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EVALUATING THE ECONOMIC IMPACTS OF THE RENEWABLE FUEL STANDARDS (RFS) AND THE ETHANOL QUANTITY MANDATE

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Introduction

Ethanol, or ethyl alcohol, is a plant-based fuel made from various biomass feedstocks including corn, sugarcane, and general cellulose. Approximately 98% of gasoline in the United States contains ethanol, most of which is in a 10% blend. Flex fuels, or 85% blends, are also available for specific flex fuel vehicles, and 15% blends are approved for new car models. Pure ethanol contains approximately 30% less energy than gasoline. It is principally used as an oxygenating agent, resulting in less volatility and a cleaner fuel burn that produces less air pollutants.[1] In the last fifty years, the United States has instituted federal policies designed to increase the prevalence and use of ethanol. In this paper, I will discuss the basis of ethanol support and the impact of the most current legislation, the Renewable Fuel Standard.

History

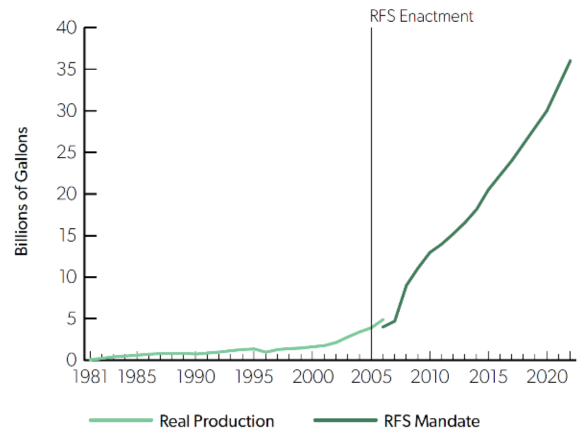
The United States has a short yet established history of ethanol support. Ethanol subsidization began with the 1978 Energy Tax Act, which placed a motor fuel excise tax exemption of 40 cents per gallon on gasoline blends with more than 10% ethanol; the following year, alcohol-blended fuels were first marketed commercially in the United States.[2] Initially, the justification for ethanol support was based on the reduction of greenhouse gas (GHG) emissions. That changed when the 1980 Omnibus Reconciliation Tax Act placed tariff of 54 cents on imported ethanol with the stated purpose of increasing energy security and supporting domestic agriculture, expanding support among both interest groups and the general public.

The method of ethanol support was modified in the 1990 Clean Air Act Amendments, which instituted a mandate of the use of ethanol in a 10% blend (rather than a tax), based on its cleaner burn and its ability to raise the octane level of the fuel.[3] This was followed by the 2004 Volumetric Ethanol Excise Tax Credit (VEETC), providing a tax credit of 51 cents per gallon of pure ethanol blended with gasoline to blenders through 2011, which in 2006 alone resulted in the distribution of $2.5 billion in tax credits by the federal government. In 2005, the Energy Policy Act, known as the first Renewable Fuel Standard, placed a quantity mandate on total blended ethanol with a set schedule of increases through 2012. This was updated and extended through 2022 in the 2007 Energy Independence and Security Act, known as the second Renewable Fuel Standard.[4]

[1] US Department of Energy. 2019. “Alternative Fuels Data Center: Ethanol.” Energy Efficiency & Renewable Energy.
[2] Jay P Kesan, Hsiao-Shan Yang, and Isabel F Peres. 2017. “An Empirical Study of the Impact of the Renewable Fuel Standard (RFS) on the Production of Fuel Ethanol in the U.S.” *UTAH LAW REVIEW*, 1: 167-168.
[3] Robert W Hahn. 2008. “Ethanol: Law, Economics, and Politics.” *SSRN Electronic Journal*: 6-8.
[4] Jay P Kesan, Hsiao-Shan Yang, and Isabel F Peres. 2017. “An Empirical Study of the Impact of the Renewable Fuel Standard (RFS) on the Production of Fuel Ethanol in the U.S.” *UTAH LAW REVIEW*, 1: 161-162.

The RFS as a Quantity Mandate

Figure 1: Real Ethanol Production pre-2005 vs. Renewable Fuel Standard Mandate



Source: Wardle (2018)

The Renewable Fuel Standard (RFS) mandates a defined quantity of ethanol that must be blended into total gasoline rather than as a percentage adjusted for annual gasoline sales. It is administered by the EPA through a system of buying and selling renewable identification numbers (RINs).[5] The system is coupled with other government supports for ethanol production, including trade barriers and infrastructural subsidies.[6] The RFS outlines steady increases in mandated production, rising from 3.4 billion gallons in 2005 to 36 billion gallons in 2022 (see Figure 1).[7] After 2022, the EPA will have the authority to set further quantity mandates as it wishes.[8]

The RFS outlines quantity mandates for four different forms of ethanol: cellulosic, advanced, biodiesel, and conventional (corn), with varying requirements on lifecycle greenhouse gas emission reductions. These reductions vary from 20 – 60% and are intended to address the varying environmental impacts of different forms of ethanol fuel. Cellulosic fuel has the largest mandated increase through 2022. The implementation of the RFS also came alongside the elimination of methyl tertiary butyl ether (MBTE)[9] as a gasoline additive due to groundwater and soil contamination concerns. MTBE was prevalent in the 1990s due to its low price, clean burn, and ability to increase the octane rating to meet requirements, but it was phased out in 25 states when environmental and health risks began to appear. The RFS nationalized this shift, leaving ethanol as the main viable fuel additive and oxygenating agent.[10]

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5 For more on the specific operation of the RIN system, see, Lihong McPhail, Paul Westcott, and Heather Lutman. 2011. "The Renewable Identification Number System and U.S. Biofuel Mandates," *Economic Research Service/USDA*, no. BIO-03: 24.

6 For a list of alternative fuel subsidies and support systems, see "Alternative Fuels Data Center: Federal Laws and Incentives." 2019. https://afdc.energy.gov/laws/fed_summary.

7 Arthur R Wardle. 2018. "A Review of the Environmental Effects of the Renewable Fuel Standard's Corn Ethanol Mandate." *The Center for Growth and Opportunity*: 5-6.

8 Kelsi McPhail. "The Renewable Fuel Standard (RFS): An Overview." *CRS Report*, January 23, 2019, 16.

9 MBTE is an oxygenate liquid produced from the reaction of methanol and isobutylene. Most of the negative health effects are associated with inhalation, leading to increased cancer risk. See "Overview - Methyl Tertiary Butyl Ether (MTBE) - US EPA." 2019. https://archive.epa.gov/mtbe/web/html/faq.html.

10 Jay P Kesan, Hsiao-Shan Yang, and Isabel F Peres. 2017. "An Empirical Study of the Impact of the Renewable Fuel Standard (RFS) on the Production of Fuel Ethanol in the U.S." *UTAH LAW REVIEW*, 1: 167-168.

A quantity mandate, such as the RFS, functions as a subsidy in that it provides guaranteed market demand to the benefit of suppliers. In the energy market (driven principally by commodity prices), this protects suppliers from a significant amount of downside volatility. By its design, demand is artificially created and held vertical at the mandated quantity.[11] A subsidy in this form is intended to correct for an externality, in this case a positive externality; there must be a positive social benefit of ethanol that is not accounted for by individuals in their private choice of fuel. The subsidization of ethanol is based on its comparison to traditional petroleum, which faces its own economic structure that is also impacted by both taxes and subsidizations. When burned, neither fuel source has positive environmental effects; the discussion is instead focused on the comparison of the effects between the two fuel sources, and how the difference in environmental externalities can be altered by the use of ethanol support and subsidization to reach a more optimal market price, quantity, and level of greenhouse gas emissions.

Support

Several stakeholder groups have supported the implementation of the RFS based on four central factors. The first is environmental; ethanol has lower greenhouse gas emissions associated with the pure burning process in comparison to traditional pure petroleum, and gives blended gasoline a higher octane rating.[12] Biofuels are also a sustainable fuel source and reduce the acceleration of climate change. Second, 98% of biofuels are produced domestically (the remaining 2% is imported from Brazil in the form of sugarcane[13]); encouraging their use thus reduces reliance on foreign oil and promotes energy independence and domestic agricultural industries. Third, the RFS encourages more innovation and renewable biofuel investment through guaranteeing lasting market demand for advanced biofuels and traditional ethanol. Finally, the structure of the RFS builds upon existing ethanol support and continues aid for the involved industries, as previously outlined.[14]

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[11] For more on the economic models of a blend mandate, see Harry de Gorter, and David R. Just. 2009. "The Economics of a Blend Mandate for Biofuels." *American Journal of Agricultural Economics* 91, 3: 738–50.
[12] The level of this reduction depends on the ethanol form and source. See Michael Wang, Jeongwoo Han, Jennifer B Dunn, Hao Cai, and Amgad Elgowainy. 2012. "Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for US Use." *Environmental Research Letters* 7, 4.
[13] Sugarcane is the second largest global form of biofuel, but US biofuel policies restrict imports. See Christine Crago, Madhu Khanna, Jason Barton, Eduardo Giuliani, and Weber Amaral. 2010. "Competitiveness of Braxilian Sugarcane Ethanol Compared to US Corn Ethanol." *Agricultural & Applied Economics Association*, 38.
[14] Congressional Budget Office. 2010 "Using Biofuel Tax Credits to Achieve Energy and Environmental Policy Goals," 4044: 5-18.

Opposition

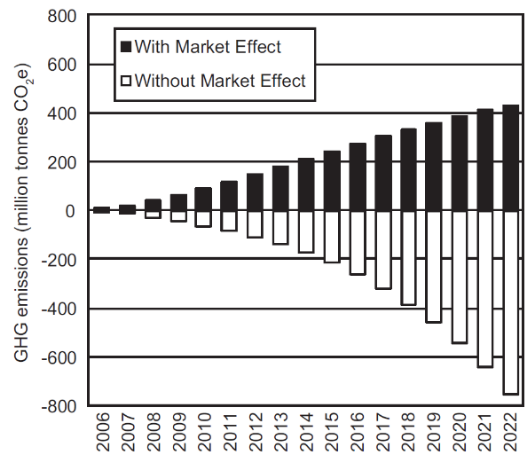

Figure 2: Cumulative Change in GHG emissions by biofuels qualifying for the RFS2.
Source: Hill (2016).

Nuance complicates many of the arguments offered in support of ethanol and the RFS. First, the GHG reductions outlined in the RFS are based on 2005 pure petroleum baseline, which is a difficult assessment as life cycle emissions are not clear and technological innovation is difficult to predict.[15] This simplification is likely to overestimate the true reductions achieved by ethanol. There are other negative environmental costs associated with ethanol when considering more complex lifecycle factors, such as the overall quantity of GHG emissions and net environmental effects. Government-administered support for ethanol pushes corn farming into previously unfarmed land, including wetlands and forests, that serve critical ecological purposes as carbon stores, flood mitigation zones, and centers of ecological diversity. The transition of these areas to large monocultures negatively impacts crop resiliency.[16] Additionally, corn ethanol production requires large quantities of nitrogen fertilizer[17] and irrigation,[18] placing further strain on the ecosystem.[19] [20]

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[15] Furthermore, the value of time discounts of lifecycle emissions and emission locations can be distortionary if not properly accounted, and cumulative warming factors are exacerbated by environmental damage early in the lifecycle process, such as in the case of land clearing for biofuels. See M O'Hare, R J Plevin, J I Martin, A D Jones, A Kendall, and E Hopson. 2009. "Proper Accounting for Time Increases Crop-Based Biofuels' Greenhouse Gas Deficit versus Petroleum." *Environmental Research Letters* 4, 2.

[16] The efficiency of monocultures increases food production at the expense of biodiversity. These effects are compounded over time and exacerbated with further environmental change, which has been seen particularly in the case of biofuel production. See Miguel A Altieri. 2009. "The Ecological Impacts of Large-Scale Agrofuel Monoculture Production Systems in the Americas." *Bulletin of Science Technology Society Online*.

[17] Fertilizer use in corn production is associated with increased nitrogen emissions and harmful soil effects. See Seungdo Kim, Bruce E. Dale, and Robin Jenkins. 2009. "Life Cycle Assessment of Corn Grain and Corn Stover in the United States." *The International Journal of Life Cycle Assessment* 14, 2: 172–73.

[18] Biofuels are particularly water-heavy fuel sources, even in comparison to petroleum fuels. This produces further environmental effects that may become exacerbated as global population continues to grow and water becomes more scarce . See Kevin R Fingerman, Margaret S Torn, Michael H O'Hare, and Daniel M Kammen. 2010. "Accounting for the Water Impacts of Ethanol Production." *Environmental Research Letters* 5, 1.

[19] Arthur R Wardle. 2016. "A Review of the Environmental Effects of the Renewable Fuel Standard's Corn Ethanol Mandate." *The Center for Growth and Opportunity*: 6-18.

[20] Jason Hill, Liaila Tajibaeva, and Stephen Polasky. 2016. "Climate Consequences of Low-Carbon Fuels: The United States Renewable Fuel Standard." *Energy Policy* 97: 351–53.

The environmental argument is again challenged by the crowding out effect; artificially supporting traditional corn ethanol places other alternatives, such as more advanced biofuels or hydrogen fuel, at a disadvantage in price competition.[21] This is particularly crucial due to the high investment risk and research costs of new forms of renewable energy.[22] In additional to these negative consequences of ethanol production, the RFS' central goal of reducing CO_2 emissions can be challenged by the rebound effect – increasing the supply of biofuels through subsidization increases total fuel supply and decreases fuel prices. This increases consumption demand, leading to more fuel use and therefore more total GHG emissions (see Figure 2).

There are further concerns based on the form of ethanol that has been supported by the RFS through its current implementation. The main beneficiary of the quantity mandate in previous years has been traditional corn, an industry that produces nearly all of the ethanol used in 10% blends. However, the majority of the expansion into 2022 concerns cellulosic biofuel, a more nascent area of ethanol production that has repeatedly missed RFS production goals in past years. Ten million gallons of cellulosic fuel was produced in 2018, a miniscule fraction of the 200 billion gallons of total transportation fuel and far from the 16-billion-gallon goal for 2022. Existing infrastructure has been centered around corn rather than cellulosic ethanol production because past increases have been mostly isolated to corn, and political agents are much more active and established in the corn industry. Further, cellulosic ethanol production is currently prohibitively expensive without government support and it requires significant energy for production, reducing its efficacy as an energy-efficient fuel source. For production to increase to mandated quantities in an efficient manner, it is clear that support needs to be administered in a more comprehensive manner; this demonstrates a flaw in the goal to propel biofuel innovation through the RFS.[23]

The increased demand for corn production for traditional ethanol under the RFS has effects on the prices of agricultural and food goods. Based on price back casting using 2004 quantities as a baseline, approximate 2009 agricultural prices have been calculated to have been 21% higher for corn, 9% higher for wheat, and 5% higher for soybeans,[24] as farmers face significant economic incentives to transfer from food crops to ethanol-corn production. As compared to the general level of price increases for agricultural goods from 2004-2009, these increases are significant yet modest, and there is debate on their impact on overall

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[21] Ibid.

[22] Further complexities exist within the renewable energy innovation space, which are greatly influenced by government support and available technology. See W. Short, D.J. Packey, and T. Holt. 1995. "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies," 73-82.

[23] Subcommittee on Environment. 2018. Advanced Biofuels Under the Renewable Fuel Standard: Current Status and Future Prospects, Pub. L. No. 35–142, § Energy and Commerce, 172.

[24] This time period, 2004-2009, was used due to the prevalence of data and proximity to the initial implementation of the RFS. These values are based analysis done by Bruce A Babcock. 2011. "The Impact of US Biofuel Policies on Agricultural Price Levels and Volatility." *International Centre for Trade and Sustainable Development*, 35: vii-ix. Other calculations find similar values over similar time periods. See Aaron Smith. 2018/ "Effects of the Renewable Fuel Standard on Corn, Soybeans an Wheat Prices." UC Davis.

food security.[25] Nevertheless, the distortions on the overall price system extend beyond corn or energy production.[26]

While it is true that ethanol use increases energy security, the magnitude of this effect is dated. With the advent of the "shale revolution" and increased production of oil particularly in the Permian basin, the US imports less oil from foreign nations than it has in the past and domestic oil prices are less susceptible to changes in OPEC production. Volatility still exists in domestic oil production, and worldwide prices are affected by current events and conflicts; however, quantity-driven security controls are less prevalent than they have been in the past. Agricultural products, which are also commodity price driven, face similar (if less severe) volatility associated with weather patterns that may be exacerbated with continuing climate change.

Policy Implications

The integration of the two complex industries of energy and agriculture is implicit in biofuel production and mixes the nuanced policy goals of the industries. This is apparent with regards national security, price stability, and seasonal variation; changes in one industry affect the economics and policies of the other. With increasing globalization, issues regarding trade and climate change will affect both industries more drastically due to this entanglement. Furthermore, by mandating a higher demand for corn ethanol, the market signals and incentive structures for corn agriculture are altered beyond what would be normal for the market, leading to potential overproduction.[27]

This integrates the goals of special interest groups that are motivated to appeal to their individual constituents and exhibit rent-seeking behavior in order to enact policy. Well-funded lobbying groups, such as the National Corn Growers Association, spend considerable funds and human labor to support political candidates who will vote alongside their economic goals. They often increase their power by partnering with more specific ethanol lobbying groups[28] (as well as broader natural security interests) to pressure Congress to achieve their goals, such as the extension of ethanol tax credits in 1996.[29] As seen in the Volumetric Ethanol Excise Tax Credit, excise tax credits also reduce the available government funds for other subsidization or spending efforts in and beyond the green energy sector; in 2009 alone RFS credits resulted in a $6 billion revenue reduction.[30]

[25] For more on the ethicality of the impact of biofuel policies on food production, see Paul Thompson. 2012. "The Agricultural Ethics of Biofuels: The Food vs. Fuel Debate." *Agriculture* 2, 4: 339–58.
[26] Bruce A Babcock. 2011. "The Impact of US Biofuel Policies on Agricultural Price Levels and Volatility." *International Centre for Trade and Sustainable Development*, 35: vii-ix.
[27] Gian Carlo Moschini, Harvey Lapan, and Hyunseok Kim. 2017. "The Renewable Fuel Standard in Competitive Equilibrium: Market and Welfare Effects." *American Journal of Agricultural Economics* 99, 5: 1-4.
[28] The largest ethanol lobbying group is the Renewable Fuel Association (RFA). See https://ethanolrfa.org
[29] Robert W Hahn. 2008. "Ethanol: Law, Economics, and Politics." *SSRN Electronic Journal*: 27-28.
[30] Congressional Budget Office. 2010 "Using Biofuel Tax Credits to Achieve Energy and Environmental Policy Goals," 4044: 1.

This distortion encourages wasteful rent-seeking behavior on the part of lobbying groups and politicians who seek to gain for themselves and their individual constituents.

These benefits and consequences are unevenly distributed both geographically and temporally. The main advantages are allocated to corn ethanol farmers primarily located in Iowa, Nebraska, and Illinois who are able to profit from the guaranteed market created by the RFS. Politicians often use ethanol support policies to gain votes and appeal to agricultural constituents and energy security interests.[31] Consumers benefit in the short term with access to cheaper biofuels and fuel blends;[32] however, they also face higher food and agricultural prices (as previously discussed). Producers of other forms of renewable energy are harmed by the augmented competitiveness of ethanol, and environmentally vulnerable regions face significant negative effects from the increase in lifetime GHG emissions and decreased biodiversity. The timing of GHG emissions is also critical based on flow and stock atmospheric pollutant quantities, as pollutants released early in the production process (for example, from corn irrigation or fertilizer use) can have much larger effects than the same amount of pollutants produced later based on the duration of their environmental impact; those pollutants are compounded earlier in the emission timeline and thus have more time to contribute to climate change and other forms of environmental degradation.[33] This produces unseen harms on future generations.

Externality Model and Economic Uncertainty

The design of an ethanol subsidy can be examined using the Pigouvian tax externality model (see Figure 3). It is inherently very difficult to calculate the true marginal effect of ethanol production (including land development, farming, refinement, and distribution) and burning, both as an independent

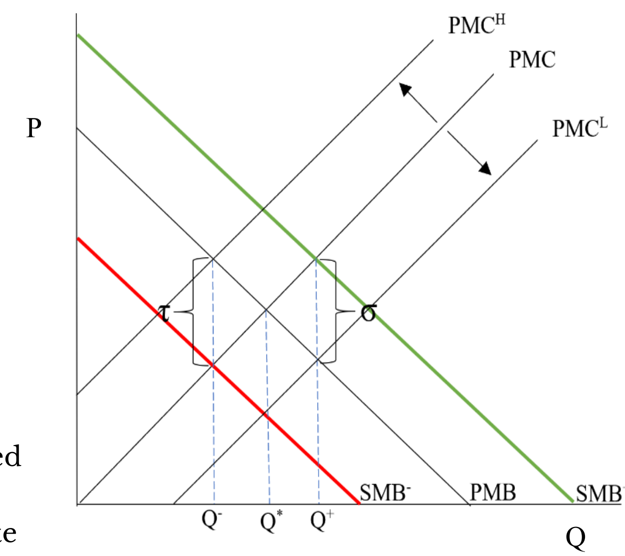

Figure 3: Pigouvian Tax Implementation on a Supply and Demand Model. Source: Based on concepts from Hindriks (2013)

[31] In 2018, the major recipients of RFA money was Deb Fischer of Nebraska and Rodney Davis of Illinois. See https://www.opensecrets.org/pacs/pacgot.php?cmte=C00518910&cycle=2018/1. Ethanol support has been a political talking point of both President Trump (centrally from an energy security and agricultural support platform) and of 2020 democratic candidates. See https://www.desmoinesregister.com/story/news/elections/presidential/caucus/2019/05/17/iowa-ia-caucus-election-2020-bill-de-blasio-ethanol-biofuels-president-democrat-rural-america/3693898002/ and https://www.reuters.com/article/us-usa-trump-ethanol/trump-raises-ethanol-use-in-gasoline-appeases-farmers-ahead-of-elections-idUSKCN1MJ29Y

[32] Moschini, Gian Carlo, Harvey Lapan, and Hyunseok Kim. "The Renewable Fuel Standard in Competitive Equilibrium: Market and Welfare Effects." *American Journal of Agricultural Economics* 99, no. 5 (October 2017): 20-23. https://doi.org/10.1093/ajae/aax041.

[33] Hill, Jason, Liaila Tajibaeva, and Stephen Polasky. "Climate Consequences of Low-Carbon Fuels: The United States Renewable Fuel Standard." *Energy Policy* 97 (October 1, 2016): 351–53. https://doi.org/10.1016/j.enpol.2016.07.035.

value and as compared to traditional forms of unblended petroleum. Calculations by different research agencies have found varying positive *and* negative consequences; by introducing subsidies or quantity mandates on ethanol, the government encourages higher production which may not reflect the true social optima for ethanol production. Externality effects are unevenly distributed geographically and temporally, further complicating attempts to arrive at a "correct" value for the true social cost based on discount values. In the case that the "correct" response to ethanol is not subsidization, a much larger deadweight loss is created through current policies, and government funds are spent subsidizing an industry that should instead be revenue generating through taxation. This can be seen in Figure 3 by comparing the deadweight loss of production on the green line at Q^+ if the true optimum is reflected by the red line at Q^-. This demonstrates one of the largest difficulties of environmentally motivated policy; it is difficult to calculate the true social optima and necessary government response.[34] Even if the externality is truly positive, over subsidization results in deadweight loss, and under subsidization does not maximize the possible benefits. This subsidy logic fits similarly into the functioning of a supply quantity mandate like the RFS.

By artificially increasing demand beyond what would be economically viable in an unaltered market, a feedback cycle is created that further drives down prices and increases demand. This pulls resources out of other industries and distorts incentive structures. The scale of this is uncertain, but evidence supports the premise. Ethanol fuel prices have fallen since the implementation of the RFS, and quantity has indeed increased. Causation cannot be directly drawn, but the increase in farmland dedicated to corn ethanol production is, at least in some part, influenced by the RFS-guaranteed market. The question then becomes, is this effect negligible enough to be justified, and are the benefits of correcting the ambiguous externality large enough to outweigh any potential market distortion?[35]

Self-Control Model

The self-control model of behavior economics (see Figure 4) has a political application for ethanol support, which measures the changes in current and future behavior based on the temporal discount rate, β. This can be viewed in terms of immediate benefits and delayed harms, where a β valued at less than one denotes the discounting of future values. For politicians, there is an immediate benefit of appealing to constituents such as ethanol corn producers, as well as a delayed and discounted impact of cutting other programs or raising taxes to fund ethanol support. This can also be considered in an environmental context; the immediately visible pure

$$U = U_0 + \beta\delta U_1 + \beta\delta^2 U_2 + \ldots + \beta\delta^T U_T$$

Figure 4: Self-Control Model Equation.
Source: Hindriks (2013)

[34] Jean Hindriks, and Gareth D. Myles. 2013. *Intermediate Public Economics*. 2nd ed. Cambridge, MA: The MIT Press: 221-249.
[35] Jay P Kesan, Hsiao-Shan Yang, and Isabel F Peres. 2017. "An Empirical Study of the Impact of the Renewable Fuel Standard (RFS) on the Production of Fuel Ethanol in the U.S." *UTAH LAW REVIEW*, 1.

reductions in GHG emissions associated with ethanol burning can be contrasted against the long-term impacts of the rebound effect, monocultures, and reduced competitiveness of other renewable alternatives.[36]

Policy Prescription

Because of these issues associated with the RFS, especially the uncertainty of the direction and degree of the externality compared to pure petroleum,[37] it is important that careful analysis of the successes, failures, and ability for growth of the RFS is conducted at its expiration in 2022 that takes into account the history of the policy, as well as the anticipated effects in future climate and economic conditions. It is possible that a more specific policy would be better suited to achieving a central goal for the use of ethanol, whether that is energy security, emission reduction, agricultural support, or a combination thereof. Broad policies like the RFS can encompass more potential goals, but they also include more potential consequences. However, enacting a new policy that would institute a sudden and complete transition away from traditional corn ethanol support would have catastrophic consequences for the agricultural industry as a whole due to its history of reliance on government support.

To maximize long-term benefits, support efforts should be transitioned in two main ways. First, ethanol support and related industry support (in the form of tariffs and subsidization) should be tied toward environmentally focused efforts, including crop rotation, reduced fertilizer use, and cleaner burning. This is especially true regarding traditional corn ethanol. Such initiatives would support the industry while encouraging green innovation by targeting the specific aspects of corn ethanol production that cause the most environmental harm. Second, comprehensive support should be transitioned towards advanced biofuel fuel alternatives. Nuance is required in the development of policies to support biofuels, as it is a broad category that stretches to more innovative technologies using algae, agriculture waste, and other forms of flora. The environmental effects of these methods vary greatly, primarily in their production, including resource intensiveness and

[36] Jean Hindriks, and Gareth D. Myles. 2013. *Intermediate Public Economics*. 2nd ed. Cambridge, MA: The MIT Press: 55-57.

[37] Vendenov and Wetzstein develop a theoretical model in which they attempt to arrive at the optimal level of ethanol subsidization. However, in their analysis they focus on the effects of economic development rather than what they claim to be questionable environmental grounds. They argue instead that, if reasoning is based on the environmental goal, gasoline excise taxes should be increased, and that a region design would be more appropriate than a national one. See Dmitry Vedenov and Michael Wetzstein. 2008. "Toward an Optimal U.S. Ethanol Fuel Subsidy." *Energy Economics* 30, 5: 2073–90.

scalability.[38] The energy security goal, assuming it to still be valid at the very least in terms of price volatility, can still be supported by advanced biofuels without the other potentially harmful and ambiguous consequences of corn ethanol support and subsidization. As a whole, this can successfully mitigate and avoid some of the main concerns surrounding the uncertainty of the direction and level of the externalities associated with ethanol production; however, it will require more comprehensive support than is currently given, especially in infrastructure and research.

This discussion is not intended to demonize ethanol or the larger category of biofuels as a form of fuel simply because they do not meet an undefined standard of perfection in their environmental or social impacts; all forms of energy have associated externalities that are unequally distributed across regions, time, and socioeconomic classes. However, to follow the opposing extreme and state that an ethanol mandate must be instituted based only in comparison to 2005 petroleum emission standards is equally harmful. In discussing the vitality of a fuel source, nuance must not be lost in favor of political simplicity. This paper is intended to address the inherent complexity in recognizing and measuring the externalities of fuel sources and provide a framework to consider future evidence and discussions on support for ethanol and biofuels.

[38] Significant biofuel research is focused on the production of ethanol from algae when isolated into set conditions, which holds promise for potential small-scale individual production and reductions in land and resource use. However, it is still far from commercial viability. For an in-depth analysis of microalgae biofuel production and impacts, see T.J. Lundquist, I.C. Woertz, N.W.T. Quinn, and J.R. Benemann. 2010. "A Realistic Technology and Engineering Assessment of Algae Biofuel Production." *Energy Biosciences Institute, University of California Berkley* 17, 4: 58.

Other forms of ethanol utilize cellulosic biomass including agricultural waste products and wood, attempting again to reduce land use, increase farming efficiency, and mitigate the harmful environmental effects of modern agriculture. However, this is further complicated in that farmers often use this "waste" in other forms and sell it to other farmers as feedstock or to be turned into fertilizer. Although ethanol production may be more profitable and efficient for the farms, it will require both the infrastructure for transportation and refinement, as well as a cultural shift for farmers around the use of their products. See Lee R. Lynd, Janet H. Cushman, Roberta J. Nichols, and Charles E. Wyman. 1991. "Fuel Ethanol from Cellulosic Biomass." *Science* 251, 4999: 1318–23.

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