that ethanol no longer could. In 2013, blenders had 1.4 billion gallons of biofuel that had to be non-ethanol and this finally manifested itself to the extreme that RIN prices and BBD production and imports took off.

The blend mandate is a cumulative month by month obligation for blenders. As an easy to understand example of how BBD blending increased over 2013, Figure 3.5 shows biodiesel increasing nearly every month and exceeds its mandate for 2013 by over 750 million ethanol equivalent gallons. In the figure the difference between advanced (e.g., D4 and D5) and BBD RIN generation is composed mostly of sugarcane ethanol. Once BBD spills over into the renewable fuel gap, D6 and D4 RINs must equalize as fuel blenders have the option to start using biodiesel RINs or blend BBD to meet their obligations (Irwin and Good, 2013).

What this really means is the RFS worked as intended (as incomprehensible as it is) by giving blenders the option of choosing BBD to meet their obligations and lower their compliance costs. Without this option, E10 fuel consumers (the majority of consumers) would have been responsible for a much larger tax (in form of a D6 RIN price) to pay for E85 stations, flex fuel vehicles, and extra consumption of the E85 fuel. It is not clear the pressure on biodiesel and D4 RIN prices in order to for D6 to approach and stay strongly correlated. What is clear from all this that RIN markets did function to provide market clearing for blenders choosing to blend or not blend biofuels. The overall mandates have changed trade patterns within the U.S. and not due to market dynamics. The RFS is driving these changes and with continued increases planned until 2022 it is possible that different trade patterns will emerge as different mandates become limiting.

Figure 3.8. 2013 EPA RIN Generation




Source: EPA (2014)

# CHAPTER 4

# MODEL OVER PREDICTION ERROR

This chapter focuses on the model created by de Gorter, Just, and Drabik on predicting soy oil (de Gorter, Drabik, & Timilsina, 2013). The model has provided a close representation of the respective market prices with the exception of a few time periods. The RFS are directly responsible for market conditions during 2011 and 2013 that causes the model to over predict. Building on what has been discussed so far, we can explain the over prediction of biodiesel prices due to interacting mandates and the blend wall. Additionally, this paper will address those conditions that led to excess profits in biodiesel producers in those years.

## *Soybean Oil Pricing Prediction Model*

Following de Gorter et al., the price of soy oil is linked to the price of biodiesel because of the zero profit condition (2013) where biodiesel producers bid up the price of soybean oil until MC = MR in biodiesel production:

$$P_{soybean\ oil} = \frac{1}{\gamma} * (P_B - C_B) \tag{4.1}$$

where $P_{soy\ oil}$ is the predicted price of soybean oil ($/lb)), $\gamma = 7.6$ (gallons of soy oil produced per bushel of soybeans), $P_B$ is the price of biodiesel ($/gal), and $C_B$ is the fixed cost of processing as derived by de Gorter et al.

The predictor of the price of soybean oil given by equation 4.1 is exceptional except for two periods during 2011 and 2013 as shown in Figure 4.1. Prediction error is very tight and is usually less than 5 cents and even during 2011 does not reach 20 cents. Still, it is important to look at why the model does not closely predict all the time and we must use all the information described so far to accomplish that. The main error component in the model comes from the price of biodiesel being raised relative to its input costs. We assume blenders should have bid up the cost of processing in order for no profits to occur over the long run.

To solve for 2011, we must return to Figure 3.5 that shows the price of sugarcane ethanol rising rapidly during late 2010 and into early 2011 as Brazil experienced production issues. Blenders still had responsibilities to fill the advanced residual of the RFS and started to produce biodiesel above its mandate for the first time. Because the demand for biodiesel increased it put pressure biodiesel prices which also increased significantly. The zero profit condition underlying equation (1) requires the price of soybean oil to be bid up with$P_B$. Blender demand for biodiesel increased the price and allowed refiners to make excess profits during 2011 as they could not bid up the price of soybean oil high fast enough and did not have the production capacity to do so as shown in Figure 4.2. Biodiesel plants continued to make excess profits as the price of sugarcane ethanol stabilized and dropped during the latter part of 2011, imports started from Brazil again and this lowered demand for biodiesel to exceed its own mandate, lowering the price and ending excess profits by early 2012. This proof shows that short term demand can increase the purchase price of biodiesel at an increased rate relative to input costs although long term profits do return to zero. During 2011 the interaction within the advanced mandate was the first clue that the RFS was functioning as designed and providing biofuel blenders the ability to choose which products to use to meet their obligations.

Figure 4.1. Soybean Oil Prediction versus Actual Soybean Oil Prices

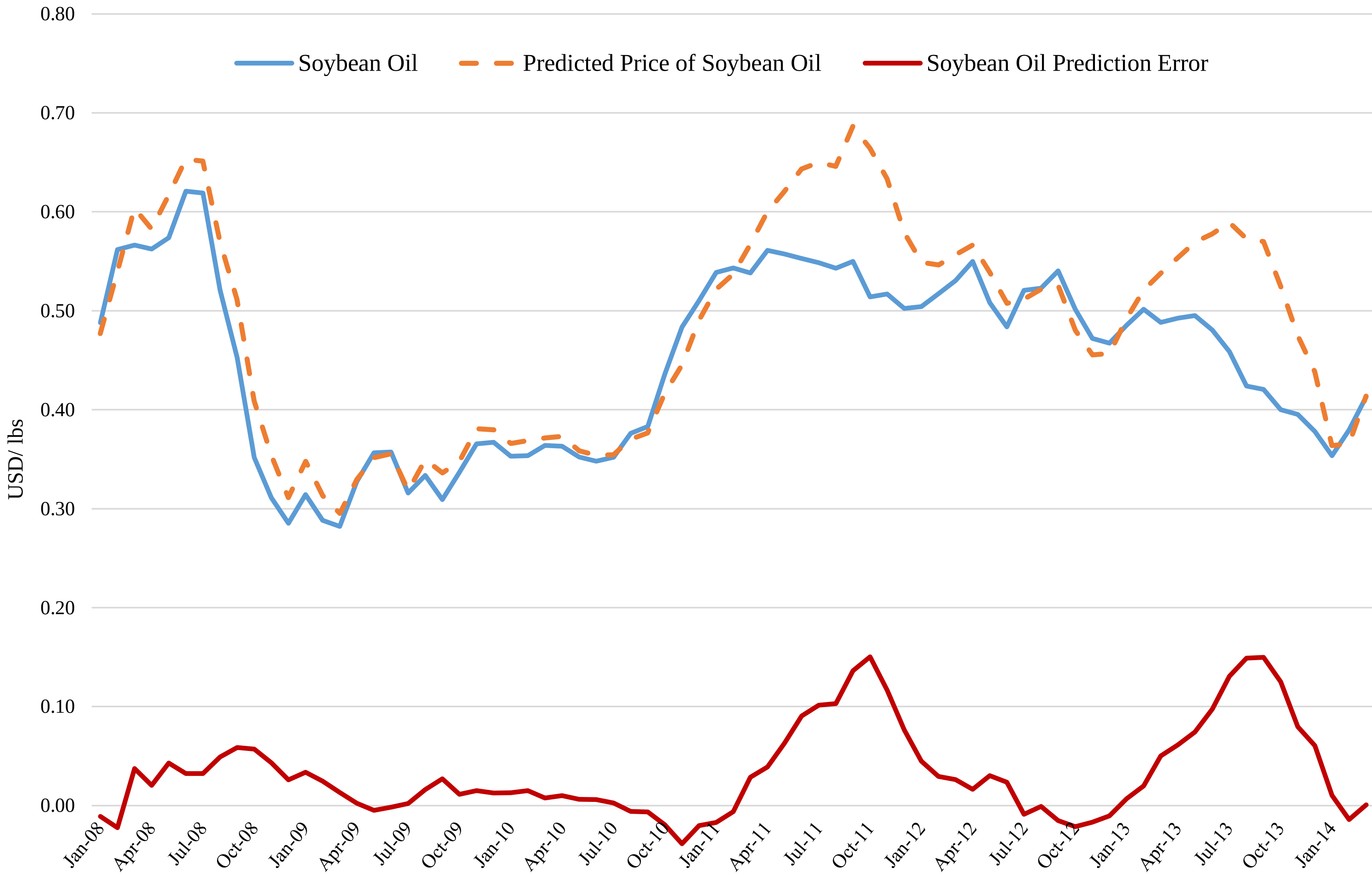
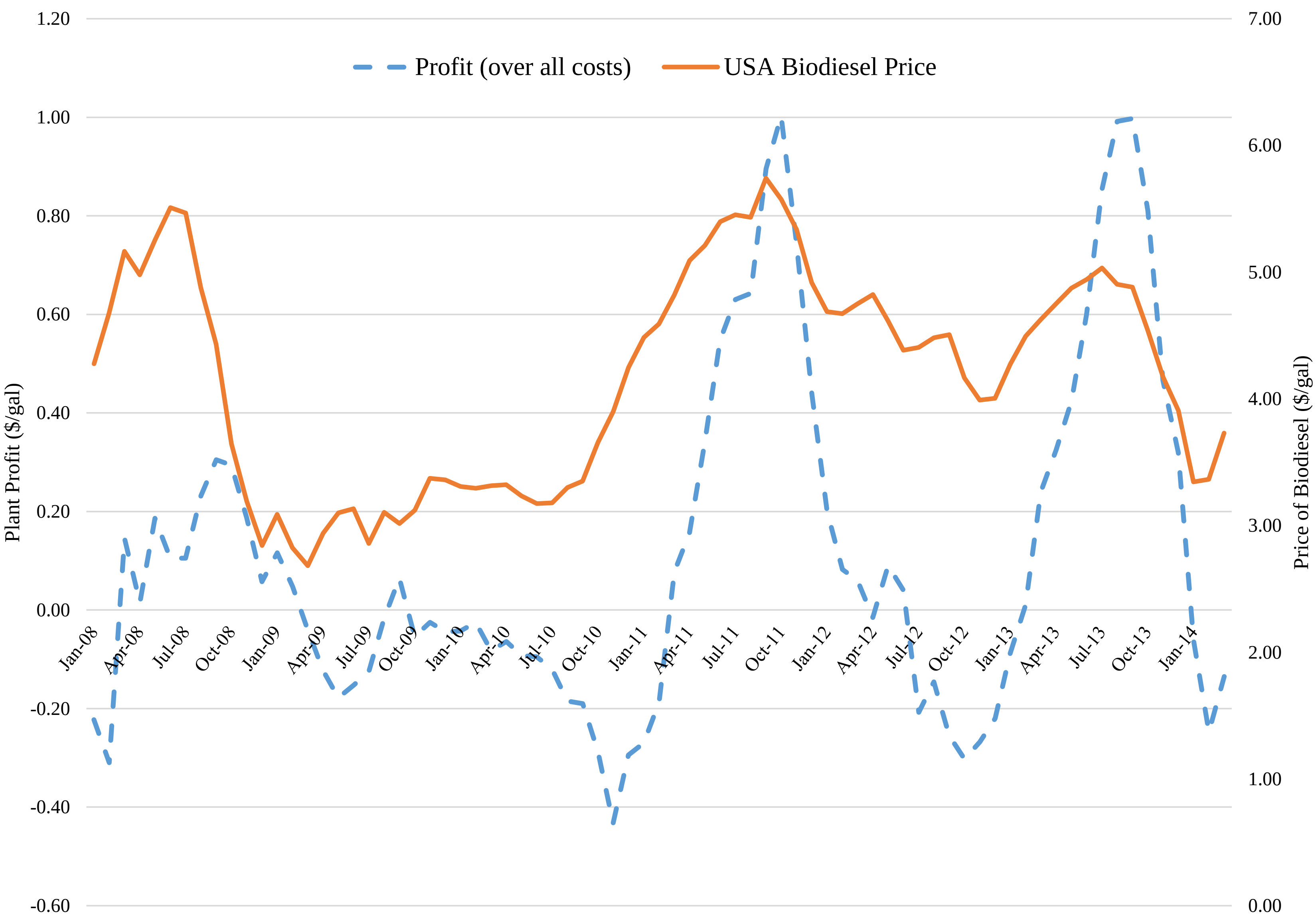


Figure 4.2. Biodiesel Plant Profit versus Biodiesel Price



Moving forward to the year 2013, Figures 4.1 and 4.2 seem to show an exact relationship relative to 2011. The soybean oil model again over predicts the actual price of soybean oil in addition to excess biodiesel plant profits that increase rapidly. While similar market price outcomes occur for the two years, there are drastic mandate interactions occurring within the RFS. During 2011 the interaction took place within the advanced biofuel mandate between biodiesel and Brazilian sugarcane ethanol. The drastic price increase of sugarcane ethanol resulted in much higher demand for biodiesel to exceed its mandate. During 2013, it is not a price increase, but the physical limitation of the ethanol blend wall. As discussed earlier, the blend wall limits ethanol to be blended off to a maximum of 10 percent into gasoline. Therefore, the biodiesel mandate is again being exceeded to help blender's lower compliance costs although it is now being pushed all the way into the renewable fuel gap.

The increased demand for biodiesel due to the blend wall again pushes its price higher starting in January, 2013. The zero profit condition expects the price of inputs to be bid up although in the short term producers cannot bid up the price quickly enough. The result of the blend wall is excess profits occurring in the short term for biodiesel producers. Throughout 2013 biodiesel producers earned excess profits although they decreased as the year progress after peaking heading towards 2014. An important note must be made about the excess biodiesel production. Figure 4.3 shows the United States biodiesel world trade relationship since 2010. One outcome of requiring more biodiesel to help breach the blend wall was the increased imports. Overall, over 500 million gallons of biodiesel was imported to be blended.[37] The increased price of biodiesel clearly had an impact on world trade as blenders preferred to import

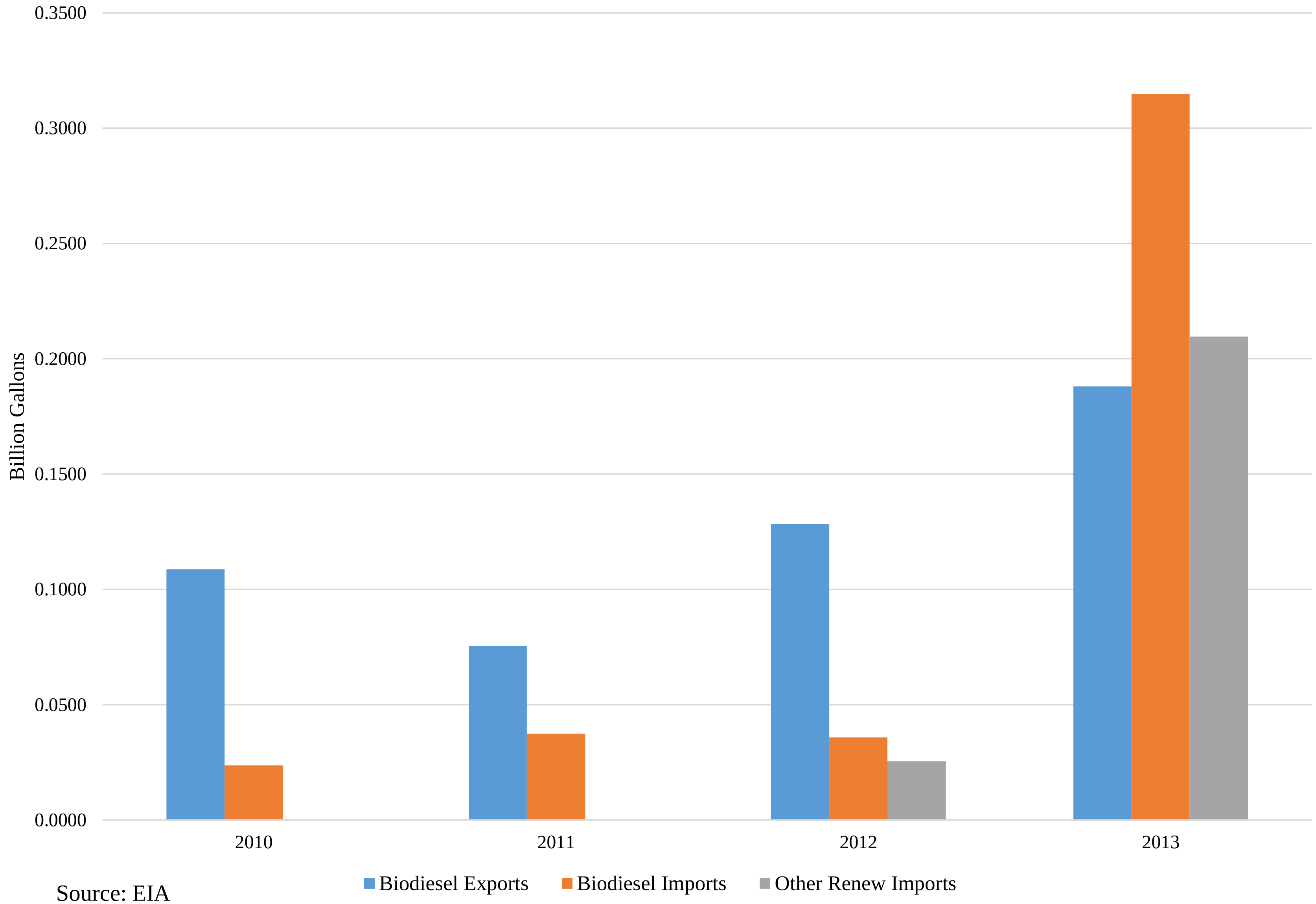
[37] Biomass based biodiesel accounted for over 300 million gallons, while renewable diesel accounted for over 200 million gallons of the imports. Exports still occurred during the time period, any export RINs are not counted.

as opposed to produce even more domestically. This also helped keep the price of soybean oil lower than the predicted as domestic producers of BBD did not have to increase their own production to bid up input prices.

Similar to 2011, excess profits of biodiesel producers decreased towards the end of 2013 and became normal. According to the 2007 EISA, the advanced, cellulosic, and total RFS were expected to increase for 2014 which would mean the blend wall would continue to be a significant issue and one would expect BBD profits to continue. Instead, the EPA released its 2014 RFS and decreased the overall mandate for the first time, reducing the demand for excess biodiesel production over and above its mandate (EPA, 2013a). As of halfway through 2014, everyone is still awaiting the final ruling of the RFS for 2014 which will help blenders make decisions on which biofuels are required to comply while still having the blend wall imposed on it as describer further in appendix 1. Clearly, as more biofuel continues to be required, mandate interactions and how blenders choose to comply with their obligations will become an even more important market driver.

The zero profit condition holds true for the long term in calculating the price of soybean oil. In the short term, the RFS allows mandate interactions that can increase demand instantly for biofuels that cause excess profits. In this case, biodiesel has interacted with sugarcane ethanol during 2011 and corn ethanol during 2013 to cause model prediction error that have been explained in this chapter. Future interactions will continue to occur and depending on EPA RFS changes it may lead to more short term profits although over the long term we expect to see profits to return to normal.

Figure 4.3. BBD U.S. - World Trade




Source: EIA

# CHAPTER 5

## CONCLUSIONS

This thesis analyzed biofuel production, consumption, pricing, and trade due to mandate interactions between that occur due to the United States Renewable Fuel Standard. The EPA has created and segregated biofuels according to type of fossil fuel replacer and expected greenhouse gas reduction. The nested structure of the RFS allows different biofuels to flow down after filling its own respective mandate and then competing for the next mandate. In addition to these differences, biofuels also count towards mandates according to their energy content. The result is biodiesel can count up to 1.7 times towards the total renewable mandate while ethanol, regardless of its source and mandate category, can only count once.

We only considered biofuels that were blended into transportation fuels such as gasoline and diesel, as well as with limited cellulosic biofuel production only considered it from its mandate impact on other advanced biofuels. Up to 2011, biofuels only filled their own respective mandates and spillover did not occur. During 2011, BBD was forced to exceed its mandate resulting from high sugarcane ethanol prices and created competition for the first time for the remainder of the advanced biofuel mandate. This forced increased BBD production and drove the price of biodiesel very high relative to the input costs. Producers of BBD were not able to bid up input prices quickly enough to prevent excess profits which occurred throughout the year. As the year progressed, sugarcane ethanol imports resumed and reduced BBD demand decreased prices and zero profits resumed. Understanding this market interaction shows how short term profits can arise for producers due to biofuels interacting across nested mandates although long term profits return to normal.

The EPA publishes volumes yearly that are used to determine percentage standards that blenders must comply with. Many economists get fooled into thinking the volumes are what is important for biofuel consumption in the U.S., and view the RFS as a consumption mandate. We showed that while the volume is used in calculating the actual blend ratios, the RFS is a blend mandate and blenders must comply with a percentage of fuel. This distinction is vital, if fuel consumption is half of forecast and the blend ratio is 10%, blenders only are required to use 10% of half the forecast as opposed to a static total volume. The percentage standards given in the form by the EPA are still not convenient for calculating how much ethanol and biodiesel needs to be blended into gasoline and diesel, respectively. In Chapter 2, we show how to convert the percentages provided by the EPA into ethanol and biodiesel blend ratios and are shown in Figures 2.4 and 2.5, respectively.

An extremely important realization in Figure 2.4 shows that the United States has been at the perceived blend wall since 2010 of 9 percent. Clearly this is not the blend wall or RFS mandate interactions would have occurred significantly before. The blend wall value is around 9.5 percent and blenders have been watering down the scotch since 2010. Why does 2013 become the key year for converging RIN markets and mandate interactions? The issue is increasing mandates, while blenders were able to blend more ethanol then required previously and water down the scotch, in 2013 the increasing advanced biofuel mandate (and waiving of cellulosic imposing additional blending on BBD and sugarcane ethanol) forced blenders to reach maximum ethanol blending and not breach it with either sugarcane or corn ethanol, but biodiesel.

The result of the blend wall show up in different ways. It forced D6 RINs, traditionally trading for a few cents, over $1/gallon as blenders attempted to induce more E85 consumption by subsidizing it with increased RIN value. If ethanol was the only biofuel that existed within the

RFS, RINs would simply increase to a value where blenders and consumers would be compensated to adopt higher volumes of ethanol (including flex fuel vehicles and stations). Due to the nested structure of the RFS, D6 RINs cannot be valued more than D4 RINS. Through 2013, biodiesel RINs continue to be determined according to its blending margin which correlates to the cost of producing more biodiesel than mandated. The result is D6 RINs only reached a value equal to D4 RINs and were not able to induce additional ethanol consumption within the U.S. by a significant volume. Biodiesel demand increased by blenders who valued it as much and more as ethanol in order to meet their RFS obligations.

The increased biodiesel demand led to a huge increase in imports of biodiesel and renewable diesel by the U.S., as well as larger domestic production. The additional demand forced higher biodiesel prices and excess profits by producers of BBD who were not able to bid up input prices fast enough until the end of 2013. Similar to 2011, due to a mandate interaction, this time within the renewable fuel gap, led to excess biodiesel plant profit throughout the year. The RFS has the potential to create biofuel interactions yearly due to the nested structure and valuing biofuels differently. It will be interesting to see the 2014 final percentage standards that are released by the EPA as different groups attempt to persuade them based on their expected gains (i.e., biofuel plants) and reducing losses (i.e., oil companies).

# APPENDIX 1

## EPA adjustments to formal mandates

The EPA has the authority ability to adjust the total renewable mandate as well as cellulosic, biomass based biodiesel, and the advanced mandates. The EPA until 2014, had not altered a mandated volume except for cellulosic of which it has had to do yearly. The cellulosic mandate has been waived each year since the RFS inception. While the cellulosic mandate has been waived, the EPA has not reduced the total amount of advanced fuels to be blended. In 2012, the EPA forecast 500 million gallons of cellulosic fuels produced, while only 8.65 million gallons actually produced. This means the extra volume in the advanced mandate that was supposed to be filled by cellulosic fuels needed to be made up with BBD and imported sugarcane ethanol. In essence it creates a large ‘other’ advanced sector although with the much slower than anticipated production of cellulosic biofuels deeper change within the RFS structure may be required. Once the advanced mandate has been filled these fuels are able to compete for the total renewable mandate with corn ethanol.

The total renewable fuel mandate had not been altered until 2014 when the EPA suggested a lower amount and used ranges because they were not sure what volume was acceptable. This has been subject to debate and so is at the time of this writing still under debate (even though we are well into 2014) (EPA, 2014). In addition to being lowered, wide ranges were provided for total renewable fuels so the exact standard is not known for 2014 (Office of Transportation and Air Quality, 2013). The advanced mandate was also lowered even though it was met and exceeded by a large amount in 2013. The EPA offered a comment period that ended January 28, 2014 that has resulted in thousands of comments sent in to retain the original renewable fuel mandated volumes. Many comments are arguing that the EPA does not have the ability to change the volumes by improperly interpreting the Clean Air Act waiver authority to reduce them. Moving forward the decision will have a large impact of the amount of renewable fuels blended in the United States.

## APPENDIX 2

EPA Yearly Calculation of Blend Mandates (EPA, 2013)

$$Std_{CB,i} = 100 * \frac{RFV_{CB,i}}{(G_i - RG_i) + (GS_i - RGS_i) - GE_i + (D_i - RD_i) + (DS_i - RDS_i) - DE_i}$$

$$Std_{BBD,i} = 100 * \frac{RFV_{BBD,i}}{(G_i - RG_i) + (GS_i - RGS_i) - GE_i + (D_i - RD_i) + (DS_i - RDS_i) - DE_i}$$

$$Std_{AB,i} = 100 * \frac{RFV_{AB,i}}{(G_i - RG_i) + (GS_i - RGS_i) - GE_i + (D_i - RD_i) + (DS_i - RDS_i) - DE_i}$$

$$Std_{RF,i} = 100 * \frac{RFV_{RF,i}}{(G_i - RG_i) + (GS_i - RGS_i) - GE_i + (D_i - RD_i) + (DS_i - RDS_i) - DE_i}$$

*Where:*
$Std_{CB,i}$ = The cellulosic biofuel standard for year i, in percent.
$Std_{BBD,i}$= The biomass-based diesel standard for year i, in percent.
$Std_{AB,i}$= The advanced biofuel standard for year i, in percent.
$Std_{RF,i}$= The renewable fuel standard for year i, in percent.
$RFV_{CB,i}$= Annual volume of cellulosic biofuel required (adjusted) for year i, in gallons.
$RFV_{BBD,i}$= Annual volume of biomass-based diesel required for year i, in gallons.
$RFV_{AB,i}$= Annual volume of advanced biofuel required for year i, in gallons.
$RFV_{RF,i}$= Annual volume of renewable fuel required for year i, in gallons.
$G_i$= Amount of gasoline projected to be used in the 48 contiguous states and Hawaii, in year i, in gallons.
$D_i$= Amount of diesel projected to be used in the 48 contiguous states and Hawaii, in year i, in gallons.
$RG_i$= Amount of renewable fuel blended into gasoline that is projected to be consumed in the 48 contiguous states and Hawaii, in year i, in gallons.
$RD_i$= Amount of renewable fuel blended into diesel that is projected to be consumed in the 48 contiguous states and Hawaii, in year i, in gallons.
$GS_i$= Amount of gasoline projected to be used in Alaska or a U.S. territory, in year i, if the state or territory has opted-in or opts in, in gallons.
$RGS_i$= Amount of renewable fuel blended into gasoline that is projected to be consumed in Alaska or a U.S. territory, in year i, if the state or territory opts-in, in gallons.
$DS_i$= Amount of diesel projected to be used in Alaska or a U.S. territory, in year i, if the state or territory has opted-in or opts in, in gallons.
$RDS_i$= Amount of renewable fuel blended into diesel that is projected to be consumed in Alaska or a U.S. territory, in year i, if the state or territory opts-in, in gallons.
$GE_i$= The amount of gasoline projected to be produced by exempt small refineries and small refiners, in year i, in gallons.
$DE_i$= The amount of diesel fuel projected to be produced by exempt small refineries and small refiners in year i, in gallons, in any year they are exempt.

APPENDIX 3

Forecast data used by the EPA to calculate percentage standards

| | *2014* | *2013* | *2012* | *2011* | *2010* | *2009* | *2008* |
|---|---|---|---|---|---|---|---|
| Cellulosic biofuels | 0.017 | 0.006 | 0.01045 | 6.000 | 0.0065 | 0 | 0 |
| BBD | 1.28 | 1.28 | 1.00 | 0.80 | 0.65** | 0.50 | 0 |
| Advanced biofuel | 2.20 | 2.75 | 2.00 | 1.35 | 0.95 | 0.60 | 0 |
| Total Renewable fuels | 15.21 | 16.55 | 15.20 | 13.95 | 12.95 | 11.10 | 9 |
| Motor Gasoline | 132.65 | 132.80 | 135.39 | 139.07 | 139.20 | 138.47 | 144.5 |
| Motor Diesel | 47.12 | 51.76 | 50.68 | 49.21 | 46.71 | 0 | 0 |
| Renewable fuels to be blended with gasoline | 13.12 | 13.31 | 13.31 | 13.45 | 12.11 | 11.03 | 9 |
| Renewable fuels to be blended with diesel | 1.38 | 1.23 | 0.93 | 0.71 | 0.7665 | 0 | 0 |
| GE* | 0 | 0 | 4.87 | 0 | 0 | 18.73 | 19.55 |
| DE* | 0 | 0 | 2.28 | 0 | 0 | 0 | 0 |

All volumes are in billion gallons

*GE and DE are the small refineries who are exempt from the RFS during these years. For 2013 they are assumed to be 0 to protect confidentiality

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