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The Distinct Economic Effects of the Ethanol Blend Wall, RIN Prices and Ethanol Price Premium due to the RFS

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Abstract

The ethanol blend wall and high RIN prices has become a controversial policy issue. We develop a model showing how RIN prices reflect the costs of overcoming the blend wall, namely biodiesel consumed in excess of its mandate and expansion of E85 sales. These costs are very high and are shown to be borne by producers and consumers of ethanol and gasoline. Although RIN prices reduce consumer prices of ethanol in both the E10 and E85 blends, the net price of E10 rises because obligated parties, who are required to purchase RINs, recoup the cost by passing on higher gasoline prices to blenders. This tax on gasoline production to pay for the subsidy on all ethanol consumption and RIN prices are a means of payment for "excess" RINs that are required to pay for costs overcoming the blend wall.

Burkholder (2015) and EPA (2015) emphasize this first round subsidy that also increases ethanol market prices. But these papers downplay the overall increased costs of fuel to consumers due to RINs taxing gasoline producers, and the separate adverse market effects of a binding blend mandate. The latter has been missing in the debate where it is often implied that the RIN price represents the degree to which the ethanol mandate is binding. We show the RIN price represents the costs of overcoming the blend wall and the ethanol price premium due to the binding blend mandate reflects costs of the RFS itself.

Our model determines RIN prices, the costs of overcoming the blend wall and the relationship with the ethanol price premium due to the binding mandate. We use economic theory consistent with the reality of the RFS and its associated complexities. From our empirical simulations, we find RIN prices went up because of the costs of the blend wall. Increasing the mandate with a blend wall caused E10 prices and market gasoline prices to increase, along with an increase in ethanol consumption and market prices. But ethanol and market prices would increase far more without a blend wall for the same increase in the mandated volume.

In addition to the costs of overcoming the blend wall, our analysis finds the cost of the mandate price premium for ethanol to fuel consumers is $53.7 billion between 2007 and 2014, and to consumers of crops (including animal agriculture) by $285.4 billion per year worldwide. Our model also obtains the result that the RFS of the 2007 EISA is infeasible with exponentially increasing volume mandates under two situations. First, the E85 price goes to zero with ever increasing RIN prices. Second, when we assume costs of E85 sales expansion levels off at $2 per gallon with the ethanol price peaking and then slowly declines (with E85 and E10 consumption). This may explain why the EPA scaled back the RFS.

Key words: RIN prices, blend wall, blend mandate price premium, E85, ethanol.

JEL codes: Q18, Q28, Q42, Q48

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1. Introduction

In early 2013, the price of Renewable Identification Numbers (RINs) for ethanol sky-rocketed from its normal value of around 1 to 5 cents per gallon to over $1 per gallon. RINs are a means to ensure compliance with the mandate – the Renewable Fuel Standard (RFS). There has been much controversy since then as to what RIN prices represent. Stock (2015) states "In theory, RIN prices provide support for and promote the use of renewable fuels." We argue RIN prices reflect the cost of overcoming the bend wall, requiring "excess" RINs (for ethanol above and beyond the 10 percent blend wall E10 that represents the maximum ethanol regular cars can consume). Most of these "excess" RINs in reality come from biodiesel RINs (for biodiesel consumed in excess of its mandate) and the rest from consumption of E85 by flex fuel vehicles (FFV). Hence, we show in theory and in practice that high RIN prices results in higher overall fuel prices to consumers and lower consumption and market prices for ethanol than otherwise.

Because of concerns over high RIN prices and the cost of overcoming the ethanol blend wall, the Environmental Protection Agency (EPA) subsequently scaled back the RFS from the 2007 Energy Independence and Security Act (EISA) in 2014 and again in 2015.[1] This generated the current controversy and debate around the effect of the ethanol blend wall on RIN prices, and the market effects of both the blend wall and RIN prices.

Following the important paper by Pouliot and Babcock (2014a), who correctly model the RIN price as reducing the consumer price of ethanol in both the E10 and E85 blends, Stock (2015), Burkholder (2015) and EPA (2015) emphasize this first round subsidy that also increases ethanol market prices. These studies are also concerned about the lack of pass-through of the RIN price to E85 consumers. But these papers downplay the overall increased costs of fuel to consumers as the RIN price acts as a tax on gasoline producers who are the obligated parties and required to purchase all RINs from blenders. To recoup the cost of the RINs, refiners charge a higher market price for gasoline to domestic blenders while the world price (and that received by domestic producers) of gasoline falls (there is a wedge now between domestic consumer and world/domestic producer market prices for gasoline) (Pouliot and Babcock 2014a). These costs, borne by producers and consumers of ethanol and gasoline, *inter alia* include the over blending of biodiesel and expansion of E85 sales.

What has been missing in the debate so far is the relationship between the RIN price and the ethanol price premium due to a binding mandate.[2] It is often implied that the RIN price represents the

[1] The November 29, 2013 proposal for 2014 standards were withdrawn and re-proposed on June 10, 2015.
[2] A mandate price premium is defined as the amount by which the observed ethanol market price exceeds free market levels. In other words, the premium that exists in ethanol markets, as a result of the mandate, over free

degree to which the ethanol mandate is binding and hence is the ethanol price premium over the free market ethanol price (e.g., McPhail et al. 2011; Pouliot and Babcock 2014a). We show that the RIN price and mandate premium mean very different things: the RIN price represents the costs of overcoming the blend wall, and in theory, as the RIN price increases with an ever expanding mandate, the ethanol mandate premium rises only slightly (as opposed to much more if there was no blend wall and RIN prices remained relatively low). But this does not negate the basic economics of a binding blend mandate in de Gorter and Just (2009) where gasoline consumption is taxed to support the ethanol market price (the ethanol market price is the same for consumers and producers as are domestic and world gasoline prices, but the latter decline due to the binding blend mandate).

This paper develops a general model that integrates the blend mandate model of de Gorter and Just (2009) and Drabik (2011) with that of Pouliot and Babcock (2014a) to disentangle the effects of an ethanol price premium due to a binding mandate and a high RIN price due to the costs of overcoming the ethanol blend wall. This will allow us to determine the net impact of a binding blend wall versus a binding blend mandate on each of the gasoline and ethanol prices paid by consumers and received by producers. We extend the blend mandate model of de Gorter and Just (2009) to include the important analysis of Pouliot and Babcock (2014a) and so clarify as to what a RIN price represents, how the cost of overcoming the blend wall reflects itself in the RIN price, and discern the differential meaning and effects of a RIN price versus the degree to which the mandate is binding (the ethanol mandate price premium over the free market ethanol price). In so doing, we clarify some issues in the literature.

We reach our conclusions by developing an economic model of the RIN market, RIN prices and the blend wall, using economic theory consistent with the reality of the RFS and its associated complexities. From our economic simulation model, we find RIN prices went up because of the costs of the blend wall. Increasing the mandate with a blend wall caused E10 prices and market gasoline prices to increase, along with an increase in ethanol consumption and market prices. But fuel consumption and ethanol market prices would increase far more without a blend wall for the same increase in the mandated volume.

In addition to the costs of overcoming the blend wall (reflected in lower market prices to ethanol and gasoline producers than otherwise and higher fuel costs to E10 consumers), our analysis finds the cost of the mandate price premium for ethanol has increased costs of ethanol to fuel consumers by $53.7 billion between 2007 and 2014, and to consumers of crops (including animal agriculture) by $285.4 billion per year worldwide. Our model also obtains the result that the RFS of the 2007 EISA is infeasible with exponentially increasing volume mandates under two situations. First, the E85 price goes to zero with ever increasing RIN prices. Second, when we cap the RIN price at $2 per gallon (reflecting the cost of overcoming the blend wall leveling off at some point), the ethanol price peaks and then slowly declines (with E85 and E10 consumption).

The rest of the paper is organized into the following sections: Section 2 reviews the RFS mechanics and develops an analytical model that determines RIN prices with the various costs of overcoming the blend wall (increasing E85 sales and purchasing D4 biodiesel RINs). The model also specifies

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market levels that would have otherwise existed. See Box 2.3 on p. 32 of de Gorter et al. (2015) for a full explanation.

how the volume mandate is implemented as a blend mandate, a sub-mandate ratio for E10 and an overall mandate ratio that necessarily exceeds 10 percent for the blend wall to be binding. Section 3 gives the empirical results of ever increasing mandate volumes and separates out the market effects of RIN prices and the binding blend wall versus the effects of an ethanol price premium due to a binding blend mandate. Section 4 will show the EPA's interpretation (Burkholder, 2015 and EPA, 2015) on the effects of high RIN prices is technically correct but fails to include the high costs to society of both overcoming the blend wall and of the ethanol price premium due to the binding mandate. The final section concludes.

2. Background and a Model of the Blend Wall, RIN Prices and Mandate Premiums

A core controversy over the ethanol blend wall is what RIN prices represent and what impact RIN prices have on markets and social costs. We therefore first summarize how RINs are created. Then, we explain the effect of RINs under a binding blend mandate when a blend wall is not an issue (as it was the case, for example, before 2012). We then discuss the effects of RINs when the blend wall binds (i.e., when the mandated share of ethanol in the fuel blend is above a technologically feasible threshold). Finally, we develop an analytical model that will be the basis for empirical simulations in section 3.

The Energy Independence and Security Act (EISA) of 2007 specifies ever increasing volumes of biofuels each year to be used as transportation fuel. The EPA uses these volumes and forecast fuel consumption provided by the Energy Information Administration (EIA) as inputs to a formula that calculates percentage standards that apply to gasoline and diesel. There are four broad categories of biofuel mandates as outlined in Figure 1. These are cellulosic biofuels, biomass-based diesel (BBD), advanced biofuels, and the overall or total "mandate" (the RFS). The cellulosic biofuels and BBD mandates are nested within the advanced biofuel mandate with the latter nested within the total RFS (Panel (a) of Figure 1). The residual of the advanced mandate is often referred to as "other advanced" or "non-specified advanced" whereas the difference between the total RFS and advanced is often referred to as "conventional" biofuel (i.e., ethanol derived from corn starch) or the RFS residual.

There is an "equivalence value" for each biofuel, with corn- and sugarcane-ethanol along with biogas counting as one. All other biofuels get a higher equivalence value, ranging from 1.3 (biobutanol) to 1.7 (cellulosic biodiesel and renewable diesel). Note that BBD has an equivalence value equal to one when counted toward its own mandate but is equal to 1.5 for biodiesel when counted toward the advanced mandate. Hence, 50 percent of the mandated BBD consumption automatically counts towards the non-specified advanced biofuel mandate. Once BBD consumption exceeds its own mandate, then part of mandated BBD counts towards the advanced mandate. As shown in Panel (b) of Figure 1, if the advanced mandate is filled, the excess counts as a conventional biofuel. In 2013 and 2014, BBD consumption exceeded the advanced mandate itself and so part of the BBD mandated volume was counted as a conventional biofuel, as did the 50 percent equivalence volume.[3]

[3] Each category is has a minimum level of greenhouse gas (GHG) emissions reduction relative to the fossil fuel (gasoline or diesel) it is assumed to replace. This minimum requirement is 60 percent for cellulosic biofuel, 50 percent for advanced biofuels and 20 percent for biofuels that are only eligible for the conventional biofuel part of the RFS.

Using ethanol as an example (and because it is the focus of our paper), we now explain how the Renewable Identification Numbers (RINs) are generated. Each gallon of ethanol produced by independent producers is assigned a unique RIN;[4] this is when RINs are generated. When ethanol producers sell ethanol to independent blenders, the RINs become detached from ethanol at which point blenders own them. The blenders then sell the detached RINs to obligated parties (refiners and importers of gasoline) who retire them to the EPA to demonstrate compliance with the RFS.[5] Obligated parties can acquire RINs through blending qualified fuels or purchasing separated RINs from other parties.[6] When blenders purchase gasoline from obligated parties, these parties are obligated to purchase the corresponding RINs. Purchasing RINs is a cost to obligated parties. They recoup it by charging a higher gasoline price to blenders, which results in a gap between domestic gasoline prices faced by blenders and world market prices of gasoline. This implicit tax exists with or without the blend wall as long as obligated parties have to purchase RINs.[7] In order for the obligated parties to retire a required number of RINs, each year EPA determines a ratio, κ that represents a percentage of gasoline in the form of RINs to be retired.

The determination of κ is an elaborate process. Although a specific biofuel volume is set each year, the obligated parties are required to fulfill the Renewable Volume Obligation (RVO), which for ethanol is defined as $\kappa = E^*/G^*$, where E^* is the mandated ethanol volume and G^* is forecast gasoline consumption.[8] Once κ is determined, then required quantity of ethanol to be blended, E, equals

$$E = \kappa G, \tag{1}$$

where G is an actual quantity of gasoline consumed. Notice that if the forecast of gasoline consumption for the next year differs from reality, then the actual quantity of ethanol also differs from the mandated quantity because the ratio κ does not change in a given year.
In our model, we define the ethanol blend mandate α as the ratio of the mandated quantity of ethanol in the total forecast fuel blend, that is, $\alpha = E^*/(E^* + G^*)$. Then using the definitions for κ and α it is straightforward to derive a one to one relation between them

$$\kappa = \frac{\alpha}{1-\alpha}, \tag{2}$$

which implies $\kappa > \alpha$.

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[4] Each of the four biofuel categories is assigned its own RIN number: D6 for the conventional biofuels (e.g., corn-ethanol); D5 for the non-specified advanced biofuels, D4 for BBD and D3 for biofuels in the cellulosic mandate.
[5] Technically, refiners and importers have time until the end of the year to retire RINs; the final documentation for 2013 has not yet been completed and EPA has proposed compliance deadlines for 2014–2016. Additionally, RINs are valid for two years, so surplus RINs can be accrued and carried over to the next compliance period. In the case of insufficient RINs, an obligated party can borrow RINs from the following year.
[6] This analysis greatly simplifies the reality of the complex marketplace by depicting the renewable fuel producer, fuel blender, obligated party, and fuel retailer as independent entities (Pouliot and Babcock 2014a). In reality, two or more of these functions may be conducted by the same company. Traditionally, many obligated parties have also functioned as fuel blenders; furthermore, Valero is an example of a company that refines crude oil, retails fuels and also owns ethanol production facilities.
[7] This follows directly from a first-order condition for profit maximization of a refinery (see the derivations below).
[8] As Stock (2015, p. 8) notes, it is not practical to enforce volumetric requirements.

The effect of RINs under a binding blend mandate and no blend wall

Let us assume the ethanol mandate is binding and consumers demand miles traveled. We set α = 0.08 to rule out a blend wall. We define a mandate price premium as the amount by which the observed ethanol market price (determined by the mandate) exceeds the free market ethanol price. The free market price is lower than the gasoline price for two reasons. First, a gallon of ethanol achieves only 70 percent of the miles traveled as compared to gasoline. Second, the fuel tax is applicable to ethanol as well so consumers are only willing to pay 70 percent of the tax.[9] Hence, the price blenders are willing to pay for ethanol when they have choice (i.e., with no mandate) has most often been substantially below observed market prices. For these two reasons, a high mandate price premium for ethanol has existed, and it has supported ethanol (and corn) prices. This premium is financed by an implicit tax on fuel consumption that pays for higher ethanol prices charged to consumers (de Gorter and Just 2009). Total fuel consumption (and fuel prices) can go up or down with an increase in the mandate, depending on market parameters, but domestic consumption of gasoline always goes down, thus lowering market prices to domestic and world gasoline producers.

RINs are traded under a binding blend mandate even when a blend wall is not an issue. The RIN price reflects differential costs among firms in complying with the mandate. Suppose there is no RIN market. Then the US system would be like the system in Brazil and every retailer would have to offer E8 (i.e., an 8 percent ethanol blend) at every pump in the country. But the United States has a more efficient system. Some blenders have lower costs of blending ethanol and will therefore be willing to blend over the mandated percentage for a price. Others will have higher costs and so prefer to buy excess RINs and under blend ethanol.

The overall market impact of RINs is to reduce the cost of delivering blended products to consumers while complying with the mandate; therefore, the net market impact is lower fuel prices compared to no RIN system. At the same time, trade in RINs results in higher fuel consumption and ethanol prices (assuming competition and zero profits in gasoline and ethanol production). When we extend the model below to include the blend wall, the efficiency improvement of having tradable RINs does not disappear but the increase in RIN prices to much higher levels is a result of the costs to overcome the blend wall. Then the opposite occurs: high RIN prices mean inefficiency and lower ethanol prices, and higher fuel prices and thus lower fuel consumption.

Blend wall and ways to circumvent it

The blend wall technically was reached as early as 2012 as shown in Figure 2. Through 2011, the mandated ethanol blend ratio α (see the discussion earlier) was lower than the actual blend ratio. There can be several reasons for this, including the possibility of storing RINs for future use. However, beginning in 2012, the mandated ratio has exceeded the actual ratio. This would indicate that a blend wall was "hit" (at a blend ratio of 0.096, almost the exact same value for 2011). This can be viewed as the "natural" blend wall where extra incentives would be needed to induce lower blends.

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[9] See Box 2.3 on p. 32 of de Gorter et al. (2015) for a full explanation.

Obligated parties have several options to fulfill their obligations. These options include using stored RINs, borrowing RINs from the following year, increasing E85 sales, or buying D4 RINs from the over-blending of biodiesel and D6 RINs from new biodiesel production. The quantity of "excess" RINs required for each year is given in Figure 3. The year 2013 was a watershed year for several reasons. While not the first year where the mandated blend ratio exceeded the actual ratio, the market reacted very quickly and strongly in 2013 as the RIN deficit was over 1.6 billion (see Figure 3). As we will see later, overcoming the blend wall is very costly and could spin out of control if the mandated blend ratio increased exponentially in face of declining demand for fuel (ethanol plus gasoline). So after the explosion of D6 RIN prices early in 2013 and the controversy it created, in November 2013 the EPA proposed to sharply reduce the 2014 mandate from statutory levels as shown in Figure 4. This proposed reduction, and if extended to 2015, would have reduced the number of ethanol RINs required to overcome the blend wall in 2014 and 2015 from 2013 levels as shown in Figure 3. This is now projected to reverse and increase considerably again in 2016. The number of excess RINs will depend critically on whether there will be an upward or downward adjustment in the forecast fuel consumption prior to EPA finalizing the annual percentage standards (the consumption will depend on consumer preferences, improved fuel mileage, crude oil prices, growth in GDP and any adjustments the EPA makes on mandated volumes of biofuels).

The source of excess RINs (RINs required to overcome the blend wall) over this time period is given in Figure 5 (based on final and proposed standards). The bulk of the excess RINs have so far come from over-blending of biodiesel. E85 sales were a small part of the excess RINs and show little growth. Reducing E0 has been a far larger contributor to excess RINs than increases in E85 sales. But as the "actual E10" blend approaches 10 percent, the ability to reduce E0 or other lower blends becomes very restricted.

A very revealing story of how the blend wall was breached is shown in de Gorter et al. (2015) where the United States became an exporter of ethanol (because of the blend wall) and an importer of biodiesel (with an ethanol equivalence factor of 1.5) and renewable diesel (300 million gallons of imports in 2013 alone) with an ethanol equivalence factor of 1.7.[10] As panel (c) in Figure 1 shows, the blend wall has forced advanced biofuel consumption to grow and count as a conventional biofuel and so squeezes out corn-ethanol. Breaching the blend wall with non-ethanol advanced fuels is another result of the blend wall, even though increasing E85 sales that have been the central focus of the blend wall debate and apparently a far more costly option, even with high D6 RIN price levels in recent years.

The effect of RINs under a blend mandate and a binding blend wall

A typical way to represent the impacts of a RIN price is to specify a supply and demand for ethanol where their intersection represents the free market ethanol price (McPhail et al., 2011; Pouliot and Babcock, 2014a). The U.S. mandate is depicted as a vertical line (fixed volume mandate, although in reality it is implemented as a blend mandate). If the mandated volume is to

[10] Actual imports of conventional non-ethanol renewable fuels in 2014 plunged in 2014 to 53 million gallons of biodiesel and 151 million gallons of renewable diesel as the demand fell for excess RINs – see Figure 3. Advanced biofuel volumes in 2014 were below 2013 volumes because imports of sugarcane ethanol dropped significantly so BBD volumes were slightly higher in 2014.

the right of the free market equilibrium for the supply and demand for ethanol, the mandate becomes binding and the vertical distance between the ethanol supply and demand curves is the RIN price. But this RIN price is also interpreted as the degree to which the mandate is binding, and hence it is implied to be the mandate price premium for ethanol as well.

It is not immediately obvious that the vertical distance between the ethanol supply and demand curves represents the marginal costs of overcoming the blend wall (to be modeled below). The vertical distance does not necessarily represent the mandate price premium for ethanol over its free market price either. In addition, there is no clear relationship between the ethanol price premium and the RIN price. The mandate premium (defined earlier as the difference between observed ethanol market prices and a calculated free market level assuming no blend mandate) was often much higher than the RIN price pre-2013 (compare Figure 3.2 to Figure 10.3 in de Gorter et al. 2015), and the reverse, as in many months after early 2013.Our empirical results below show the properties of our model are such that there is a weak positive relationship between the RIN price and mandate premium, but in no way do they represent the same thing in theory or in practice.

Unlike the standard way of modeling D6 (corn-ethanol) RIN prices in the literature, we model them as a cost of overcoming the ethanol blend wall. The observed blend wall in any year has historically been less than 10 percent as depicted in Figure 2 (for example, going into 2013, the actual blend for "E10" was 9.644 percent).

Although there are several ways to overcome the blend wall,[11] in our analysis we stress three major channels. First, discounting the price of the E85 blend, P_{E85}, to consumers to induce an increase in flexible fuel vehicles (FFVs) purchases and/or increasing E85 sales per car (in which case a price discount is required to induce consumers to buy more E85 for a given level of infrastructure). Second, discounting the price of the E85 blend, P_{E85}, so the supplier of E85 has to provide infrastructure (e.g., pumps, tanks) independently of what the P_{E85} price is relative to the price of E10, P_{E10}. In other words, for a given price differential, more E85 can be consumed by providing more infrastructure. Third, D4 (biodiesel) RINs can be purchased from biodiesel producers blending more than the biodiesel mandate requires, or D6 RINs are generated by blending biodiesel not qualified as an advanced biofuel. Actual consumption of E85 does not occur, yet RINs from biodiesel count toward the ethanol mandate (we call this "unblended ethanol) with an ethanol-equivalence factor of 1.5 for biodiesel and 1.7 for renewable diesel.

Each channel described above generates a certain number of RINs at a different marginal cost which in equilibrium is equal to the RIN price. Channels 1 and 2 generate RINs associated with ethanol that is consumed in FFVs and, therefore, the ethanol must also be physically produced. This means the ethanol corresponding the marginal cost curves for channels 1 and 2 is embedded in the ethanol supply curve. That is why we do not explicitly model the marginal cost curves underlying channels 1 and 2. However, in calibrating the demand for E85 in the numerical

[11] Other means are to reduce the consumption of E0; to increase the consumption of E15, renewable gasoline, butanol, biogas in CNG vehicles, renewable jet fuel, heating oil, and biofuels from non-food based feed stocks (page 33118, EPA, 2015). Another options discussed is the co-development of new technology vehicles and engines optimized for new fuels. We omit all of these options from our analysis, but the theory and empirical framework can be easily extended to include these.

model, we do take into the discount required to induce more E85 sales (represented by move along the E85 curve) as well as the discount required in E85 prices to increase E85 sales (a shift in the E85 demand curve).[12] On the other hand, we do explicitly model the marginal cost curve for RINs generated in the biodiesel market (channel 3) because these RINs correspond to ethanol not physically blended and this needs to be properly accounted for in the model. RIN prices reflect the cost of overcoming the blend wall. This point has been missing in the debate. It is less straightforward to realize that compared to a situation of no blend wall, the RIN price now also reflects the demand for "excess" RINs by under-blenders (who save costs by blending less than is required) and the supply of excess RINs by over-blenders (who incur costs by blending more than is required) because of the existing blend wall. In other words, because of a blend wall, there is a cost to overcome it and the cost is reflected in the RIN price. The market outcome under a blend wall has nothing to do with ethanol producers or refiners (assuming no storing and borrowing of RINs, or speculation and inter-temporal considerations) except that refiners are obligated to purchase all of the RINs, not just excess RINs to overcome the blend wall.[13]

In addition to buying RINs from ethanol over-blenders, under-blenders can also purchase D4 RINs to fulfill the mandated ethanol blend ratio. There are two "sources" for these RINs.

First, biodiesel counts 1 toward the BBD mandate but 1.5 toward the overall mandate; therefore 50 percent of all biodiesel RINs that count toward the BBD mandate are "not blended" and can be made available to D5 blenders (e.g., sugar-cane ethanol) and/or to D6 blenders (corn-ethanol). Under-blenders of ethanol purchase these and sell to obligated parties, who then increase gasoline prices to consumers to recover the costs of the RINs. The "not-blended" RINs count toward the non-specified advanced renewable fuel mandate or even directly toward the conventional biofuel portion of the overall mandate (i.e., ethanol derived from corn starch). The price of diesel is unaffected by the 50 percent not-blended RINs that under-blenders of ethanol get to purchase because the sales of these D4 RINs do not affect the amount of biodiesel produced because the BBD mandate has to be filled, regardless).[14]

Second, under-blenders of ethanol *also* purchase D4 RINs from over-blenders of biodiesel (every gallon of biodiesel blended with diesel above mandated levels of BBD does not count toward the BBD mandate but still carries a 1.5 equivalence factor towards ethanol) so 1.5 times the level of biodiesel blended with diesel over the BBD mandate is also "not-blended" ethanol. Again, obligated parties purchasing these D4 RINs from ethanol blenders charge higher prices for gasoline. But now the blend wall increases the demand for biodiesel consumption and so the market for diesel is directly affected in that biodiesel prices and diesel fuel (biodiesel plus diesel) consumption are higher but diesel consumption (and hence diesel market prices) or lower as a result.

Following the important paper by Pouliot and Babcock (2014a), who correctly model the RIN price as a consumption subsidy for ethanol in both E85 and E10 blends, and as a tax on gasoline

[12] Pouliot and Babcock (2014b) provide a more detailed estimation of the marginal cost curves corresponding to channels 1 and 2, and their interaction effects.
[13] Recall we are assuming a very simple representation of the ethanol and gasoline market – see footnote 6.
[14] There is an indirect impact in increasing diesel prices as gasoline consumption and hence the amount of crude oil refined declines.

producers who are the obligated parties and required to purchase all RINs from blenders. To recoup the cost of the RINs, refiners charge a higher market price for gasoline to domestic blenders while the world price (and that received by domestic producers) of gasoline falls (there is a wedge now between domestic consumer and world/domestic producer market prices for gasoline).

But this does not negate the basic economics of a binding blend mandate in de Gorter and Just (2009) where gasoline consumption is taxed to support the ethanol market price (the ethanol market price is the same for consumers and producers as are domestic and world gasoline prices, but the latter decline due to the binding blend mandate). We now outline a general model that integrates the blend mandate model of de Gorter and Just (2009) and Drabik (2011) with that of Pouliot and Babcock (2014a) to disentangle the effects of a ethanol price premium due to a binding mandate and a high RIN price due to the costs of overcoming the ethanol blend wall, and determine the net impact on each of the gasoline and ethanol prices paid by consumers and received by producers.

We extend the blend mandate model of de Gorter and Just (2009) to include the important analysis of Pouliot and Babcock (2014a) and so clarify as to what a RIN price represents, how the cost of overcoming the blend wall reflects itself in the RIN price, and discern the differential meaning and effects of a RIN price versus the degree to which the mandate is binding (the ethanol mandate price premium over the free market ethanol price).

This paper sets up an equilibrium blend mandate model for ethanol along the lines of de Gorter and Just (2009). We allow for an ethanol blend mandate that exceeds a maximum technological threshold. This then naturally results in a blend wall situation that is dealt with by bringing in RINs corresponding to unblended ethanol from the biodiesel market. To properly account for the different energy content of ethanol versus gasoline, within the model, we express all quantities and prices in terms of gasoline energy-equivalent gallons.

Using physical quantities, the consumption of ethanol has to equal the production of ethanol and likewise, the supply and demand for gasoline have to be equal (recall that we do not consider trade in our model). But the mandated quantity of ethanol, a product of the blend mandate and the total fuel consumption (i.e., E10 denoted by C_{E10} and E85 denoted by C_{E85}) – the left-hand side of equation (3), exceeds the (physical) supply of ethanol at price P_E, $S_E(P_E)$, by the quantity corresponding to the supply of D4 RINs purchased by ethanol blenders; this is denoted by the term $Q_3(P_{RIN})$ on the right-hand side of equation (3)

$$\alpha\left(C_{E10}+C_{E85}\right)=S_E\left(P_E\right)+Q_3\left(P_{RIN}\right), \qquad (3)$$

where P_{RIN} denotes the price of a RIN. More specifically, the term $Q_3(P_{RIN})$ corresponds to the marginal cost (supply) of biodiesel RINs and converts the number of biodiesel RINs into its ethanol quantity-equivalent. One can also interpret equation (3) as equating the total demand for RINs (the left-hand side) to the total supply of RINs (the right-hand side).

A competitive refiner seeks to maximize profits, taking into account the obligation to purchase RINs from blenders. Mathematically,

$$\max_{\{G\}} \pi = P_G G - c(G) - \kappa G P_{RIN},$$

where P_G denotes the price of gasoline, G, paid by blenders and $c(.)$ is the cost function of a refiner. The first-order condition for refiner's profit maximization yields

$$c'(G) = P_G - \kappa P_{RIN},$$

which can be inverted to produce the gasoline supply curve

$$G = S_G\left(P_G - \kappa P_{RIN}\right),$$

from which follows that the difference between the price paid by a blender and the price received by a refiner is the implicit tax due to the RIN price equal to κP_{RIN}.

The profits of a competitive fuel blender can we written as

$$\pi = \underset{\substack{\text{revenues}\\\text{from selling}\\\text{fuel}}}{P_{E10}F} - \underset{\substack{\text{purchase cost}\\\text{of ethanol}}}{\bar{\alpha} P_E F} - \underbrace{\left(1-\bar{\alpha}\right)P_G F}_{\substack{\text{purchase cost}\\\text{of gasoline}}} + \underbrace{\bar{\alpha} P_{RIN} F}_{\substack{\text{revenues}\\\text{from selling}\\\text{RINs to refiner}}} = 0,$$

where F denotes the quantity of fuel blend produced and $\bar{\alpha}$ denotes the maximal permitted share of ethanol in an E10 blend; P_{E10} denotes the consumer price of E10. Because fuel is produced through a fixed proportion technology, the profits in equilibrium have to be zero. This yields a relationship between the price of E10, ethanol, gasoline, and RIN prices

$$P_{E10} = \bar{\alpha}\left(P_E - P_{RIN}\right) + \left(1-\bar{\alpha}\right)P_G,$$

and after including the fuel tax; converting it to energy terms for ethanol; and considering a fixed marketing margins, m_E (=0.28$/gallon), we obtain

$$P_{E10} = \bar{\alpha}\left(P_E + \frac{t}{\lambda} - P_{RIN}\right) + \left(1-\bar{\alpha}\right)\left(P_G + t\right) + m_E. \quad (4)$$

Likewise for the price of E85 we have

$$P_{E85} = \gamma\left(P_E + \frac{t}{\lambda} - P_{RIN}\right) + \left(1-\gamma\right)\left(P_G + t\right) + m_E, \quad (5)$$

where the parameter γ denotes the share of ethanol in the E85 blend (γ = 0.74 is the US national average) and the marketing margin is assumed to be the same as for E10. Following Pouliot and Babcock (2014a), we do not allow for cross-subsidization (hence two zero-profit conditions) where blenders have an overall zero-profit condition, losing money in E85 blending and having excess profits in blending E10). Notice that equations (4) and (5) provide an alternative economic interpretation to RIN prices: the competition among blenders causes the "subsidy" associated with the sale of the ethanol RIN to obligated parties to be passed onto consumers (so the system forces the price paid by consumers for ethanol to be the market price of ethanol minus the RIN price in each of E10 and E85 prices).

The fuel market clearing condition requires that total fuel demand (i.e., E10 and E85) has to be equal to the total fuel supply (i.e., gasoline and ethanol)

$$D_{E10}\left(P_{E10}\right)+D_{E85}\left(P_{E85}\right)=S_G\left(P_G-\frac{\alpha}{1-\alpha}P_{RIN}\right)+S_E\left(P_E\right), \tag{6}$$

where $\alpha/(1-\alpha)=\kappa$, as per equation (2).

The equilibrium in the ethanol market requires that the total supply of ethanol has to be equal to the total use of ethanol in both fuel blends

$$S_E\left(P_E\right)=\bar{\alpha}C_{E10}+\gamma C_{E85}. \tag{7}$$

Finally, we close the model by specifying the total consumption of E10 and E85 C_{E10} and C_{E85}, respectively

$$C_{E10}=D_{E10}\left(P_{E10}\right)-X\left(P_{E10}-P_{E85}\right) \tag{8}$$

$$C_{E85}=D_{E85}\left(P_{E85}\right)+X\left(P_{E10}-P_{E85}\right) \tag{9}$$

Equations (6) and (7) represent the idea that owners of flex cars have the choice of consuming either E10 or E85 and their decision will depend on the parity gap between the two fuels, represented by $P_{E10} – P_{E85}$. The function X(.) describes the behavior of flex cars owners as not all of them will automatically switch to a less expensive fuel alternative when the relative prices change; this function represents the shift in demand of E85 versus E10, and is represented by a logistics curve in Figure 3 in Drabik et al. (2015) for Brazil between D_{E25} and D_{E100}. Therefore, it is important to capture two simultaneously occurring effects of a fuel price change. The first one is a move along the downward-sloping demand curve [represented by D_{E10}(.) and D_{E85}(.) functions] and the horizontal shift of the demand curves by the same distance but in opposite direction because of changing preference of flex car owners, X($P_{E10} – P_{E85}$). The shifter" function X(.) is calibrated as in Drabik et al. (2015).

Equations (3) – (9) represent a system of seven equations in seven endogenous variables to solve for: C_{E10}, C_{E85}, P_E, P_{E10}, P_G, P_{RIN}, P_{E85}.

3. Empirical Results

For D6 RIN prices for ethanol, we adopt the approach taken by Pouliot and Babcock (2014a), calibrated to stylized data for 2015 using elasticities and parameters commonly found in the literature (e.g., de Gorter and Just, 2009; Drabik, 2011; Pouliot and Babcock, 2014a; Holland et al., 2014).

We calibrate the model to the year 2015 and simulate three scenarios. First, we model what would happen if we remained at the "edge of the blend wall" by assuming an initial blend mandate price premium with zero E85 sales and D4 RIN purchases.[15] The edge of the blend wall is defined as the actual blend ratio for E10 of 9.82 percent, based on EPA's proposed RFS for 2015. It is less than 10 percent, among other reasons, because of demand for E0. Second, we calibrate our model to the actual situation of overall blend mandate ratio of 10.55 percent in 2015 (the overall mandate is beyond the 9.82 percent blend wall). We do these first two simulations in two market environments: with and without the blend wall. Third, we expand the blend mandate beyond what was required to see if the system is stable. In other words, would it be possible to achieve the 15 billion gallon ethanol mandate of the 2007 EISA? We find it would not be possible, with our results subject to the usual caveats (e.g., our model is static).[16]

The empirical results for a blend wall model are reported in Table 1. The first column presents the outcome if we were at edge of the blend wall with zero (insignificant) RIN prices and E85 consumption (the market situation as in a traditional blend mandate model as depicted in Figure 1 of de Gorter and Just 2009). The market prices in the first column corresponding to the 9.82 percent mandate are the same for both sets of supply elasticities. Notice that the RIN price is zero, because the blend wall is not an issue, thus no excess RINs are generated.

The second column of Table 1 is the outcome of the observed overall blend mandate of 10.15 percent. A comparison of the results of the first two columns therefore informs us about the effect of increasing the blend mandate (binding in both cases) with a blend wall. RIN prices increase to about 60 cents per gallon, and the price of gasoline goes up about 6.7 cents per gallon, reflecting the implicit tax obligated parties have to pay for the cost of the RINs.

As expected, the price of E85 declines sharply by about 42 cents per gallon. However, the price of E10 increases slightly even though (a) the RIN price subsidizes ethanol price in the fuel blend; and (b) a higher blend mandate would lead to a lower E10 price if there was no blend wall, given that the gasoline supply curve is assumed to be more inelastic than ethanol supply.[17] These differing price developments occur despite gasoline and RIN prices increasing. The reason is a different share of ethanol in both fuel blends. Whereas the E10 blend contains only up to 10 percent of ethanol, the share is 74 percent for E85. Therefore, the subsidy effect of the RIN price on the

[15] Consider Figure 1 of de Gorter and Just (2009) where there is an ethanol price premium with the mandate but no blend wall (lay this figure next to Figure 8 of this paper but with zero E85 sales and D4 RIN purchases – the demand for ethanol RINs beyond the blend wall is zero).

[16] Pouliot and Babcock (2014a) also have their model fail to solve after a mandated volume of 13.75 billion gallons.

[17] The de Gorter and Just (2009) finding is that fuel prices (the price of E10 here) decline with an increase in the blend mandate if the supply elasticity for ethanol is greater than that for gasoline. Hence, the results in Table 1 are reported under two sets of supply elasticities: when the ethanol supply elasticity exceeds that for gasoline, and vice-versa.

ethanol part of the final fuel blend is more than offset by the tax effect on the gasoline part in E10, resulting in a small price increase in E10 prices. However, the subsidy effect dominates in reducing E85 prices due to a high share of ethanol in E85, pushing the consumer price of E85 down as the RIN price increases.

Likewise, the market price of ethanol goes up slightly with the increased mandate. Finally, the mandate premium goes up very slightly.

Table 1: Price Effects of Increasing a Mandate under a Blend Wall; 2015

	(1)	(2)	(3)	(4)	(5)
Mandate:	9.82%	10.15%	10.82%*	10.82%**	10.64%**
Scenario:	Edge	Actual	-----------Max----------		Fixed P_{RIN}
Price of RIN ($)	0.000	0.595	3.293	3.303	2.000
Price of gasoline ($/gallon)	1.760	1.827	2.148	2.154	1.994
Implicit tax on gas. producer ($/gallon)	0.000	0.067	0.400	0.384	0.238
Price of E85 ($/gallon)	2.357	1.936	0.037	0.043	0.960
Price of E10 ($/gallon)	2.507	2.509	2.536	2.541	2.524
Market price of ethanol ($/gallon)	1.526	1.529	1.547	1.563	1.557
Mandate premium ($/gallon)	0.441	0.444	0.462	0.478	0.425

* Ethanol supply elasticity = 2; gasoline supply elasticity = 0.8.
** Ethanol supply elasticity = 1; gasoline supply elasticity = 1.6

To determine if 15 billion gallons of ethanol could be mandated or not, we increased the blend mandate accordingly but the model did not solve with a blend ratio above 10.82 percent (results in the third and fourth columns in Table 1). Once ethanol consumption reached 14 billion gallons, the model becomes unstable and fails to solve. The price of RINs go up sharply, as does the domestic price of gasoline, reflecting the increasing tax on gasoline producers (approximately $0.40 per gallon under either elasticity combination). The gasoline price received by refiners in the third column of Table 1, for example, can then be calculated as $2.148 minus $0.400 equals $1.748 per gallon. The price of E85 declines. Notice as the blend mandate increases to 10.82 percent, the consumer price of E10 increases regardless of the underlying gasoline and ethanol supply elasticities. This is in contrast to the well-established results for a model with no blend wall, the empirical results of which we show below. The higher market (producer) price of ethanol as compared to the 9.82 percent mandate implies more ethanol produced, meaning that biodiesel (D4) RINs are not the only channel through which the ethanol market shows the compliance with the RFS indicating—more ethanol is consumed also by discounting the price of E85 and building infrastructure for flex vehicles. Finally, the mandate premium increases as the market price of ethanol increases, while the free market ethanol price is fixed at baseline value.

The final column in Table 1 is the same simulation as in the fourth column except we fix the RIN price at $2 per gallon once that level is reached. The model specifies there will be investment in E85 infrastructure and more flex cars sold with more ethanol consumed per flex cars. Once a blend mandate of 10.64 percent is reached, ever increasing levels of the blend mandate percentages result in a downturn in ethanol market prices (albeit slight) and ethanol consumption as the "tax" of the RIN price overtakes the subsidy effect such that ever increasing mandates simply have the market go (ever so slowly) in the opposite direction what is intended. It is not that the model fails to solve; it is an ever evolving equilibrium going in the wrong direction and is a result of the basic economic fundamentals of a blend mandate with a blend wall and fixed RIN prices at $2 per gallon.[18] The mandate premium falls with a fixed RIN price in Table 1.

Table 2 gives the results if there was no blend wall. In this situation, we only model the demand for E10, under the assumption that all vehicles can take blends exceeding 10 percent of ethanol. Unlike with a blend wall (Table 1), a higher blend mandate affects the fuel price differently, depending on the relative supply elasticity of gasoline and ethanol.[19] The gasoline price decreases unambiguously, however, because under the no blend wall case in Table 2, the ethanol production due to the mandate is always financed by gasoline producers (and also fuel consumers if the fuel price increases). The price of ethanol increases more when the ethanol supply is less elastic.

Table 2: Price Effects of Increasing a Mandate under no Blend Wall

	(1)	(2)	(3)	(4)
Mandate:	9.82%*	10.82%*	9.82%**	10.82%**
Scenario:	Edge	Max	Edge	Max
Price of gasoline ($/gallon)	1.760	1.743	1.760	1.749
Price of E10 ($/gallon)	2.508	2.505	2.507	2.519
Market price of ethanol ($/gallon)	1.527	1.606	1.526	1.683
Mandate premium ($/gallon)	0.442	0.533	0.441	0.606

* Ethanol supply elasticity = 2; gasoline supply elasticity = 0.8.
** Ethanol supply elasticity = 1; gasoline supply elasticity = 1.6.

To summarize, the key takeaways when comparing the empirical results in Tables 1 and 2 are:

- Under the case of a binding blend wall, E10 prices increase empirically
  - regardless of relative supply elasticities, unlike with the situation of no blend wall
  - regardless of the initial effect of RIN prices lowering E10 prices slightly (as analyzed with the RIN bundle composition) before market effects are accounted for

[18] Our model, like others, is static and so the usual caveats apply. For example, if there was a large shift up in corn supply in the following year, it may have the market come out of this paradoxical situation (but then again, corn supply could drop suddenly as in 2012).
[19] This is the fundamental finding of de Gorter and Just (2009) that a higher blend mandate can lead to lower fuel prices under a certain constellation of gasoline and ethanol supply elasticities.

- The consumer price of gasoline goes up 38.8 cents per gallon (instead of declining 1.7 cents a gallon with no blend wall)
- The market price to gasoline producers always decreases, but more so with a blend wall
- The market price of ethanol increases 2.1 cents per gallon with the blend wall (versus an increase of 7.9 cents per gallon without the blend wall)
- The mandate premium increases 0.03 cents per gallon with the blend wall (instead of 9.1 cents per gallon with no blend wall)

The societal costs of the blend wall summarized above mean everybody is worse-off with the blend wall (and with the associated high RIN prices reflecting the costs of overcoming that blend wall): consumers and producers of ethanol and gasoline. Above and beyond the blend wall, there are costs to society of a binding mandate.

To summarize, there are several implications of not analyzing the impact and source of changing RIN prices in a market model of ethanol, and of the costs of overcoming the blend wall. Depicting RIN prices as a zero-sum game in terms of having no net effect on consumer fuel prices (Irwin and Good, 2013 as quoted in EPA (2015) while Burkholder (2015), Stock (2015) and Pouliot and Babcock (2014a), using consumer fuel prices as the only indicator, can be misinterpreted to imply RIN prices can be a positive sum game). In fact, the section on RINs in EPA (2015, pages 33118 to 33120) understates the costs of overcoming the blend wall and is misleading by emphasizing the subsidy effect of the RIN price as a means of reducing the consumer price of ethanol as if overcoming the blend wall helps all fuel consumers.

To provide more insight as to how RIN prices and mandate price premiums are related, consider the empirical results in Tables 1 and 2. In moving from the edge of the blend wall to various mandated blend ratios in Table 1, the mandate premium goes up very slightly compared to the sharp increase in RIN prices (that surpass the mandate premiums). It is typical in the literature that economists confuse RIN prices with the mandate premium, the latter truly measuring the extent to which the mandate is binding (relative to free market ethanol prices) and hence the distortionary effects on the various markets. So the RIN price does not reflect the extent to which the mandate is binding but the extent to which the blend wall is costing society (with each affecting the other).

Comparing the empirical results in Tables 1 and 2, clearly the mandate price premium in Table 2 increases with the mandated blend ratio much more than is the case with a blend wall model (Table 1). The blend wall puts a brake on the mandate.

Finally, it should be noted that the ethanol RIN market is not like a cap and trade scheme where one measures the welfare effects in the product market itself. For example, the welfare effects of the RIN market should not be analyzed with the supply and demand curves for ethanol alone (unlike for the welfare economics of a cap and trade scheme where it is analyzed in the product market where the permits refer to, like that for analyzing a production and import quota).[20] Instead, the welfare economics of a RIN market is analyzed in Figures 6 and 8, and any repercussions on prices and quantities of fuel supplied and demanded, the welfare effects have to be analyzed under

[20] The efficiency of a trading system for RINs is analogous to that of a trading scheme or permits in a cap and trade scheme; i.e., it is the most efficient way, given the policies and circumstances. See de Gorter, Drabik and Just (2013). But that is a different issue.

the demand curves for E10 and E85, and above the supply curves for ethanol and gasoline. The reason for why the ethanol RIN market is not modeled like a cap and trade scheme is that the blend mandate ratio is a minimum requirement, an obligation; not a right (and maximum) like with cap & trade permits and production (import) quotas. This is an important distinction.

Implication for the RFS program in 2016 and beyond, the Possibility of the RFS being Economically Infeasible

Some commentators like Stock (2015, p. 7) believe the EPA's proposed 2014 RFS ruling is "a conservative approach that stays within the E10 blend wall while attempting to support low-carbon domestic advanced biofuels" and instead, favor:

"…an ambitious plan for expanding both conventional and advanced biofuels…would entail a conscious decision to expand ethanol consumption beyond the E10 blend wall through higher ethanol blends, in particular E85. But because this path would entail a substantial increase in volumes of renewable fuels, by itself it runs the risk of high and economically inefficient compliance costs. The analysis in this paper suggests that the third expansive path is the most likely to achieve the twin goals of promoting low-carbon domestic advanced fuels and enhancing macroeconomic energy security.

Stock (2015) recognizes there are risks and costs. One such risk is the possibility of the RFS to be infeasible. In other words, the market and policy mechanisms may be such that the system may fail to converge and so exhibit very unstable outcomes. When increasing the blend mandate, our model fails to solve after a certain point, indicating the possibility of such infeasibility.

The basic idea of infeasibility is as follows: if total motor gasoline is following a downward secular trend and the mandated volumes of ethanol are increasing exponentially, then it follows that the mandated blend ratios grow exponentially each year even more. But on top of that, because of the blend wall, the growth of ethanol consumption can only occur if RIN prices rise each year to overcome the cost of the blend wall. This is a tax on gasoline production, causing consumer gasoline prices to rise and cause even further reductions in gasoline consumption, causing the blend mandate ratio to grow even more. Under some circumstances, the system may become unstable, as witnessed by our model failing to solve over time.

Taking our model of the blend wall and blend mandate outlined earlier, we tested for the possibility of an infeasible outcome. We analyze the main shock occurring to the system every year: exponentially increasing mandated ethanol shares. For the set of baseline supply and demand elasticities, we find that our model always fails to solve at some point—it is only a question of time when that happens. This is can be explained by examining results in Table 3.

Initially, we assume that the blend mandate increases exponentially at the rate of 3 percent a year. In that case, the system would collapse after 7.38 years. As the annual mandate growth increases to 5 percent a year, the mandate becomes infeasible after 4.56 years. We also simulate a mandate growth of 9 percent a year, which reflects historical observations. In that case, the mandate would become infeasible approximately after two and half years.

The first row of Table 3 presents the initial market prices (in italics). The subsequent rows show where the prices would be at the point of infeasibility. Table 3 presents an interesting result: the point of infeasibility of the RFS is associated with the same market prices, regardless of the rate of growth of the mandate. The only difference the growth rate makes is the time when the point of infeasibility of the system will be attained.

Table 3: Possibility of an Infeasible RFS with the Blend Wall

Growth rate of mandate	Years until collapse	Price of E10 ($/gallon)	Price of E85 ($/gallon)	Price of gasoline ($/gallon)	Price of ethanol ($/gallon)	Price of RIN ($)
		3.579	*2.981*	*2.900*	*2.470*	*0.500*
0.03	7.53	3.734	0.036	3.526	2.459	4.690
0.05	4.56	3.734	0.036	3.526	2.459	4.690
0.09*	2.58	3.734	0.036	3.526	2.459	4.690

Notes: Initial prices in italics. The baseline calibrated to 2013 with much higher gasoline prices than 2015.
* Growth rate of ethanol mandated in 2007 EISA.

It should be noted that these "collapses" of our model occur at fairly high RIN prices so over time, E85 sales may increase. The risk of instability is therefore more likely to be a short run phenomenon.

But on the other hand, we capped the RIN price at $2 per gallon (assuming the marginal cost of overcoming the blend wall will flatten out at some level). The empirical results are given in the final column of Table 3. In this instance, the model continued to solve as the blend mandate ratio is increased but total fuel consumption declined slowly, as did the ethanol market price and ethanol consumption. Even if infinite supplies of E85 are forthcoming at $2 per gallon RIN price, the RIN prices are too much of a tax on fuel consumption to support ever increasing mandated ethanol volumes as in the 2007 EISA.

4. An Analysis of the EPAs Understanding of RIN Prices

Preceding the EPAs proposed standards for the 2014, 2015, and 2016 RFS on June 10, 2015 (EPA 2015), Burkholder (2015) of the EPA published a now well known "RIN market memo" on May 14. The stated purpose of Burkholder's (2015) memo is "to describe and explain the factors that caused this increase in the price of …. (D6) RINs, and the impact this increase in RIN prices may have had on retail fuel prices." This memo follows the arguments of Stock (2015) published a month earlier quite closely while the EPA reinforces the arguments made in Burkholder (2015). The other major issue addressed in the Burkholder memo (and in Stock 2015) is the insufficient RIN price pass through to the retail level. We address each issue in turn.

D6 RIN prices: Causes and consequences

Burkholder (2015) and the EPA (2015) both emphasize the basic result of Pouliot and Babcock (2014a) that competition among blenders who receive the subsidy from their sale of RINs to obligated parties result in this subsidy to be passed onto to consumers in the form of lower ethanol prices. This means consumers are better off and higher prices for ethanol result. But Pouliot and Babcock (2014a) also emphasize that obligated parties (e.g., refiners) who have to buy RINs recoup these costs by taxing gasoline producers and importers by increasing the domestic market price of gasoline to blenders while world market prices decline.

We show earlier in this paper that adding a blend wall to an already binding mandate (with mandate price premiums for ethanol) means high RIN prices reflect the costs of overcoming the blend wall. These are real costs to be borne by producers and consumers of ethanol and gasoline (along with actors in the biodiesel and diesel markets where D4 RINs are also purchased to overcome the costs of the blend wall). These costs take the form of higher E10 prices, lower overall fuel consumption and lower market prices for ethanol and gasoline. And this is all because of the costs of overcoming the blend wall. Before the blend wall, RIN prices reflected an efficient way to implement the RFS and as such, lowered costs to all. But with the blend wall, the increase in RIN prices reflect the opposite: the costs of overcoming the blend wall and impose costs on all actors in each sector (including the taxpayer as lower fuel tax revenues are collected).

All of the aforementioned papers omit the costs of the binding blend mandate reflected in the mandate price premium for ethanol. Burkholder (2015) admits that he "does not quantify the total cost of the RFS program to consumers or other parties," even though he acknowledges that the program "is likely to have a cost if the cost of renewable fuels is greater than the petroleum based fuels they replace on an energy equivalent basis and if this cost outweighs the overall decrease in the cost of transportation fuel that results from increased fuel supply."

As for the first statement, corn ethanol has almost always been more expensive in energy terms than gasoline but Burkholder does not explain how one calculates the cost, nor does he give an estimate by how much more ethanol has cost consumers as a result. We do so in Table 4 where the first column gives the ethanol mandate price premium in cents per gallon.

In other words, the observed ethanol price exceeded free market levels by an estimated 51 cents per gallon in 2014,[21] even though the RFS was scaled back (it would have been higher if the 2014 RFS was not scaled back). Multiplying this price premium by the gallons of ethanol consumed gives the total gross costs to consumers. The second column in Table 4 shows that the value of this added cost totaled 53.7 billion dollars over the life of the program. Because of low crude oil prices in 2015, mandate price premiums continue to prevail and so costs society. In addition to the gross cost of the ethanol price premium due to the mandate in Table 4, missing in the debate is the extremely high cost to society of higher grain/oilseed prices due to the RFS. Economists are becoming more aware of the impact biofuels have had on crop prices – see the work of Wright and colleagues work summarized in Wright, 2014, and the work of de Gorter, Drabik and Just, summarized in de Gorter et al., 2015.[22]

[21] The free market ethanol prices has been explained earlier in this paper and more fully in the discussion of equation 2.2 on p. 31 in de Gorter et al., 2015. To reiterate, the intuition is as follows: because a gallon of ethanol obtains on average only 70 percent of the miles as a gallon of gasoline, consumers are therefore willing to pay only 70 percent of the gasoline price (inclusive of the fuel tax) for ethanol, and that is how the first column in Table 4 is calculated.

[22] It should be noted that Wright (2014) takes a very different approach than de Gorter et al. (2015) yet comes to the same conclusions.

Table 4: Annual mandate price premium costs for ethanol

	c/gal	mn $
2007	0.65	4,329
2008	0.60	5,749
2009	0.63	6,906
2010	0.48	6,207
2011	0.79	10,190
2012	0.42	5,370
2013	0.60	7,986
2014	0.51	6,924
Total		**53,661**

Source: Based on spot ethanol prices obtained from CARD, fuel tax data from GasPriceWatch.com and ethanol consumption figures from the EIA Short-Term Energy Outlook (STEO)

Table 5 below shows the transfers averaged $285.4 billion from 2012 to 2015, which represents a revision from $328.4 billion per year averaged over 2007 to 2011[23]. Part of the controversy is that the corn-ethanol lobby is not getting its promised 15 billion gallon implied mandate (the difference between the total renewable fuel and advanced renewable fuel mandates of the RFS). This "subsidy" to producers and cost to consumers shown in Table 5 would have been higher had the EPA not scaled back the RFS. The value-added agricultural sectors of the United States (included workers in the processing and distribution of dairy, poultry, egg, livestock and meat products) pay a heavy price for the RFS.

Table 5: Increase in corn prices due to mandate premiums[24]

	Premium ($/bu)	Premium as a ratio of corn price	Corn price ($/bu)	Transfers to grain/oilseed producers** (mn $)
2012	2.40	0.35	6.94	397,719
2013	1.78	0.29	6.18	316,361
2014	0.39	0.10	4.02	70,339
2015*	2.10	0.58	3.64	357,090
			Average	**285,392**

Source: Calculated based on spot Iowa corn, ethanol and DDGS prices obtained from CARD, as well as fuel tax data from GasPriceWatch.com *Projected ** Worldwide

[23] Table 3.4 on p. 61 of de Gorter et al. (2015)

[24] We assumed profits which were in excess in 2013 so the increase in corn prices were not nearly as high as it otherwise would or could be if there were no capacity constraints that causes excess profits in ethanol production in the first place.

Just to show how costly the blend wall is to society, consider the inefficiency costs of the mandate before the blend wall and after the blend wall. Two studies from professors at Iowa State University inform us. First, Cui et al. (2011) estimated inefficiency costs of $1.7 billion with a mandated increase in ethanol consumption of 11 billion gallons ($155 million of inefficiency costs for every 1 billion gallons of ethanol) in 2009, well before the blend wall became binding. Second, Pouliot and Babcock (2014a) estimate inefficiency costs of the blend wall and RIN prices to be $533 million per 1 billion gallon increase in the ethanol mandated. This is a striking increase in inefficiency costs.

The cost to consumers of grains/oilseeds are monumental due to biofuel policies as it is, without having ethanol consumption at 15 billion gallons as the corn and ethanol lobby groups desire. But the EPA increased biodiesel's share of the mandate relative to ethanol in deviating from the 2007 EISA. This directly affects soybean oil prices that are locked onto diesel prices and so affects soybean prices. Because soybean prices and other field crop prices are linked through competition for land (and crop rotations) and substitution in demand, allowing D4 RIN prices to exceed D6 RIN prices may not give the crop price relief anticipated.

Hence, this leads to another inefficiency, namely not having equalized RIN prices across biofuel categories. In January 2013, the prices of all RINs converged (prior to that, D4 and D5 RIN prices were far higher than D6 RIN prices). All RIN prices were pretty much equal from January 2013 until EPA's June 10 2015 proposed RFS standards for 2014, 2015 and 2016. Currently, D4 RIN prices are close to double that for D6 RIN prices. This implies more inefficiency in the market.

Furthermore, BBD is considered amongst economists to be a very inefficient biofuel compared to ethanol, reflected by its blend ratio of less than 2 percent and both higher D4 RIN prices and mandate price premiums in the past and now again. The fact that BBD was used to breach the blend wall between January 2013 and June 2015 is an indicator that breaching the blend wall is truly expensive.

As for the second statement in the foregoing Burkholder sentence last discussed "…and if this cost outweighs the overall decrease in the cost of transportation fuel that results from increased fuel supply" refers to the decrease in world crude oil prices with more ethanol supply. The statement implies that it will benefit domestic consumers. However, this assumes that domestic consumers consume gasoline at the lower world price, which is not the case for two reasons. First, although the market price of gasoline goes down for consumers in the rest of the world, the U.S. blend mandate is a tax on domestic gasoline consumption so the price of gasoline to domestic consumers goes up to pay for the extra $53.7 billion due to higher ethanol prices, as described in Table 3. Second, as Pouliot and Babcock (2014a) have shown, one market effect of a RIN price is to drive a wedge between the gasoline price paid by blenders and the price paid by producers (importers) who are obligated to pay for the RINs. This results in an export subsidy for gasoline, the costs of which we do not analyze in this paper (see Pouliot and Babcock 2014a)

Furthermore, Burkholder (2015) fails to separate out the social cost of an ever increasing mandate from the costs of overcoming the blend wall, two distinct concepts. It is true that an increasing mandate will cause the blend wall to become binding and thereby affect RIN prices. But RIN prices are directly a result of the blend wall which would not be an issue without the RFS.

Burkholder (2015) implies the RIN price is a mandate premium and the mandate has just become binding and so mandate premiums arise. But these mandate premiums have always been there. The large increase in D6 RIN prices have to do with the blend wall and as such is a separate issue from the mandate price premium for ethanol. We showed in our empirical results earlier that an increase in RIN prices due to an increase in the blend mandate results in a much lower increase in the observed mandate premium as gasoline prices rise (instead of fall without the blend wall) and ethanol prices do not rise as much because of the blend wall. This means total social costs of the increasing mandate go up.

An example of this misunderstanding by Burkholder (2015) stating that "as the demand price for ethanol shifts from a volumetric relationship with gasoline, as was the case for E10" assumes consumers are unaware of differential miles achieved between a gallon of ethanol and a gallon of gasoline or do not demand miles traveled. Ethanol was never priced on a volumetric basis with gasoline. Ethanol has rarely been priced on a miles equivalent basis either because of the binding mandate. Consumers had no choice. Ethanol was not priced by consumers demanding miles because consumers were not allowed to choose; that is what a mandate does. The ethanol price was determined by corn/ethanol/fuel market conditions, which impacts the extent to which the mandate was binding. Ethanol prices were not determined on a volumetric basis vis-à-vis gasoline and were not priced on a miles per gallon equivalent basis either because of the binding mandate. One needs to differentiate the mandate price premium from the RIN price arising because of the blend wall. The ethanol supply price is higher than gasoline prices, which will always occur under a binding mandate. Pre-2013, ethanol was also never sold on a volume basis – mandate price premiums can be very high but because of the mandate; not because of consumer choice. High D6 RIN prices are due to the blend wall. The analysis must separate out the mandate price premium from the blend wall and corresponding RIN prices.

On p. 7, Burkholder (2015) states "When ethanol is sold in an E10 blend we believe that the demand price is approximately equal to the price of the gasoline fuel into which it is blended on a volumetric basis, despite the fact that ethanol contains approximately 33% less energy per gallon than gasoline." This again confuses what consumers demand versus what they are forced (mandated) to pay. Besides, the mandate premium varies a lot (see figure 3.2 on p. 52 of de Gorter et al. 2015) so such volumetric pricing did not occur.

One key point the Burkholder memo (and that of Stock 2015 and EPA 2013) emphasize is that high RIN prices do not affect retail prices of E10 "…because the RIN price, rather than acting as an additional cost, generally acts as a transfer payment between parties that blend renewable fuels and obligated parties..." But this ignores the market effects of high RIN prices; it only points to the first round accounting effects of competitive blenders reducing ethanol prices to consumers by the RIN price. But it is not a zero-sum game or even positive-sum outcome but a negative sum game once market effects are taken into account as the empirical results of our model simulations earlier showed.

Burkholder's analysis is like that of Stock (2015, p. 18) who intentionally sets up a simple case of accounting to explain the mechanics (but not social costs) of the blend wall and RIN price mechanism:

"Because much of the debate has focused on the short-*run link between RIN prices and fuel prices, the discussion here focuses on the short run, over which supply does not change and RIN prices change not because of current supply and demand considerations but for some other reason, such as changes in policy expectations*."

This exercise by Stock (2015) and repeated in the Burkholder memo does not consider market forces affecting RIN prices ("*RIN prices change not because of current supply and demand considerations but for some other reason*…) nor of the costs of overcoming the blend wall. In this simple world, it is possible to have positive sum games as Stock (2015, p. 18) goes on:

"*Although specific tax and subsidy values depend on the RIN prices and the obligation percentages, the structure has the effect of taxing the lowest-renewable final fuel (diesel) and subsidizing the highest-renewable fuel (E85), with E10 receiving a slight subsidy because it has slightly more renewable content than the 2013 total renewable fractional obligation*."

Again, in a strictly accounting sense with no regard for supply/demand considerations and the market forces that affect RIN prices, this is a technically correct statement, like the Burkholder memo (p. 2) "…rather than acting as an additional cost, generally acts as a transfer payment between parties".

Burkholder (2015) cites Irwin and Good (2013) that RIN prices are a zero-sum game. But this is not the case because high D6 RIN prices are due to the blend wall and represent a social cost. Price premiums for ethanol also increase with ever increasing mandated ethanol blend ratios. These both result in higher costs to fuel consumers of ethanol.

Finally, the Burkholder memo attempts to explain the D6 price spike principally through examining the shift from E10 to E85 consumption as the marginal provider of the excess RINs needed. We showed in Figure 5 that E85 sales was an insignificant source of excess RINs, compared to D4 RINs and reduced E0. Therefore, Burkholder (2015) largely ignores the role of excess blending of biodiesel, and its societal costs by increasing the cost of every good and service in the country through higher fuel prices to consumers for gasoline and diesel.

Insignificant pass through of D6 RIN prices to retail fuel prices

One major issue in the discussion of RIN prices and the blend wall by the two EPA papers is the extent to which RIN prices are actually passed onto consumers. For example, on p. 12, Burkholder (2015) argues there is "…the lack of competitive markets leading to limited RIN value pass through to consumers in many markets." On the other hand, Burkholder (2015) and EPA (2015) continuously argue RINs represent a pure transfer to consumers with no net change in retail fuel prices while at the same time discuss in various places in their respective texts that there is imperfect competition in the fuel supply chain and RIN prices are not passed onto consumers, especially in the E85 market. One cannot have it both ways. Either RIN prices are subsidies to consumers with lower retail prices for E10 or E10 prices go up because of market power by blenders and retailers. But we have shown so far that once you take into account of market effects, E10 prices do go up, even if the first round effect of RINs is to subsidize consumer prices for ethanol, and independent of market power. This is because high RIN prices reflect the costs of overcoming the blend wall.

The question now becomes, have RIN prices been passed onto consumers? The empirical research is scarce but Stock (2015, p. 19) provides empirical evidence that RIN prices were not passed onto consumers of E85 "Regression analysis that includes lagged effects suggests that of a $1 increase in RIN prices, roughly one-third is passed through to consumers in the form of lower E85 pump prices."

Instead of doing regressions, we look at the issue from a different perspective. Note first that in theory, discounting the ethanol price by the price of the RIN does not necessarily mean parity pricing between E85 and E10. There is no necessary value of RIN prices that would result in the price of E10 in equation (4) above be equal to the price of E85 determined by equation (5) above. Each price depends on a number of parameters and the RIN price has to be the same in each equation. Having said that, Figure 6 plots the free market ethanol price against the observed ethanol price less RIN price since early 2013. The results show there has been a strong relationship between these two time series data, suggesting some validity to Burkholder's hypothesis that parity pricing is occurring in that ethanol prices less the RIN price are tracking the free market ethanol prices. But that is not requiring the price of E85 and E10 to be equivalent on a miles per gallon basis. These are two different concepts.

Furthermore, Anderson (2012) shows E85 has been consumed with discounts less than that of mileage parity in the past. Parity pricing is calculated to be a 20 percent discount in the price of E85 over E10.[25] Note also that the mandate has been fulfilled every year. Even EPA's proposed 2014 rule (that was never finalized) was not only surpassed, even the upper bound given was surpassed. So if E85 consumers are willing to pay a premium for E85 over E10 (on a miles per gallon attained) as Anderson (2012) so thoroughly showed, then why fault the industry for not passing on the discount? Or perhaps the discount has been passed on as we do not have the appropriate data?

We use two sets of data for the price discount afforded E85 over E10. The first price series is published by the Renewable Fuels Association (RFA) website http://www.e85prices.com/ and is based on non-random sampling so issues of accuracy arise (Stock, 2015). Figure 7 plots this published E85 price discount against E85 sales. Consumers did increase E85 purchases in tandem with the E85 published price discount more in 2014 than in 2013 but E85 sales seem to drop off in significantly in relation to the E85 price discount in 2015.

The second price we used for E85 was constructed in the following way. We first solved for the marketing margin m_E in determining the E10 price using equation (4) that uses monthly time series data that predicts a P_{E10} with an average error of zero compared to the observed P_{E10}. The value for marketing costs m_E was 28 cents, versus 26 cents used in the model by Pouliot and Babcock (2014a). Using 28 cents per gallon marketing margin for E85 prices, we constructed a price for E85 (P_{E85}) from equation (5). This constructed price uses the same data from which we had

[25] This assumes (a) a gallon of ethanol gets 70 percent of the mileage of a gallon of gasoline; and (b) the average gallon of E85 contains 75 percent ethanol by volume.

constructed P_{E10} prices that were on average equal to the observed or reported P_{E10} price, and so presumably does not suffer from bias using nonrandom data. From that, we constructed a "constructed" E85 price discount.

There are two key characteristics of this "constructed" E85 price discount shown alongside that of the published E85 discount in Figure 7. First, the data in Figure 7 shows the constructed E85 price discount (the right hand side vertical axis) is much higher (compared to the discount calculated from the published E85 price reported by the RFA) and often above the 20 percent indifference value. Second, E85 sales follow the constructed E85 price discount much more than the published price discount obtained from the RFA website.

The next exercise is to relate the two different price discounts to the observed RIN prices. This is shown in Figure 8. Our constructed E85 price discount tracks the RIN prices more closely early on but in following years, as the RIN price falls, both E85 price discounts hold up compared to the early part of 2013, suggesting the pass through is higher after 2013. Figure 8 does provide some evidence that RIN prices did result in E85 prices being discounted more. Such a positive relationship between D6 RIN prices and E85 price discounts does not prove E85 sales went up (the link with E85 sales is given in Figure 7) but that the outcome cannot be blamed on the market power of firms in the fuel supply chain.

5. Concluding remarks

This paper clarifies the relationship between the blend wall, RIN prices and ethanol mandate price premiums. Although high RIN prices are a subsidy to ethanol consumers, high RIN prices mean high costs of overcoming the blend wall through over-blending of biodiesel and E85 sales expansion. Obligated parties, being forced to buy RINs, recover the costs by increasing the gasoline prices charged to blenders. Compared to no blend wall, the costs of overcoming the blend wall mean everybody is worse-off with ever increasing mandated volumes of ethanol: consumers and producers of ethanol and gasoline. Above and beyond the blend wall, there are costs to society of a binding blend mandate.

The EPA's Burkholder RIN market memo and EPA's proposed RFS standards for the 2014, 2015, and 2016 correctly identify RIN prices to be a first round consumer subsidy but there are weaknesses and inconsistencies in EPA's methodological approach that include:

- They conclude incorrectly that high RIN prices will reduce E10 prices to consumers. Our analysis demonstrates that high RIN prices reflect the costs of overcoming the blend wall and result in higher E10 prices and hence societal costs, everything else held constant.
- Fail to properly recognize costs of overcoming the blend wall.
- Fail to distinguish between the social costs of the RIN price, higher gasoline prices, and the ethanol mandate price premium.
- The social costs of the ethanol mandate price premium are in fact ignored and so they overlook the total costs of higher ethanol prices of \$53.7 billion since 2007 and increases in crop prices to value-added agriculture of \$285.4 billion per annum.
- References are made to imperfect E85 markets and lack of competition to explain why growth in E85 sales is anemic. We find E85 price discounts do track E85 sales and that the

blend wall was overcome, but mostly by purchasing biodiesel (D4) RINs as apparently expanding E85 sales is an even more costly exercise.

We come to this conclusion by developing an economic model of the RIN market, RIN prices and the blend wall, and by using economic theory consistent with the reality of the RFS and its associated complexities.

This analytical framework guided our collection of data and its interpretation. Simulations of the calibrated economic model generated the following conclusions:

- ✓ The blend wall is costly so the ethanol price increase with ever expanding mandates is significantly lower than if there was no blend wall. This means high RIN prices impose a cost on society, not only on ethanol producers but also fuel consumers and gasoline producers. This represents a significant economic impact to society that is often overlooked.

- ✓ The mandate premium increases (induced by ever increasing blend mandates) with rising RIN prices (reflecting the increasing costs of overcoming the blend wall) because the market prices for gasoline charged to blenders go up to cover the costs of the blend wall.

- ✓ Without a blend wall, market prices of gasoline always declined and under some parameters, E10 prices declined; using these same parameters, E10 prices did not decline with increasing mandates facing a blend wall. This again reflects the high cost of the blend wall.

- ✓ The social cost of the blend wall is distinct from the social costs of the ethanol mandate premium and increased gasoline prices (even though each affect the other). One piece of evidence is that mandate price premiums have often been significant since the start of the RFS in 2007, especially after the tax credit expired at the end of 2011; high RIN prices have been low until the blend wall became an issue in early 2013.

Our analytical framework also guided us in collecting data to make qualitative conclusions:

- ✓ The gross cost of overcoming the blend wall peaked at over $1 billion in 2013.

- ✓ The number of additional RINs required for meeting the proposed volume standard in 2016 (which exceeds the blend wall) is climbing towards 2013 levels.

- ✓ E85 consumption was an insignificant mechanism for generating additional RINs to exceed the blend wall since 2012.

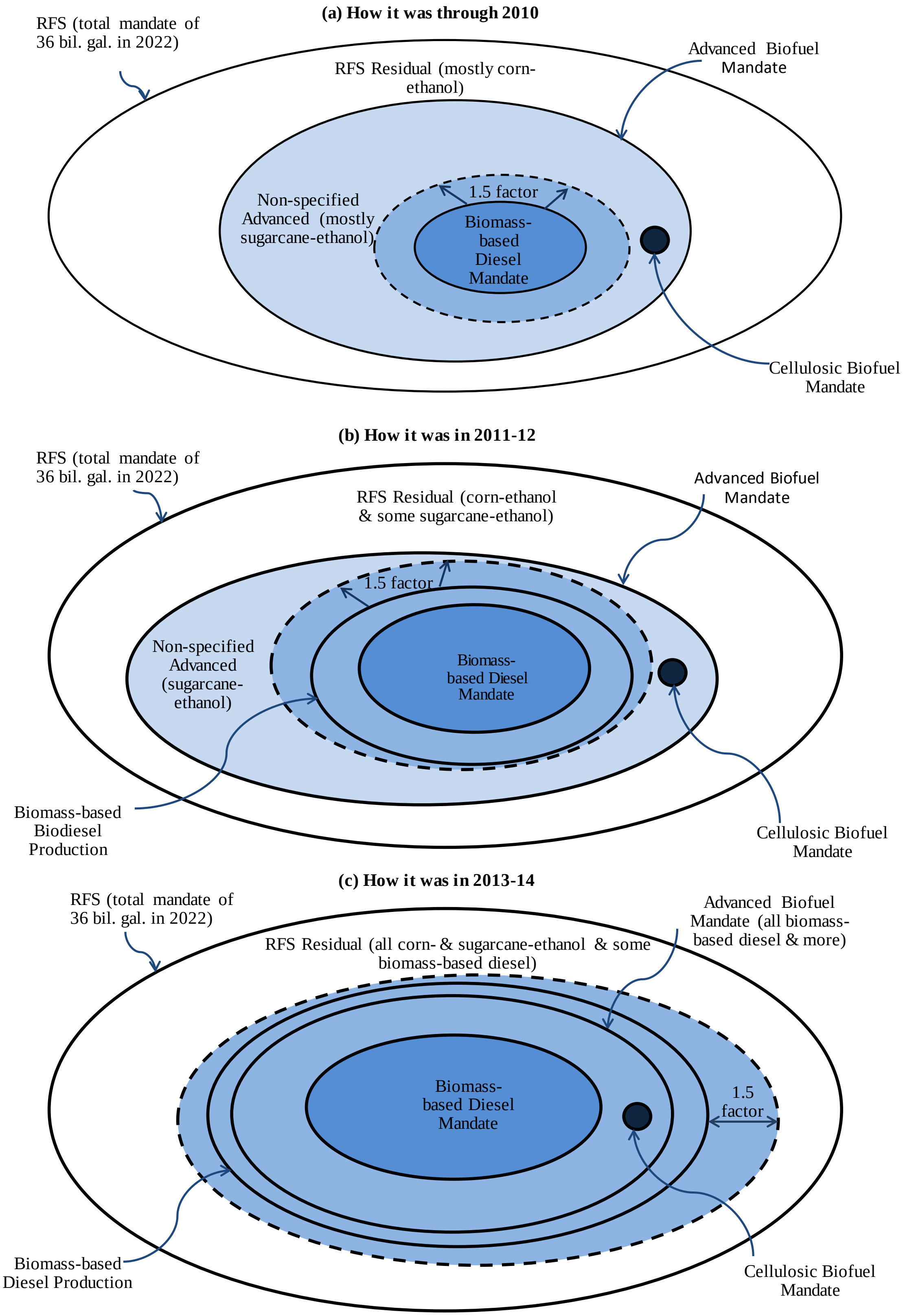
- ✓ Instead, exports of ethanol and imports of biomass-based diesel were required to meet the volume standards. This allowed the market to overcome the blend wall and demonstrated the high cost of the blend wall at recent mandated volumes and the added costs to society of the (often ignored) higher diesel fuel prices.

- ✓ Market power in the fuel chain has not prevented RIN prices from being passed onto E85 consumers and is not the underlying cause for flagging E85 sales (as emphasized in the two EPA documents)
  - o E85 sales tracked E85 price discounts, especially when constructed E85 prices are used in the analysis.
  - o There has been a steady increase in the number of FFVs and E85 stations over time. However, E85 sales per FFV and per station have not increased very much despite high RIN prices.

- ✓ The value added agricultural and food industry pays the highest price of the RFS due to higher grain/oilseed prices that result; and that these costs would be even higher if the conventional biofuel portion of the mandate was filled at the statutory 15 billion gallon level.

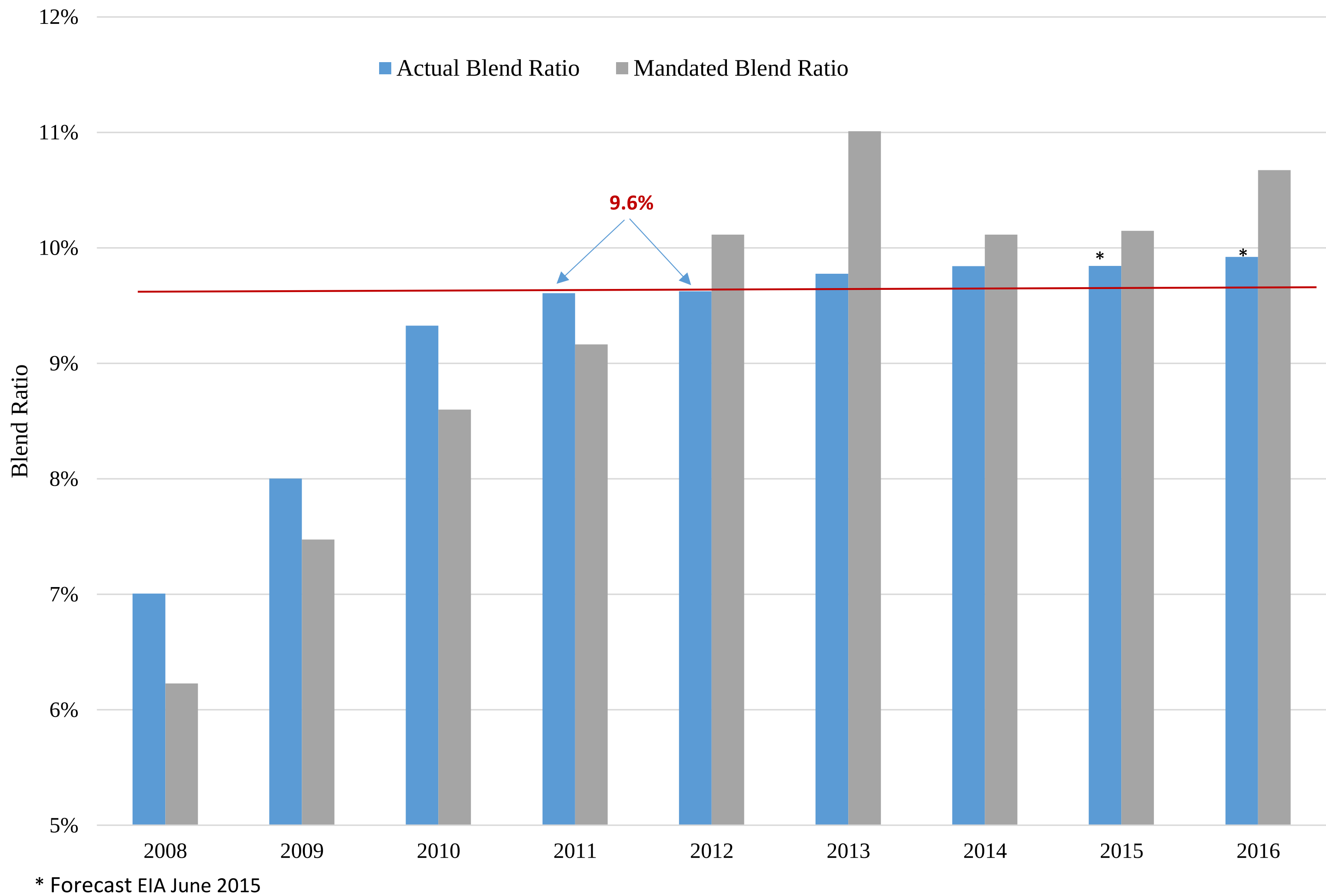
- ✓ The RFS can become economically infeasible with exponential growth in ethanol mandates and a secular decline in gasoline consumption; with a capped RIN price of $2 per gallon, an ever increasing mandate resulted in a slow decline in total fuel sales, and ethanol market prices.

Figure 1: The Nested Structure of the RFS



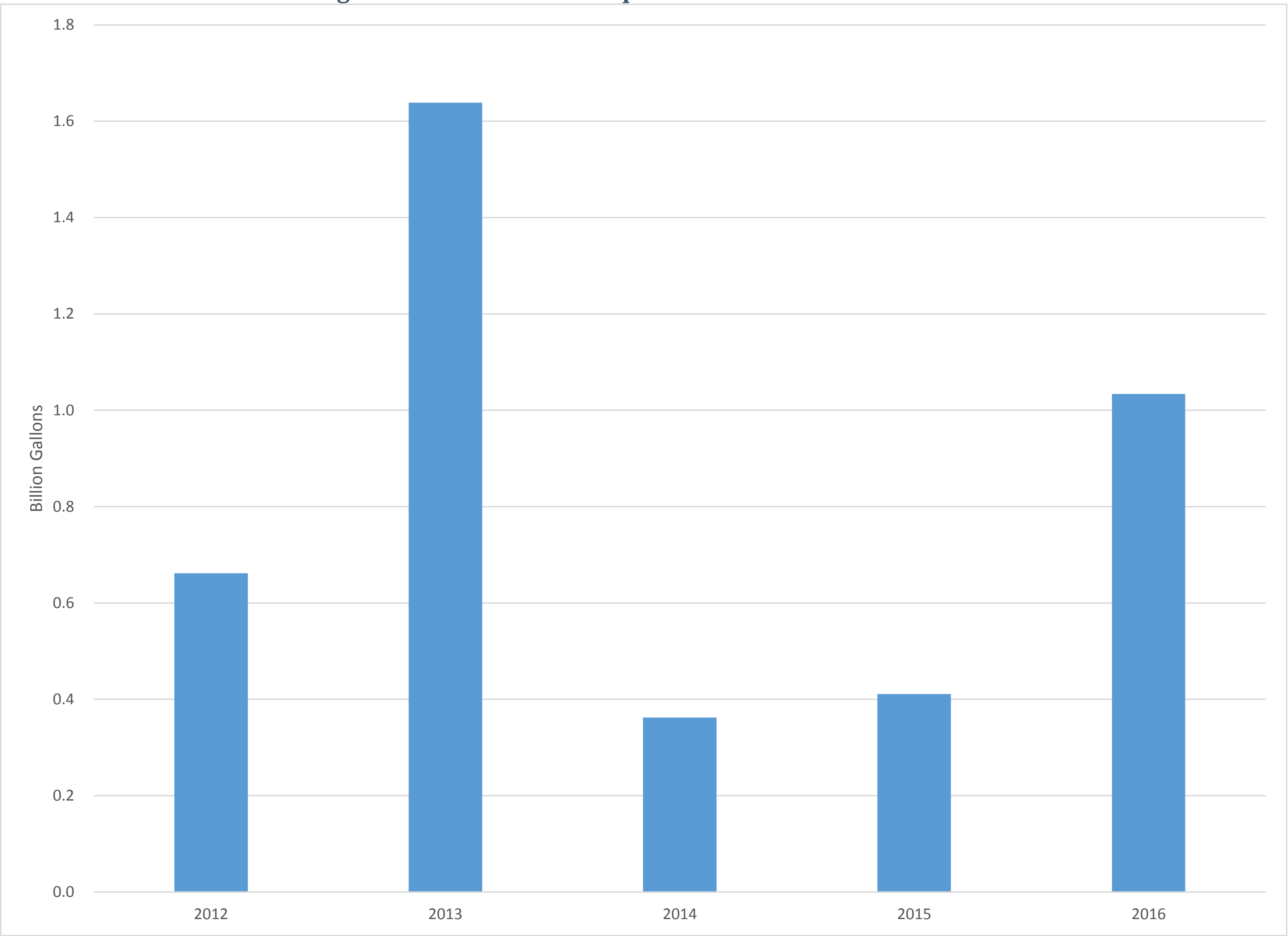
Source: Derived from de Gorter et al. (2015)

Figure 2: Ethanol Blend Ratios



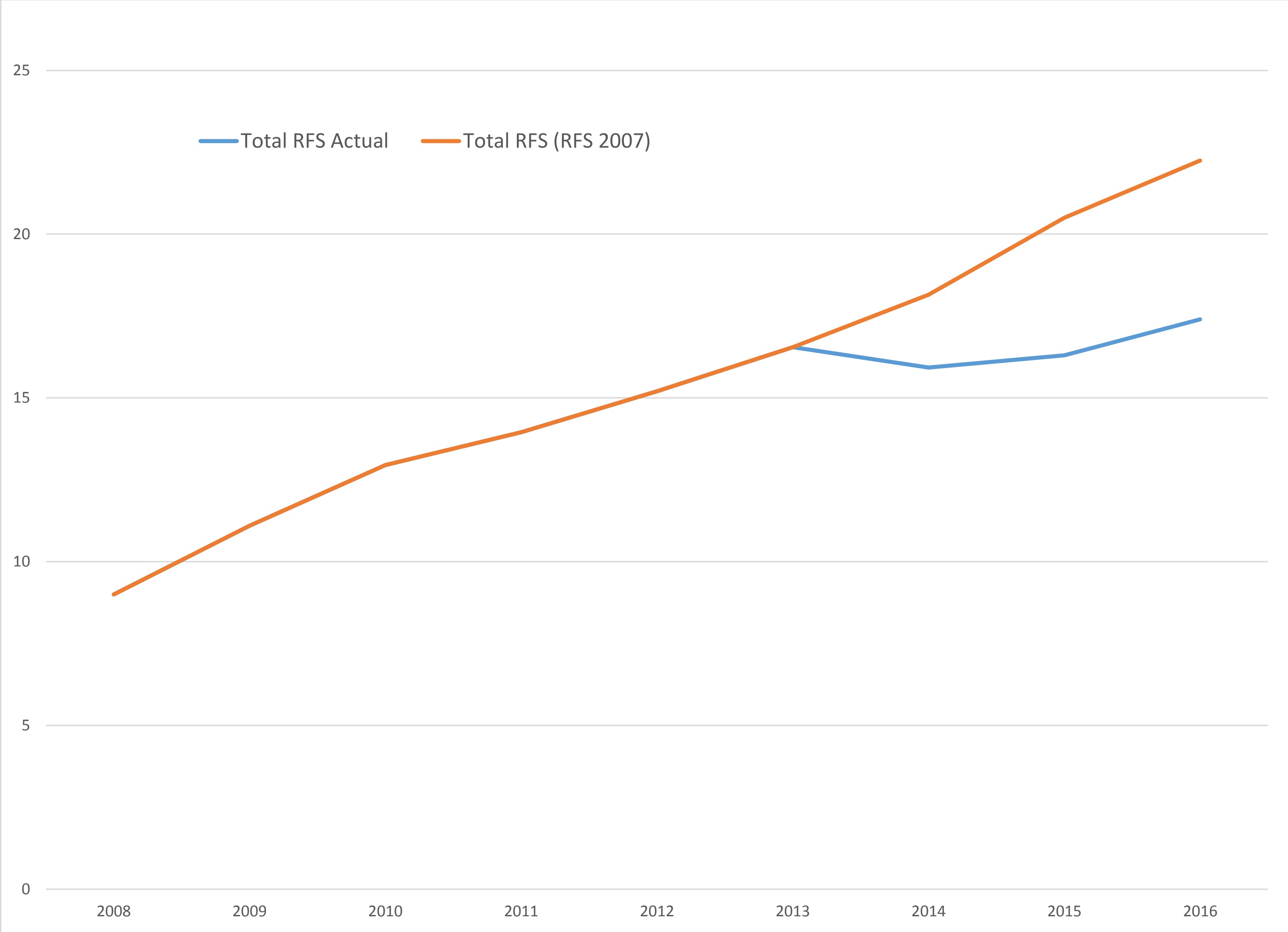
Source: Calculated based on EPA EISA RFS Mandates, EIA consumption forecasts and realized consumption figures from the Short Term Energy Outlook (STEO)

Figure 3: Ethanol RINs Required to Overcome Blend Wall



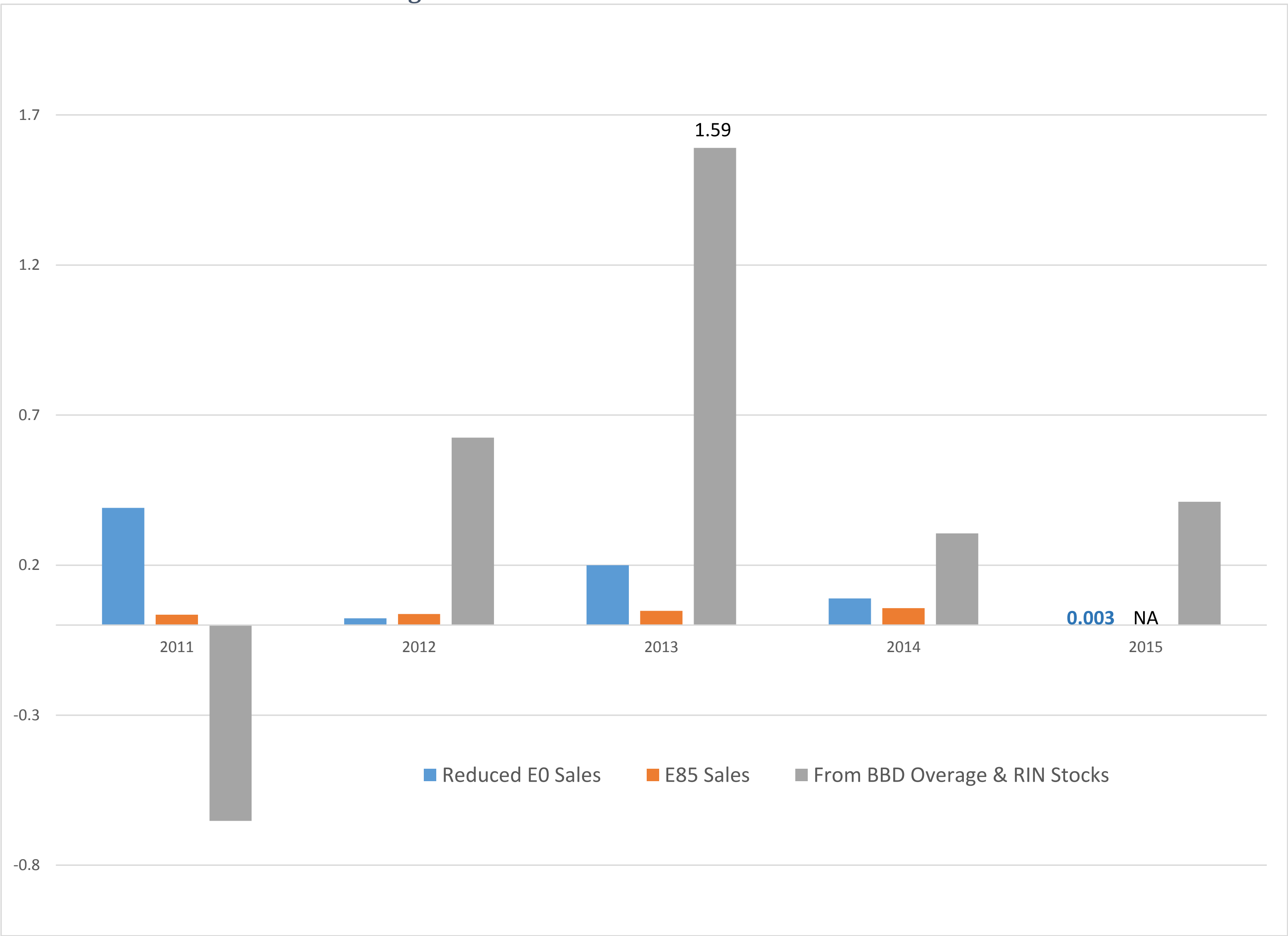
Source: Calculated based on EPA EISA RFS Mandates, EIA consumption forecasts and realized consumption figures from the Short Term Energy Outlook (STEO)

Figure 4: RFS 2007 Mandated Renewable Fuels versus Actual Mandates



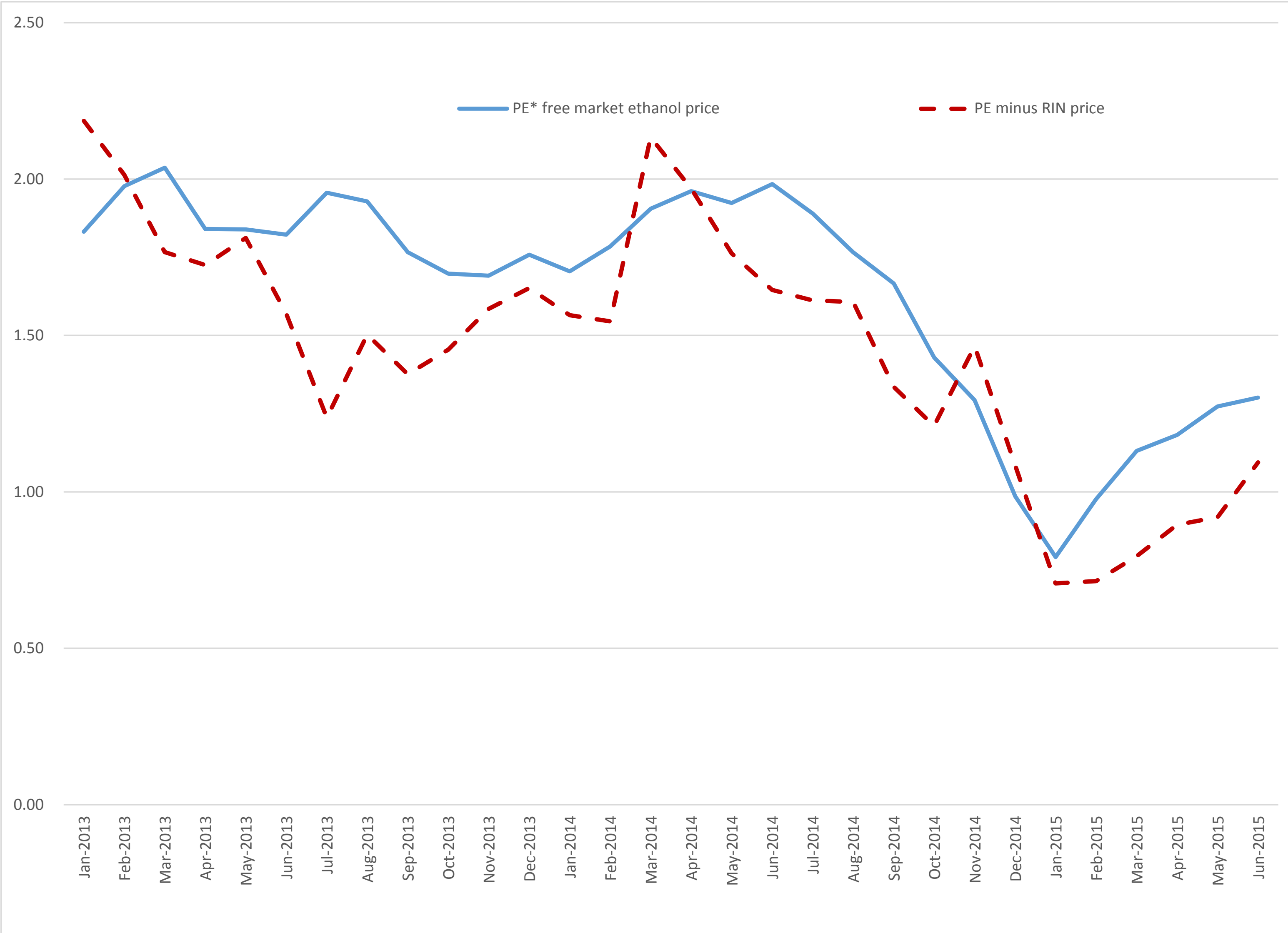
Source: EISA legislation and EPA final rules (2010-2013) and proposed rules (2014-2016)

Figure 5: Source of RINs to Overcome Ethanol Blend Wall



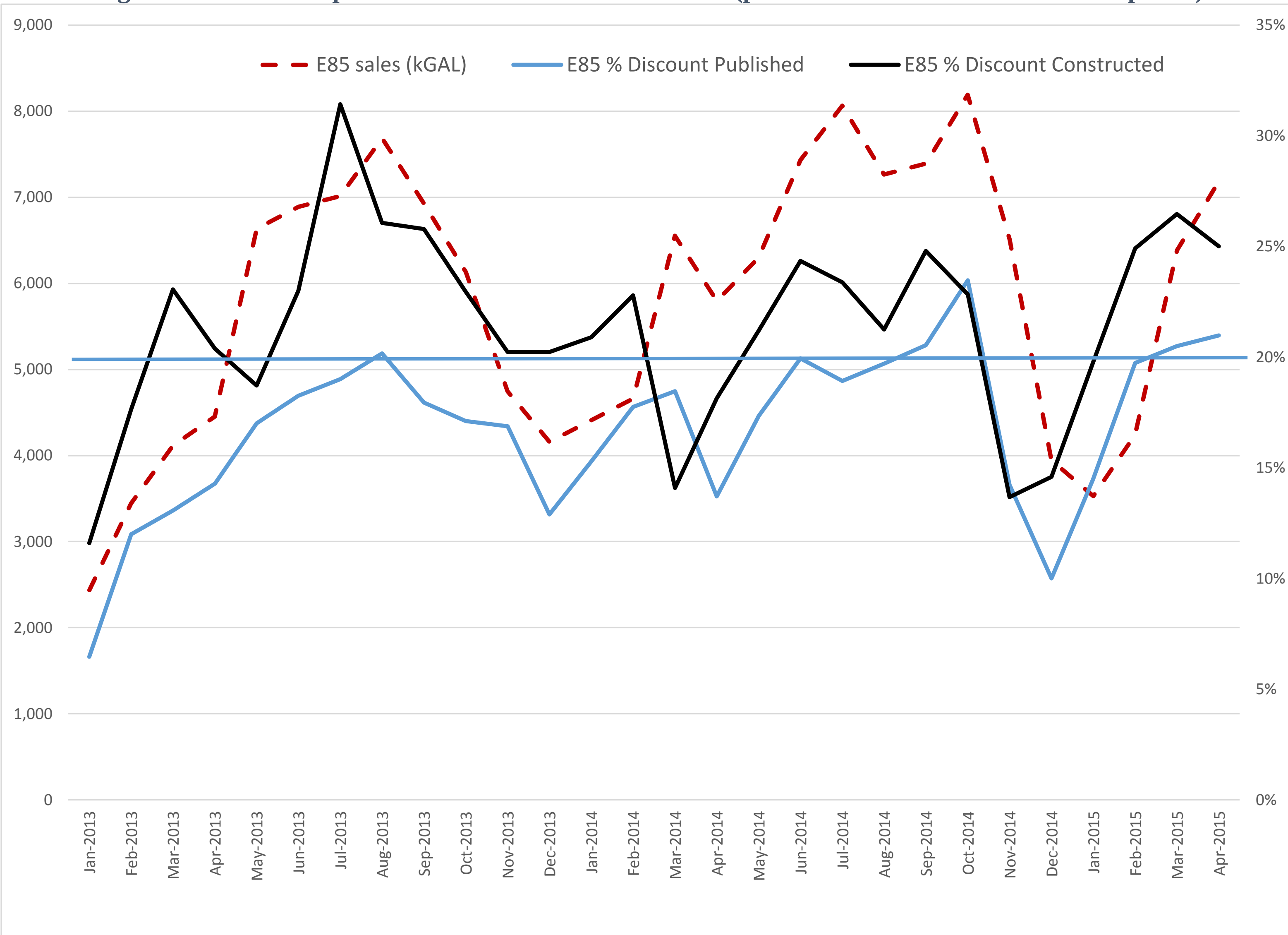
Source: Calculated based on EPA EISA RFS Mandates (final and proposed), EIA consumption forecasts and realized consumption figures from the Short Term Energy Outlook (STEO)

Figure 6: Are RIN prices providing free market ethanol prices to consumers?



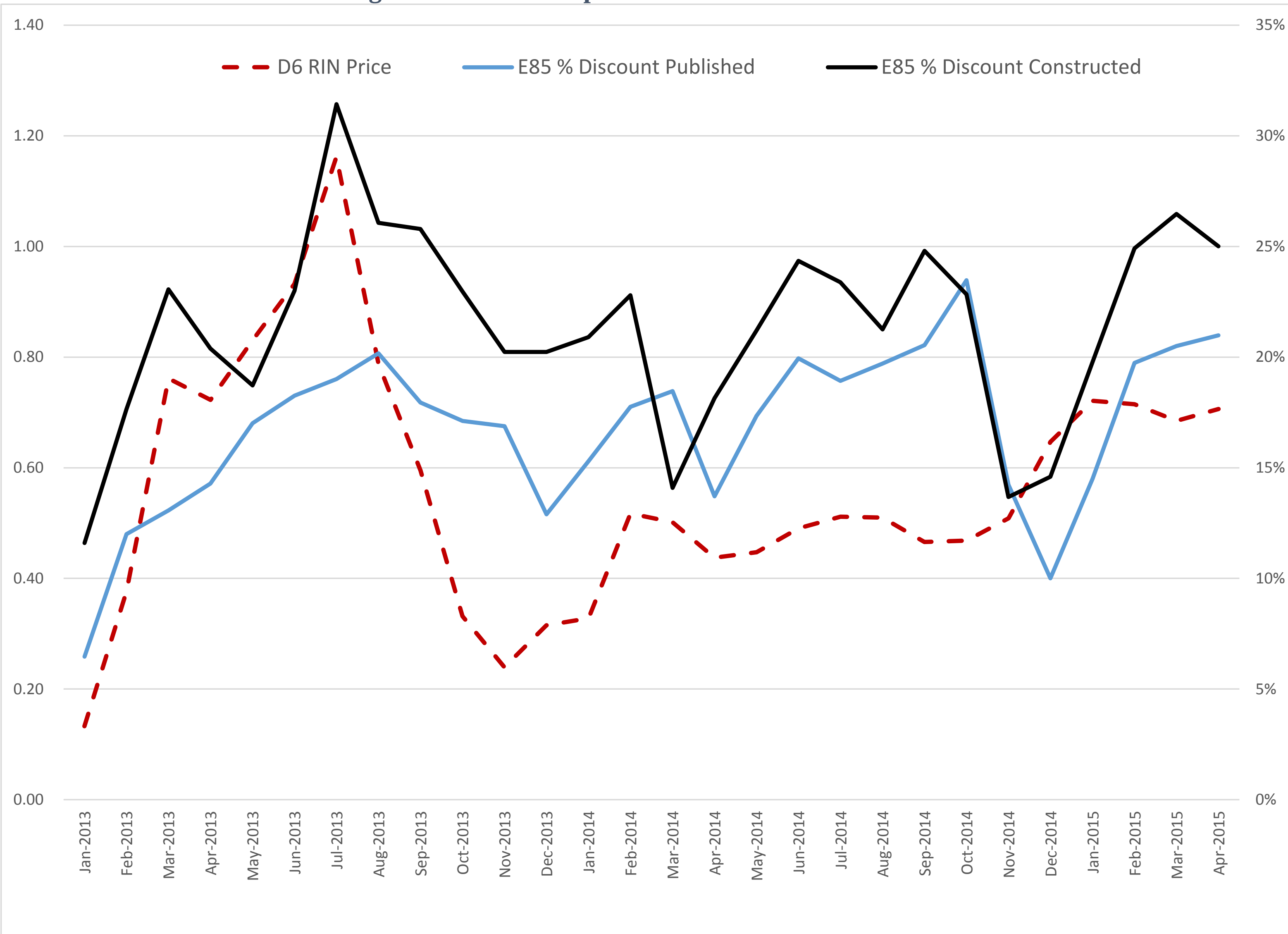
Source: RIN prices from OPIS; Ethanol relationships calculated based on Bloomberg ethanol and RBOB front month prices

Figure 7: Relationship between E85 Discounts and Sales (published versus constructed E85 prices)



Source: E85 sales from EIA Petroleum and Other Fuels Production and Refining database; E85 discount calculated based on Bloomberg ethanol and RBOB front month prices as well as tax rates from GasPriceWatch.com

Figure 8: Relationship between E85 Discounts and D6 RIN Prices



Source: RIN prices from OPIS; E85 discount calculated based on price from E85prices.com; implied E85 discount calculated based on Bloomberg ethanol and RBOB front month prices as well as tax rates from GasPriceWatch.com

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