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An Empirical Study of the Impact of the Renewable Fuel Standard (RFS) on the Production of Fuel Ethanol in the U.S.

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AN EMPIRICAL STUDY OF THE IMPACT OF THE RENEWABLE FUEL STANDARD (RFS) ON THE PRODUCTION OF FUEL ETHANOL IN THE U.S.

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Abstract

The Renewable Fuel Standard (RFS) program, which mandates the commercialization of biofuels through 2022, is the United States' most significant piece of legislation regarding renewable energy. It was first passed in 2005 and revised and expanded in 2007 in order to create a viable market for biofuels based on the policy goals of enhancing domestic U.S. energy security, reducing transportation-related greenhouse gas (GHG) emissions, and stimulating rural economic development.

The RFS requires minimum levels of consumption for different kinds of biofuels and requires increasing blending amounts of biofuels into gasoline and diesel fuels by producers and importers each year. Mandates and targets for biofuels as required by the RFS are not a policy exclusive just to the U.S. Sixty-four other countries mandate fixed quantities of ethanol use in gasoline to generally stimulate renewable energy use and to specifically promote production of biofuels.

In the past few years, there have been challenges in complying with the RFS in the U.S. As a result, legislative mandates were modified and reduced to respond to these difficulties. Proponents of the RFS argue that the policy reduces the risk of investing in renewable fuel projects, enhances the country's energy security as well as the rural sector, and addresses climate change concerns. On the other hand, critics argue that policy makers are "picking a winner" by funding biofuels over other types of alternative energy sources, and mandates for biofuels have presented unintended consequences in other areas, such as the food markets, land use patterns and the current gasoline-market infrastructure. Many studies have observed beneficial impacts of mandates on the agricultural markets and on the environment. However, there are very few empirical studies of the actual impact of the RFS on the development of the biofuel industry and none that use an industrial policy approach to analyze this issue.

In this Article, we intend to fill this gap and provide an empirical study addressing whether the RFS is an effective policy instrument that

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incentivizes an efficient and sustainable development of the biofuels industry. Our analysis uses data from the first-generation ethanol industry between the years 2000 and 2013, and we find that the industry life cycle mediates the effects of the RFS in contributing to production-related economies of scale. More specifically, our empirical findings suggest that the RFS had a significant positive effect on the production capacity of first-generation ethanol firms during the early stages of development of the first-generation ethanol industry. But the RFS does not have a statistically significant effect on plant or firm capacity after the first-generation ethanol market entered a mature stage in its product life cycle.

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I. INTRODUCTION

The federal Renewable Fuel Standard ("RFS") is the single most important law and policy affecting the commercialization of biofuels in the United States and the government's first attempt to mandate demand for a type of renewable energy.[1] As such, the RFS is considered the "most important [economic] value-added market" for agriculture since it changes the grain sector from a "surplus-driven marketplace to one that is vibrant, high-tech, and demand-driven."[2]

The RFS program was authorized under the Energy Policy Act enacted in 2005 (the RFS was initially referred to as "RFS1").[3] The RFS mandates for biofuels require U.S. fuel refiners and importers to commercialize specific volumes of biofuels each year.[4] The RFS1 marks the first instance where biofuel commercialization was mandated by law. The initial biofuel mandates were substantially revised and expanded in 2007, but the original RFS1 mandates had an immediate impact at that time.[5] In 2005, there were ninety-five ethanol refineries located in nineteen states producing four billion gallons of ethanol, an increase of 17% in ethanol production from 2004 in response to the RFS mandates.[6] The RFS1 was substantially revised in 2007 with the passage of the Energy Independence and Security Act of 2007 (i.e.*,* the "RFS2")[7] and the industry continued growing—in 2007, there were 139 biorefineries operating in twenty-one states producing 7.8 billion gallons of ethanol.[8]

The RFS policy is now facing an important time in its history. Despite increased production since the revisions brought by the RFS2, compliance with the mandated volumes has provoked several challenges to the industry and policy makers. For instance, while Congress projected the continuous increase in gasoline demand in 2007, the global recession in 2009 affected the consumption of petroleum

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[1] *Program Overview for Renewable Fuel Standard Program*, U.S. ENVTL. PROTECTION AGENCY [hereinafter *Program Overview*], http://www.epa.gov/renewable-fuel-standard-program/program-overview-renewable-fuel-standard-program [https://perma.cc/57TJ-FDBY] (last updated Aug. 16, 2016).

[2] Communications in News, *RFA to House Committee: RFS Is Single Most Important Economic Value-Added Market for Agriculture*, RENEWABLE FUELS ASS'N (April 30, 2013, 9:31 AM), http://www.ethanolrfa.org/2013/04/rfa-to-house-committee-rfs-is-single-most-important-economic-value-added-market-for-agriculture/ [https://perma.cc/8AH8-9UNQ].

[3] *Program Overview*, *supra* note 1.

[4] RANDY SCHNEPF & BRENT D. YACOBUCCI, CONG. RESEARCH SERV., R40155, RENEWABLE FUEL STANDARD (RFS): OVERVIEW AND ISSUES 1, 4 (2013) [hereinafter RFS OVERVIEW AND ISSUES].

[5] *Renewable Fuel Standard Program (RFS1): Final Rule*, U.S. ENVTL. PROTECTION AGENCY, http://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-standard-program-rfs1-final-rule [https://perma.cc/L45M-QQGG] (last updated Sept. 28, 2015).

[6] RENEWABLE FUELS ASS'N, FROM NICHE TO NATION: ETHANOL INDUSTRY OUTLOOK 2006, at 2 (2006), http://www.ethanolrfa.org/wp-content/uploads/2015/09/outlook_2006.pdf [https://perma.cc/JUP8-99AD].

[7] *Program Overview*, *supra* note 1.

[8] RENEWABLE FUELS ASS'N, CHANGING THE CLIMATE: ETHANOL INDUSTRY OUTLOOK 2008, at 2 (2008), http://www.ethanolrfa.org/wp-content/uploads/2015/09/RFA_Outlook_2008.pdf [https://perma.cc/V4JF-GKQM].

products in the transportation sector, which, consequently, affected the viability of certain amounts of biofuel to be blended into gasoline.[9]

Another challenge in implementing the different categories of biofuel mandates concerns second-generation ethanol, such as cellulosic ethanol, which is one of the categories with its own volume requirements under the RFS.[10] The commercialization of cellulosic ethanol has raised significant uncertainties—it was not until 2013 that the first three commercial-scale biorefineries producing cellulosic ethanol in the country started their operations.[11] Higher blending volumes require higher-level ethanol blends, which are currently incompatible with automobile engines.[12] Moreover, the current infrastructure also presents significant difficulties in absorbing higher ethanol mandates.[13]

Challenges to the policy place the RFS program under constant scrutiny by both supporters of the program and opposing groups, and the question becomes whether, despite these challenges, the RFS mandates have achieved successful results in promoting the nascent first-generation ethanol industry.[14] Until now, more than ten years after the enactment of the RFS program, no comprehensive studies have been conducted and no substantial data has been provided to answer that question. The existing literature fails to consider how the industry life cycle mediates the effects the RFS has on the economic sustainability of the U.S. biofuels industry. This Article answers this question and addresses the important gap in the scholarship in this area.

At present, the Environmental Protection Agency ("EPA"), the agency responsible for the implementation of the RFS program, is aware of these challenges, and it seeks to balance Congress's intent of "increasing renewable fuel use over time

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[9] *EPA Sets Final Ethanol Levels*, INST. FOR ENERGY RES. (Dec. 11, 2015), http://instituteforenergyresearch.org/analysis/epa-sets-final-ethanol-levels/ [https://perma.cc/AR4T-Y8SD].

[10] *Program Overview*, *supra* note 1.

[11] Sena Christian, *Is Cellulosic Ethanol the Next Big Thing in Renewable Fuels?*, EARTH ISLAND J. (Jan. 5, 2015), http://www.earthisland.org/journal/index.php/elist/eListRead/is_cellulosic_ethanol_the_next_big_thing_in_renewable_fuels/ [https://perma.cc/NMA4-8568].

[12] RFS OVERVIEW AND ISSUES, *supra* note 4, at 27−28.

[13] *Id.*

[14] *See, e.g.*, Todd Neeley, *Ethanol and Oil Interests Challenge EPA Authority in RFS Program – DTN*, AGFAX (June 23, 2016), http://agfax.com/2016/06/23/ethanol-and-oil-interests-challenge-epas-in-rfs-program-dtn/ [https://perma.cc/9W4T-LBDR] (discussing the reasons why both ethanol and oil interests are challenging the EPA's use of its waiver authority to set renewable volumetric obligations below statute); Daniel Simmons, *Why Congress Should Fully Repeal the RFS,* AM. ENERGY ALLIANCE (May 27, 2015), http://americanenergyalliance.org/2015/05/27/corn-ethanol-only-repeal-makes-the-rfs-worse/ [https://perma.cc/Y4GQ-YW6N] (discussing the reasons why the RFS is a failed policy and advocating that the RFS should be repealed); Energy Tomorrow Blog, *Growing Consensus On 'Unworkable' RFS,* BREAKING ENERGY (Mar. 13, 2015, 2:00 PM), http://breakingenergy.com/2015/03/13/growing-consensus-on-unworkable-rfs/ [https://perma.cc/R4ZF-4C2Q] (discussing some of the groups opposing the RFS).

in order to address climate change and increase energy security while," simultaneously, "accounting for the real-world challenges that have slowed progress toward such goals."[15] In light of these and other challenges, the EPA has had to overcome continuous criticism from petroleum-related interest industries to be able to implement the required mandates. On November 30, 2015, the EPA announced the much-expected final volume requirements for the 2014, 2015, and 2016 years as well as the final volume requirements for biomass-based diesel for 2014 through 2017.[16] The EPA is responsible for setting mandate requirements each November for the next year's mandated biofuel volumes but has been behind on the schedule the past several years due to the challenges discussed above.[17] In an effort to comply with the schedule for mandate requirements, the EPA has timely proposed volume increases across all types of biofuels under the RFS program for 2017.[18] The total renewable fuel volumes would increase by approximately 700 million gallons between 2016 and 2017 under the proposed mandates.[19]

This proposed increase for biofuels mandate is in line with the agency efforts to promote the growth of the biofuels industry. According to the EPA, this increase will "drive growth in renewable fuels, particularly advanced biofuels."[20] As we argue in this Article, our empirical evidence shows that the first-generation ethanol industry presented signs of growth with the implementation of the RFS policy. Likewise, the proposed increases under the RFS could have similar effects on the nascent second-generation ethanol industry. This Article corroborates the EPA's efforts to increase mandates in 2017 that will promote the development of the early second-generation ethanol industry. Yet, as expected given the controversial nature and impact of the program, the past and current volume requirements have been a source of disagreement among the oil industry, policy makers, and the biofuels industry. Both the oil-related and ethanol industries are constantly dissatisfied with the level of ethanol mandates proposed by the EPA, the former calling for lesser

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[15] Renewable Fuel Standard Program: Standards for 2014, 2015, and 2016 and Biomass-Based Diesel Volume for 2017, 80 Fed. Reg. 77,420, 77,422 (Dec. 14, 2015) (to be codified at 40 C.F.R. pt. 80).

[16] *See* Erin Voegele, *EPA Releases Proposed 2014, 2015, 2016 RFS Volume Requirements*, BIOMASS MAG. (May 29, 2015), http://biomassmagazine.com/articles/12000/epa-releases-proposed-2014-2015-2016-rfs-volume-requirements [https://perma.cc/52RA-FN39].

[17] *Id.*

[18] *See Proposed Renewable Fuel Standards for 2017, and the Biomass-Based Diesel Volume for 2018*, U.S. ENVTL. PROTECTION AGENCY, https://www.epa.gov/renewable-fuel-standard-program/proposed-renewable-fuel-standards-2017-and-biomass-based-diesel [https://perma.cc/AG69-GRKF] (last updated June 1, 2016).

[19] *Id.*

[20] Renewable Fuel Standard Program: Standards for 2017 and Biomass-Based Diesel Volume for 2018, 81 Fed. Reg. 34,778, 34,780 (May 31, 2016) (to be codified at 40 CFR Pt. 80).

volumes and the latter for the statutory mandates to be imposed.[21] While the EPA increased the levels of renewable fuels that it had previously proposed on June 10, 2015,[22] these levels are considerably less than the amounts required by the letter of the RFS.[23] Similarly, the 2017 proposed standards also fall below the statutory volume requirements as set initially by Congress.[24] Because the proposed levels are less than required by the statute, RFS supporters argue that the EPA has "delivered a blow" to the corn industry by not following the higher volume amounts of biofuels currently set by Congress.[25] The reason behind this statement is that failing to meet the higher statutory demands halts the expansion and availability of renewable fuels to consumers.[26] For the 2017 proposed renewable fuel volumes by the EPA, supporters of the RFS argue that the 2017 volumes failed to meet it the agency stated goal of getting the RFS program "back on track."[27] In light of such disagreements that question the actual importance of the RFS program, we come back to the question initially posed: have the RFS mandates achieved successful results in promoting the nascent first-generation ethanol industry to justify its continuance?

This Article provides an empirical study of the RFS effects on the economic sustainability of the existing U.S. biofuels industry. To evaluate these effects, we gather data on the characteristics of 216 first-generation ethanol production facilities in the U.S. Our theoretical model suggests that large-scale mandatory demand contributes to incentivizing the expansion of production capacity, and thus improves economies of scale, given that the market is still within the developing stage of its product life cycle ("PLC"). The PLC is a sequence of stages from the introduction of the product to growth, maturity, and decline that can be used to examine the

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[21] *See, e.g.*, Jessica Lyons Hardcastle, *EPA Mandates Biofuel Volumes for 2016, Big Oil and BIO Attack Requirements*, ENVTL. LEADER (Nov. 30, 2015), http://www.environmentalleader.com/2015/11/30/epa-mandates-biofuel-volumes-for-2016-big-oil-and-bio-attack-requirements/ [https://perma.cc/5ZTA-9H3N] (noting that both oil-related and ethanol industries were not satisfied with the 2016 released mandates).

[22] *Id.*

[23] *See Program Overview*, *supra* note 1 (providing a table showing the volumes standards contained in the statute. The final 2016 volume requires 18.11 billion gallons of biofuels to be used in the national transportation fuel supply, which is below the 22.25 billion gallons required under the RFS2. While 4.25 billion gallons of cellulosic ethanol are required under the RFS2 in the year 2016, the EPA mandates that 230 million gallons be mixed into the nation's fuel market. Similarly, traditional corn-based ethanol is set at 14.5 billion gallons, 500 million gallons below its target under the law).

[24] *Id.*

[25] *See* Alex Guillén, *Obama Curbs Ethanol in Blow to Corn Growers*, POLITICO (Nov. 30, 2015 6:40 PM), http://www.politico.com/story/2015/11/breaking-news-epa-scales-back-ethanol-mandate-in-gasoline-216270 [https://perma.cc/5XUW-4XG7].

[26] *Id.*

[27] *See* Spencer Chase, *2017 RFS Proposal Falls Short of Statutory Levels*, AGRIPULSE (May 18, 2016), http://www.agri-pulse.com/2017-RFS-proposal-falls-short-of-statutory-levels-05182016.asp [https://perma.cc/K2S8-YAFD].

development of an industry.[28] Since our data cover the years from 2000 to 2013, which includes periods without the RFS policy (2000–2005) and with the RFS policy (2006–2013), our study allows us to empirically investigate the impact of the RFS on production efficiency through an analysis of the changes in the first-generation ethanol firms and plant production capacity.

We show that the RFS program has had significant positive effects on developing economies of scale at the early stage of development of the first-generation biofuels industry. Our data suggests that the RFS has strengthened the growth of the ethanol market in its distinct stages of the product life cycle (PLC). However, when the first-generation ethanol industry reached a mature stage in its PLC, the RFS does not have a statistically significant effect on plant or firm capacity in this industry. As a result, this empirical study has important implications to policies related to second-generation biofuels. We discuss and contrast the development of the first and second-generation ethanol industries, and their current stages of development. Once the second-generation biofuels industry reaches a similar PLC stage as the current first-generation ethanol industry, the RFS program may have similar effects on second-generation biofuels. This concept will be further developed throughout our analysis.

This Article proceeds in five parts. Part II provides a general background and briefly explores some of the history of the U.S. ethanol industry. It will articulate the policy goals behind the RFS program and emphasize how policies of biofuel mandates have also been implemented in different countries. Next, we provide important background information and policy implications of the RFS. Part III reviews recent work examining the impact of biofuel mandates and the specific effects of the RFS policy in the United States. Part IV sets out an economic model of large-scale mandatory demand, first providing a background of the well-known work of Gort and Klepper, and second, using our model to expand the PLC model to the ethanol market. Finally, Part V presents our empirical analysis from our sample of 216 first-generation U.S. ethanol facilities that are operated by 177 firms. The purpose of this section is to investigate how the RFS mandated demand impacted the ethanol market at the different stages of its PLC. We also discuss the policy implications to our empirical findings. Part VI provides our final remarks.

II. BACKGROUND

The ethanol industry dates back decades before the RFS policy was enacted in 2005, and this prior development has important consequences for our study. In this section, we will first briefly discuss the phase out of Methyl Tertiary-Butyl Ether ("MTBE") and its impact on ethanol and some of the policies targeting ethanol consumption before the enactment of the RFS program. We will also discuss some important features of the RFS policy and assess the impact of the RFS in promoting the growth of the ethanol industry.

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[28] Steven Klepper, *Entry, Exit, Growth, and Innovation Over the Product Life Cycle*, 86 AM. ECON. REV. 562, 562 (1996) [hereinafter Entry, Exit, Growth, and Innovation].

A. The Development of the Ethanol Industry and Policies in the U.S.

The ethanol industry in the U.S. dates back to 1979, when the Amoco Oil Company began marketing commercial alcohol-blended fuels, and it has expanded rapidly since 2002.[29] U.S. ethanol consumption increased from 83 million gallons in 1981 to 2.073 billion gallons in 2002.[30] This growing trend is confirmed with recent estimates indicating that ethanol production totaled 14.313 billion gallons during the 2014 calendar year.[31] This sharp increase in ethanol consumption may have been due to two main reasons. First, the discovery of negative effects of MTBE in the environment, such as contamination of the soil and ground water.[32] Second, the increase of ethanol consumption may be due to tax credits in support of ethanol.[33] The federal ethanol fuel incentives, together with state incentives, are generally conceded as the main driving force for ethanol production and use in the U.S.[34]

Ethanol and MTBE have been mainly used as oxygenate additives to help gasoline burn more cleanly and increase its octane rating.[35] During the 1990s, gasoline refiners preferred to use MTBE because it was cheaper than ethanol and could be produced from petroleum refining outputs, but this trend was reversed around 2001.[36] MTBE consumption started falling in 2001, whereas ethanol consumption started rising, especially in 2005, in response to the replacement of MTBE and government policy incentives.[37] The MTBE effect on ethanol was

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[29] JULIE KERR CASPER, ENERGY: POWERING THE PAST, PRESENT, AND FUTURE 190 (2007).

[30] U.S. ENERGY INFO. ADMIN., ANNUAL ENERGY REVIEW 2011, at 287 (Sept. 27, 2012), http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf [https://perma.cc/HM77-XUF3].

[31] *See* Debra Levey Larson, *Ethanol Production and Corn Consumption Prospects for 2016*, UNIV. ILL. EXTENSION, (Dec. 8, 2015), http://web.extension.illinois.edu/state/news detail.cfm?NewsID=32978 [https://perma.cc/3HLC-YJVF].

[32] Charles Andrews, *MTBE—A Long-Term Threat to Ground Water Quality*, 36 GROUND WATER 705, 705–06 (1998).

[33] *See* TOM MACDONALD, CAL. ENERGY COMM'N, P600-04-001, ETHANOL FUEL INCENTIVES APPLIED IN THE U.S.: REVIEWED FROM CALIFORNIA'S PERSPECTIVE, http://www.energy.ca.gov/reports/2004-02-03_600-04-001.PDF [https://perma.cc/AM7X-CRZ3] (describing the measures employed by state and federal government to advance the production and use of ethanol fuel in the country).

[34] *See id.* at 7.

[35] *See Cleaner-Burning Gasoline Without MTBE*, CAL. ENVTL. PROT. AGENCY, http://www.arb.ca.gov/fuels/gasoline/cbgmtbe.htm [https://perma.cc/V9RY-HPLT] (last updated Sept. 25, 2008).

[36] *See* STEFAN OSBORNE, U.S. DEP'T OF COMM., ENERGY IN 2020: ASSESSING THE ECONOMIC EFFECTS OF COMMERCIALIZATION OF CELLULOSIC ETHANOL 4 (Nov. 2007), http://www.trade.gov/media/publications/pdf/cellulosic2007.pdf [https://perma.cc/9H78-MHLR] [hereinafter OSBORNE, ENERGY IN 2020].

[37] *See* Jadwiga Ziolkowska et al., *Targets and Mandates: Lessons Learned from EU and US Biofuels Policy Mechanisms*, 13 J. AGROBIOTECHNOLOGY MGMT. & ECON. 398, 398

mainly because a number of studies discovered that MTBE contaminates ground water and drinking water sources and also potentially risks human health.[38] As a result, several states banned the use of MTBE as a gasoline additive, and ethanol rapidly replaced MTBE as a gasoline additive between 2002 and 2007.[39] The RFS program has likely helped to boost this shift from using MTBE towards the common use of ethanol as a gasoline additive.[40]

It is interesting to note that until the 1970s, there were no federal tax incentives promoting ethanol or any other renewable energy source.[41] Until then, federal energy tax policy focused almost exclusively on increasing the domestic production of oil and gas.[42] The energy crisis and the increased concern with environmental issues in the 1970s caused a shift away from oil and gas in the focus of federal energy tax policy towards ethanol and other forms of renewable energy.[43] As for incentives for increasing the use of ethanol in this period, thus prior to the RFS, significant federal programs aimed at supporting biofuels focused on providing tax credits in support of the production or blending of ethanol and biodiesel.[44] For example, the Energy Tax Act of 1978 allowed for a motor fuel excise tax exemption, giving ethanol blends of at least 10% by volume a $0.40 exemption on every gallon under the federal motor fuels tax.[45] Similarly, in 2004, the federal government created the Volumetric Ethanol Excise Tax Credit ("VEETC"), which is also known as the blenders' tax credit.[46] The VEETC provided a $0.51 credit per gallon of pure ethanol blended with gasoline to blenders of ethanol, and it served as an incentive to

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(2010); Tancred Lidderdale, *Motor Gasoline Outlook and State MTBE Bans*, ENERGY INFO. ADMIN., http://www.eia.gov/forecasts/steo/special/pdf/mtbeban.pdf [https://perma.cc/K9H5-Y5U5] (last modified April 6, 2003) (showing tables indicating falling consumption of MTBE in 2001, when some states (e.g., Maine) banned the use of MTBE).

[38] *See* OSBORNE, ENERGY IN 2020, *supra* note 36.

[39] *Id.* (noting that "ethanol demand rose significantly at that time and was largely driven by state-level environmental regulations mandating oxygenate use").

[40] *See* Soren T. Anderson & Andrew Elzinga, *A Ban on One Is a Boon for the Other: Strict Gasoline Content Rules and Implicit Ethanol Blending Mandates*, 67 J. ENVTL. ECON. & MGMT. 258, 259−66 (2014) (arguing that "the MTBE bans are important pre-existing regulations that must be considered when assessing the impacts of the federal Renewable Fuel Standard (RFS). . . . Beyond 2007, it is clear that ethanol consumption is rising above the level necessary to replace the banned MTBE.").

[41] MOLLY F. SHERLOCK, CONG. RESEARCH SERV., R41227, ENERGY TAX POLICY: HISTORICAL PERSPECTIVES ON AND CURRENT STATUS OF ENERGY TAX EXPENDITURES 2 (2011).

[42] *See id.*

[43] *See id.*

[44] *See* RFS OVERVIEW AND ISSUES, *supra* note 4, at 18−19.

[45] *See* James A. Duffield & Keith Collins, *Evolution of Renewable Energy Policy*, CHOICES, 1st Quarter 2006, http://www.choicesmagazine.org/2006-1/biofuels/2006-1-02.pdf [https://perma.cc/QQ96-YFRR].

[46] Amy Diggs, *The Expiration of the Ethanol Tax Credit: An Analysis of Costs and Benefits*, 19 POL'Y PERSP. 47, 48 (2012).

encourage ethanol use in gasoline until its expiration on December 31, 2011.[47] These are just some of the examples of incentives and subsidies provided by the U.S. government for the use of biofuels since 1978.[48]

Therefore, government incentives to ethanol use and production have played a central role in the use of ethanol fuel for gasoline blending. The enactment of the RFS, however, was a new approach to ethanol as it marked the first instance where its commercialization was mandated by law by requiring refiners and importers of traditional transportation fuels (i.e., gasoline and diesel fuel) to commercialize specific volumes of renewable biofuels every year between 2006 and 2022.[49]

That being said, the RFS program differs from other programs in the U.S. as being the first legislative attempt to mandate demand for a type of renewable energy. The policy rationales behind the RFS were that increased use of biofuels in the transportation system would: (1) enhance U.S. energy security by mitigating the amount of petroleum-based fuels that need to be imported from foreign nations, (2) benefit the environment by reducing the amount of greenhouse gas (GHG) emissions from the transportation sector, and (3) act as a boon for rural economic development.[50] Given these rationales for incentivizing the use of biofuels, why was it necessary for the U.S. government to side step its typical policy instruments (e.g., tax subsidies, loan guarantees, research and development grants, etc.) and experiment with a mandatory demand regime?

The legislative history of the RFS makes very little mention of why this particular policy instrument was selected;[51] however, it likely has to do with the fact that biofuels must compete with petroleum-based fuels in the transportation fuel

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[47] *Id.* at 47–48.

[48] *See* Wallace E. Tyner, *U.S. Ethanol Policy—Possibilities for the Future*, PURDUE EXTENSION BIOENERGY (2007), https://www.extension.purdue.edu/extmedia/id/id-342-w.pdf [https://perma.cc/THM8-8R8H] (providing other examples of ethanol subsidy legislation).

[49] *Program Overview*, *supra* note 1.

[50] *Economics of Biofuels*, U.S. ENVTL. PROTECTION AGENCY, https://www.epa.gov/environmental-economics/economics-biofuels [https://perma.cc/K783-DH8X] (last updated May 27, 2016).

[51] *See* U.S. ENVTL. PROTECTION AGENCY, EPA-420-R-10-003, RENEWABLE FUEL STANDARD PROGRAM (RFS2) SUMMARY AND ANALYSIS OF COMMENTS, at 1-1 to 1-3 (2010), https://www.epa.gov/sites/production/files/2015-08/documents/420r10003.pdf [https://perma.cc/Z4M7-RMNA] (stating that the EPA believes that the "increase use of renewable fuels in place of petroleum fuels will provide both greenhouse gas and energy benefits to our nation, as well as significant economic benefits to our agricultural sector," the rule "faithfully implements the requirements of EISA in a manner consistent with [the EPA's] legal obligations, with sound science, and with sound environmental, energy, and economic policy," and extensive analysis was conducted in support of the RFS). While the EPA mostly responded to several comments and questions regarding the policy model, lifecycle methodology, suppliers, etc., it does not detail how the policy instrument was particularly selected.

market, which is predominantly controlled by the entrenched petroleum industry.[52] The petroleum industry significantly controls the production and distribution infrastructure for transportation fuels in the U.S.[53] Biofuels are traditionally blended with petroleum-based fuels before being distributed to customers,[54] and the commercial success of biofuels is, consequently, heavily reliant on their being purchased and utilized by the petroleum industry. Since actors in the petroleum industry would likely not seek to commercialize substitute products whose success would diminish the market share for their own products, it thus seems logical that the U.S. government would be the likely candidate to incentivize the increased use of biofuels. Hence, one option would be requiring the entrenched petroleum industry to commercialize biofuels via a mandatory demand regime that places its regulatory costs on the regulated entities.

In short, government incentives have been part of the ethanol industry development, and one of the most important goals of the RFS policy is to keep expanding ethanol as a gasoline additive and promoting the consumption of biofuels. In addition, the RFS also has other important policy rationales, that being reducing oil dependency, reducing GHG emissions, and promoting rural development. That said, our analysis will not address or consider the impact of the RFS program on any of these policy rationales. Rather, this Article will focus on the actual impact of the RFS on the growth of the first-generation ethanol industry.

B. The Impact of the Renewable Fuel Standard in the U.S. Ethanol Industry

In this Article, we focus on the economic impact of the RFS policy on the U.S. domestic biofuel market. Before we provide a brief overview of the program in the U.S., it is interesting to briefly note the impact of similar mandate requirements in other countries.

Biofuel mandates are not an exclusive policy under the RFS; in fact, government mandates have been successfully employed by many different countries seeking to increase renewable energy use. Target government mandates for ethanol consumption is one of the options for reducing reliance on imported oil, and

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[52] *See* Renewable Fuels Association, *Analysis Shows U.S. Ethanol Is Lowest Cost Fuel, Octane Source*, ETHANOL PRODUCER MAG. (July 22, 2014), http://ethanolproducer.com/articles/11271/analysis-shows-u-s-ethanol-is-lowest-cost-fuel-octane-source [https://perma.cc/6RQS-EN25].

[53] *See* NAT'L HIGHWAY TRAFFIC SAFETY, *Availability and Use of Alternative Fuels*, *in* REPORT TO CONGRESS: EFFECTS OF THE ALTERNATIVE MOTOR FUELS ACT CAFÉ INCENTIVES POLICY, https://one.nhtsa.gov/cars/rules/rulings/CAFE/alternativefuels/index.htm#content [https://perma.cc/96XH-4FXD] (follow the "Availability and Use of Alternative Fuels" hyperlink).

[54] *See Frequently Asked Questions: How Much Ethanol Is in Gasoline and How Does It Affect Fuel Economy?*, U.S. ENERGY INFO. ADMIN, http://www.eia.gov/tools/faqs/faq.cfm?id=27&t=10 [https://perma.cc/6QYU-CYXK] (last updated April 6, 2016).

government mandates are often combined with other policies.[55] Mandates are expected to promote positive changes in demand in the ethanol market, especially in the blending sector,[56] and, in Brazil, ethanol mandates have allowed the country to greatly reduce its petroleum imports.[57] At present, biofuels mandates are used by sixty-four other countries, which reflects their intentions to promote consumption and expansion of biofuels.[58]

Currently, some of the major blending mandates that will drive demand of biofuels globally are those of the European Union ("EU"), Brazil, and the U.S.[59] Different than in the U.S., where mandates are based on volumes, most biofuel mandates in other countries are based on percentage shares of consumption.[60] According to the 2009 Renewable Energy Directive, the EU has an overall target of at least 10% of energy to be used in the transportation system coming from biofuels by 2020.[61] Likewise, in Brazil, the government currently requires up to 27% of ethanol be mixed into gasoline.[62]

Another difference between the U.S. policy and biofuels policies in other countries is that most of the different mandates worldwide focus on promoting first-generation biofuels.[63] In the U.S., at present, the RFS provides a mandatory market for not only first-generation biofuels (e.g., cornstarch ethanol and soy biodiesel), but it also creates a market for second-generation biofuels (e.g., advanced and cellulosic biofuels).[64] Advanced biofuels mandates were part of the RFS requirements when it was first enacted in 2005. More recently, some countries have also started to require

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[55] Harry de Gorter & David R. Just, *The Social Costs and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy*, 32 APPLIED ECON. PERSP. POL'Y 4, 11–14 (2010) (noting the benefit of combining different biofuel policies).

[56] Dong Hee Suh & Charles B. Moss, *Dynamic Adjustment of Ethanol Demand to Crude Oil Prices: Implications for Mandated Ethanol Usage*, EMPIRICAL ECON., DOI: 10.1007s00191-01601112-6, at 2 (2016).

[57] Robert Wisner, *Biofuels Mandates Outside the U.S.*, AGMRC (Feb. 2013), http://www.agmrc.org/renewable-energy/biofuelsbiorefining-general/biofuels-mandates-outside-the-us/ [https://perma.cc/BJR3-L95C].

[58] Jim Lane, *Biofuels Mandates Around the World: 2016*, BIOFUELS DIGEST (Jan. 3, 2016), http://www.biofuelsdigest.com/bdigest/2016/01/03/biofuels-mandates-around-the-world-2016/ [https://perma.cc/4KKP-KSTZ].

[59] *Id.*

[60] Timothy A. Wise & Emily Cole, *Mandating Food Insecurity: The Global Impacts of Rising Biofuel Mandates and Targets* 3 (Global Dev. & Env't Inst., Working Paper No. 15-01, 2015), https://ase.tufts.edu/gdae/Pubs/wp/15-01WiseMandates.pdf [https://perma.cc/4S6A-5R32].

[61] BOB FLACH ET AL., U.S. DEP'T AGRIC. FOREIGN AGRIC. SERV., NL5028, EU BIOFUELS ANN. 2015, at 4 (2015).

[62] Erin Voegele, *Brazil to Increase Ethanol Blend to 27 Percent*, ETHANOL PRODUCER MAG. (Mar. 9, 2015), http://www.ethanolproducer.com/articles/12020/brazil-to-increase-ethanol-blend-to-27-percent [https://perma.cc/R4F8-83B2].

[63] Wise & Cole, *supra* note 60.

[64] RFS OVERVIEW AND ISSUES, *supra* note 4, at 2.

mandates for advanced biofuels.[65] For instance, the Italian government was the first in Europe to create a 0.6% advanced biofuels mandate by 2018 to foster demand for advanced biofuels.[66]

In the United States, the RFS currently exists as a system of nested mandates for four uniquely defined categories of biofuels.[67] The broadest category of biofuel is called "renewable fuel" and is defined as including any fuel produced from renewable biomass that has lifecycle GHG emissions[68] that are at least 20% lower than a baseline.[69] The second category, "advanced biofuel," is defined as including renewable fuels (with the explicit exclusion of corn-based ethanol) that have lifecycle GHG emissions that are at least 50% lower than the 2005 baseline.[70] "Cellulosic biofuel," the third category, includes any fuel produced from the cellulose, hemi-cellulose, or lignin of renewable biomass that has lifecycle GHG emissions that are at least 60% lower than the 2005 baseline.[71] The final category, "biomass-based diesel," is defined as including renewable diesel fuels produced from renewable biomass that have lifecycle GHG emissions that are at least 50% lower than petroleum-based diesel's 2005 lifecycle GHG emissions.[72] Because these four categories are nested, any fuel that qualifies as either a cellulosic biofuel or a biomass-based diesel is also capable of being used to satisfy the RFS advanced biofuel mandate.[73] Likewise, any fuel that qualifies as an advanced biofuel can also

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[65] Mila Luleva, *Use of Advanced Biofuels in Petrol Made Compulsory in Italy*, THE GREEN OPTIMISTIC (Oct. 15, 2014), http://www.greenoptimistic.com/use-advanced-biofuels-petrol-made-compulsory-italy-20141015/#.VpkY8H6rTIW [https://perma.cc/RG8B-ZRXM] (noting that the U.S. has mandates for advanced biofuels, and Italy is now the first European country to set up such a demand target for advanced biofuels).

[66] Lane, *supra* note 58; Luleva, *supra* note 65 (noting that the U.S. has mandates for advanced biofuels, and Italy is now the first European country to set up such a demand target for advanced biofuels).

[67] RFS OVERVIEW AND ISSUES, *supra* note 4, at 5–6.

[68] 42 U.S.C. § 7545(o)(1)(H) (2006) (defining lifecycle GHG emissions as "the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the [EPA], related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential").

[69] RFS OVERVIEW AND ISSUES, *supra* note 4, at 6 (noting that the baseline is defined as the 2005 lifecycle GHG emissions associated with gasoline or diesel fuel (whichever the renewable fuel is replacing)).

[70] *Id.* at 4–6 (noting that the term "advanced biofuels" comes from legislation in the 110th Congress, and is defined in Section 201 of the Energy Independence and Security Act of 2007 (EISA)).

[71] *Id.* at 6.

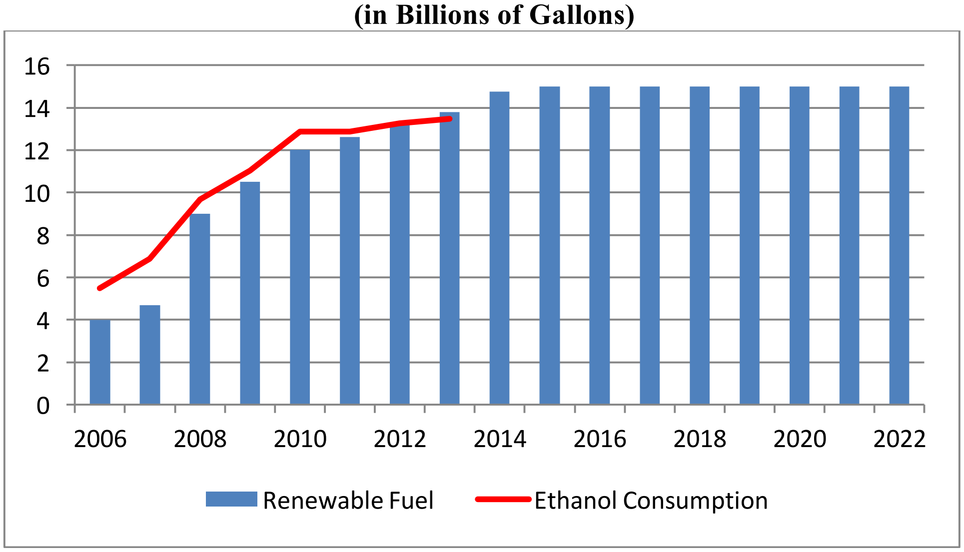
[72] *Id.*

[73] *Id.* at 5.

be used to satisfy the overarching renewable fuel mandate.[74] Finally, fuels that can only satisfy the definition for renewable fuel (e.g., ethanol derived from corn starch) can only be used to satisfy the portion of the RFS mandates that are not required to be met with advanced biofuels.[75]

Figure 1 illustrates the RFS mandates and ethanol consumption, showing the portion of the yearly RFS mandates that can be satisfied with the use of corn-based ethanol (i.e., the difference between total RFS renewable fuel mandate and its advanced biofuel mandate) and the U.S. annual consumption of ethanol. As shown in Figure 1, corn-based ethanol can be used to satisfy four billion gallons of the RFS mandates in 2006, and the volume increases over time to reach fifteen billion gallons in 2022. The trend of ethanol consumption coincides with the mandate and was at least 200 million gallons higher than the mandated volume before 2011.

Figure 1: RFS Ethanol Mandates and Consumption (in Billions of Gallons)



Source: Alternative Fuels Data Center, U.S. Department of Energy

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[74] *Id.*

[75] KELSI BRACMORT, CONG. RESEARCH SERV., R43325, THE RENEWABLE FUEL STANDARD (RFS): IN BRIEF, at 3 (2015).

Figure 1 also shows that, for the first time in 2013, U.S. ethanol consumption was less than the mandate, which was complied with through the use of nonethanol biofuels.[76] For instance, biodiesel consumption in 2013 was 1.4 billion gallons, which was 0.4 billion gallons more than the 2013 and 2014 RFS biomass-based diesel mandate.[77] In other words, in 2013 the RFS mandated that obligated parties consume more ethanol than the amount that can be consumed solely by blending 10% ethanol blends (E10) in 2013.[78] This is known as the "blend wall."[79] Scholars have investigated whether there is a shift in the RFS policy effects when the ethanol industry faces the blend wall.[80] This study suggests the effectiveness of the policy instrument is mostly driven by the PLC effect.

Next, Figure 2 illustrates the relative volumetric price of ethanol to gasoline between 1982 and 2012.[81] Based on the Nebraska Ethanol Board's report of average rack prices for ethanol and unleaded gasoline from 1982 to 2010, the correlation coefficient is estimated at 0.9189.[82] As one of the policy goals of the RFS program is to increase the energy security of the U.S. through the increased use of

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[76] *See* Enesta Jones, *EPA Proposes 2014 Renewable Fuel Standards / Proposal Seeks Input to Address "E10 Blend Wall," Reaffirms Commitment to Biofuels*, U.S. ENVTL. PROT. AGENCY (Nov. 15, 2013), http://yosemite.epa.gov/opa/admpress.nsf/bd4379a92ceceeac 8525735900400c27/81c99e6d27c730c485257c24005eecb0!OpenDocument [https://perma.cc/TR88-3U83] (discussing the reduction of 2014 standards in light of the blend wall and other issues in meeting the mandates).

[77] *Biofuels: Ethanol and Biodiesel* Explained*:* Use of Biodiesel, U.S. ENERGY INFO. ADMIN., http://199.36.140.204/EnergyExplained/index.cfm?page=biofuel_biodiesel_use (last reviewed Aug. 29, 2016) [https://perma.cc/BTT7-WNVD] (noting that substantial quantities of biodiesel were used to meet the RFS—and while consumption declined to about 870 million gallons in 2012, it then increased to nearly 1.4 billion gallons in 2013 and 2014).

[78] *EPA Finalizes Renewable Fuel Standard for 2013; Additional Adjustments Expected in 2014*, U.S. ENERGY INFO. ADMIN. (Aug. 14, 2013, 10:28 AM), http://www.eia.gov/todayinenergy/detail.cfm?id=12531 [https://perma.cc/6ADN-ZUVH] (discussing the 2013 mandates and how limits on higher ethanol blending will require adjustments to the 2014 mandates).

[79] *Blend Wall*, RENEWABLE FUELS ASS'N, http://ethanolrfa.org/issues/blend-wall/ [https://perma.cc/R62E-3DF9] (defining the "Blend Wall" as "the maximum quantity of ethanol that can be sold each year given legal or practical constraints on how much can be blended into each gallon of motor fuel").

[80] *See, e.g.*, Harry de Gorter, Dusan Drabik & David R. Just, *Policy Update: Policy Implications of High RIN Prices and the 'Blend Wall,'* 4 BIOFUELS 359, 359–61 (2013) (discussing how RIN prices show the blend wall has become a constraint).

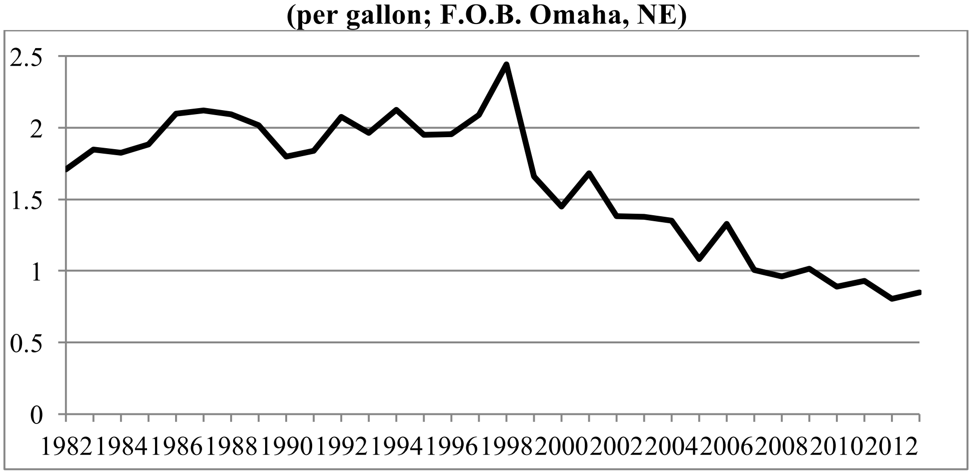
[81] *See Ethanol and Unleaded Gasoline Average Rack Prices*, OFFICIAL NEB. GOV'T WEBSITE, http://www.neo.ne.gov/statshtml/66.html [https://perma.cc/7XQR-VYLJ] (last updated Sept. 14, 2016).

[82] *Correlation Coefficient*, INVESTOPEDIA, http://www.investopedia.com/terms/c/ correlationcoefficient.asp#ixzz4KG2mC9Sk [https://perma.cc/JJM8-8RY6] (explaining that the correlation coefficient is a measure that determines the degree to which two variables' movements are associated and that the range of values for the correlation coefficient is -1.0 to 1.0).

domestically produced ethanol, it is crucial to evaluate the competitiveness of ethanol compared to gasoline.

Figure 2 shows that the relative volumetric price of ethanol to gasoline falls over time, and dips below 1 in 2008 and between 2010 and 2013. While the effective volumetric price of ethanol is now lower than that of gasoline, the fact that ethanol possesses only 66% the energy content of gasoline should be considered.[83]

Figure 2: Ratio of Fuel-Ethanol Rack Price to Unleaded Gasoline Rack Price (per gallon; F.O.B. Omaha, NE)



Source: Nebraska Ethanol Board

The current price ratio in Figure 2 indicates that although ethanol might not yet be competitive with gasoline on an energy content basis, we are seeing the increasing competitiveness of ethanol.[84] Besides, fuel economy is not the only factor to consider in determining whether gasoline and ethanol are perfect substitutes. Ethanol not only has a higher octane rating than gasoline, but consumers may begin to value the environmental benefits that result from using ethanol (e.g., reduced GHG emissions).[85]

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[83] *See* Mark M. Wright & Robert C. Brown, *Costs of Thermochemical Conversion of Biomass to Power and Liquid Fuels*, *in* THERMOCHEMICAL PROCESSING OF BIOMASS: CONVERSION INTO FUELS, CHEMICALS AND POWER 307, 320 (Robert C. Brown ed., 2011) (stating that the lower energy content of ethanol, as compared to gasoline on a volumetric basis, "affects the range of vehicles fueled on these alcohols").

[84] *See* John M. Urbanchuk, *The Economic Competitiveness of U.S. Ethanol*, ABF ECON., at 16 (July 2014), http://www.ethanolrfa.org/wp-content/uploads/2015/09/Economic_Competitiviness_Study1.pdf [https://perma.cc/SHS2-NND2] (concluding that the market prices and trade data shows that U.S. ethanol is an "exceptionally competitive additive and fuel source").

[85] *See, e.g.*, *Ethanol Vehicle Emissions*, U.S. DEP'T ENERGY, http://www.afdc.energy.gov/vehicles/flexible_fuel_emissions.html [https://perma.cc/H2MW-WC69] ("A 2012 study by Argonne National Laboratory found that when these entire fuel life cycles are

Annual ethanol production capacity has grown significantly in recent years. In 2013, the U.S. ethanol production was 13,300 million gallons.[86] The number of plants and firms has also increased with the growth of the ethanol industry, and we can observe that mergers and acquisitions ("M&A") events happened more frequently in the past several years.[87] The M&A activity indicates that the ethanol market is still within its early stage of product life cycle.[88] This is the case because merger activity is associated with changes in the market, and still progressing to a mature stage.[89] Figure 3 illustrates M&A transactions in the ethanol industry between 2001 and 2013, and show two concave climbing patterns for plant and firm number. It is observed that the number of firms drops in 2008, and the reason for this drop might be that inefficient firms exited the market during the nationwide recession of 2008.[90]

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considered, using corn-based ethanol instead of gasoline reduces life cycle GHG emissions by 19–48% depending on the source of energy used during ethanol production.").

[86] *Industry Statistics*, RENEWABLE FUELS ASS'N, http://www.ethanolrfa.org/resources/industry/statistics/ [https://perma.cc/867B-B4JV] (click on "2013" to view the statistics).

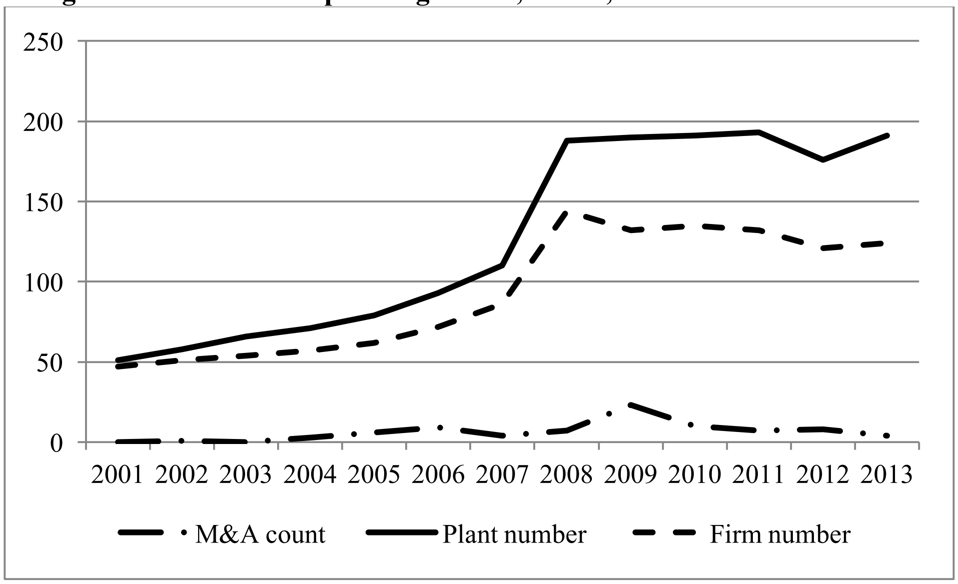
[87] *See* Chris Prentice, *CHS Buys Ethanol Plant, In Long-Term Biofuels Bet*, REUTERS (Jun. 1, 2015, 6:36 PM), http://www.reuters.com/article/markets-ethanol-chs-idUSL1N0YN2KS20150601 [https://perma.cc/N9HE-Z3W5] (discussing a new acquisition and how parties involved in the transaction believe "ethanol industry is going to continue to evolve and consolidate over time"); *see also* JAMES A. DUFFIELD & HARRY BAUMES, U.S. DEP'T AGRIC., CHAPTER 8: POLICY CHANGES AND FUTURE DIRECTION OF BIOFUELS*, in* U.S. ETHANOL: AN EXAMINATION OF POLICY, PRODUCTION, USE, DISTRIBUTION, AND MARKET INTERACTIONS 70 (James A. Duffield et. al. eds., 2015) http://www.usda.gov/oce/reports/energy/EthanolExamination102015.pdf [https://perma.cc/83TZ-PP4P] ("Since the 1970s, the ethanol industry has grown from a few small firms to about 200 plants operating in 29 States, with an annual operating capacity of 14.6 billion gallons." (citation omitted)).

[88] *See* Michael Gort, *An Economic Disturbance Theory of Mergers*, 83 Q. J. ECON. 624, 627 (1969) (arguing that mergers are in many instances prompted by a shock, such as a change in technology).

[89] *Id.*

[90] Erin Voegele, *Recession Continues to Impact Ethanol Industry*, ETHANOL PRODUCER MAG. (May 4, 2009), http://www.ethanolproducer.com/articles/5677/recession-continues-to-impact-ethanol-industry [https://perma.cc/R4F8-83B2].

Figure 3: Number of Operating Plants, Firms, and M&A Transactions



Source: Renewable Fuels Association and CapitalIQ.
Note: M&A count in 2013 only includes data before March, 2013, thus the number is underestimated.

Additionally, the cost of corn rose sharply in 2008 while the price of gasoline dropped, which put tremendous pressure on the profit margins for corn-based ethanol producers.[91] Figure 3 also shows that the growth in number of plants is greater than the growth in number of firms. That might be the result of M&A activity since the rising M&A number after 2008 implies that firms expanded through acquiring existing plants.

The RFS policy comes to provide for mandatory blending levels for renewable fuels, and similar policies are successfully being used in several other countries. The importance of the policy is illustrated in Figures 1 and 2, which show that ethanol fuel is still not able to compete with gasoline, and the ethanol industry is still in its nascent stage where the industry is marked by M&A transactions. Given these scenarios, the RFS policy provides for a steady demand of biofuels and plays an important role in promoting the biofuels industry in its early stage.

III. PREVIOUS WORK STUDYING THE IMPACT OF THE RENEWABLE FUEL STANDARD

We now draw attention to some of the recent studies of the RFS program and its environmental, agricultural, and economic impacts in the U.S. ethanol and related markets. Ever since it was enacted in 2005, the RFS and its impacts on different areas have received a great deal of scholarly attention.

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[91] Robert Wisner, *Impact of High Corn Prices on Ethanol Profitability*, AGMRC (Aug. 2008), http://www.agmrc.org/renewable-energy/ethanol/impact-of-high-corn-prices-on-ethanol-profitability/ [https://perma.cc/BJR3-L95C].

First, the RFS effects on global GHG emissions have been widely studied. Hertel et al. assessed the interaction between the renewable fuel mandates of the two largest biofuel programs, the U.S. and the EU, and its impacts on global GHG emissions.[92] The authors concluded that the mandates and policy interactions between these two important players may have a significant impact on global land use and, in turn, a significant impact on GHG emissions.[93] Mosnier et al. also examined the impacts of the RFS and other alternative biofuel policy designs on global GHG emissions from land use change and agriculture between 2010 and 2030.[94] They concluded that the RFS program would significantly increase the agricultural land needed for biofuel feedstock production and it would also affect the price of U.S. exports.[95] As for GHG, the authors assert that the effects vary: first, if the mandate level is reduced below what is determined by the RFS (50% or 75% of the current mandate), the emissions outside the U.S. would reduce proportionally with the increase in U.S. emissions, and there is no net change in global GHG emissions from altering the U.S. mandate; second, if the current RFS mandate is raised (125% or 150%), this raise in the mandate would lead to an increase in emissions outside the U.S. that exceeds reductions in U.S. fossil fuel emissions, which in turn means a net increase in emissions globally.[96]

Huang et al. examined the economic implications of incorporating both the RFS and the Low Carbon Fuel Standard and concluded that using both policies would lead to a greater GHG emission reduction than would be achieved when employing one policy over the other.[97] Similarly, Khanna et al. concluded that "supplementing the RFS with a price on all fuels based on their GHG intensity raises social welfare above the level with the RFS alone and lowers GHG intensity and overall fuel consumption."[98] Rajagopal et al. compared the RFS mandates and a fuel emission standard that may be utilized to achieve different outcomes, such as a reduction in fuel prices, fuel imports, and GHG emissions.[99] In regards to the GHG emissions, the authors found that when compared to an ethanol mandate, an emission

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[92] Thomas W. Hertel, Wallace E. Tyner & Dileep K. Birur, *The Global Impacts of Biofuel Mandates*, 31 ENERGY J. 75, 75 (2010).

[93] *Id.* at 97–98.

[94] A. Mosnier et al., *Alternative U.S. Biofuel Mandates and Global GHG Emissions: The Role of Land Use Change, Crop Management and Yield Growth*, 57 ENERGY POL'Y 602, 602 (2013).

[95] *See id.* at 609.

[96] *Id.*

[97] Haixiao Huang et al., *Stacking Low Carbon Policies on the Renewable Fuels Standard: Economic and Greenhouse Gas Implications*, 56 ENERGY POL'Y 5, 14 (2013).

[98] Madhu Khanna et al., *Land Use and Greenhouse Gas Mitigation Effects of Biofuel Policies*, 2011 U. ILL. L. REV. 549, 580 (2011).

[99] Deepak Rajagopal et al., *Multi-Objective Regulations on Transportation Fuels: Comparing Renewable Fuel Mandates and Emission Standards*, 49 ENERGY ECON. 359, 359–61 (2015).

standard would result in lower global emissions while requiring less biofuel, but emissions standards result in somewhat higher fuel prices.[100]

Moreover, Thompson et al. posits that biofuel mandates may have both positive and negative impacts on GHG emissions and these impacts are related to indirect effects of biofuel policies in the petroleum product markets.[101] The authors reiterate that the reduction of GHG emissions is one of the goals of the U.S. biofuel policy, and they use economic models to show how biofuel tax credits, ethanol tariffs, and mandates may influence the extent to which this goal is achieved.[102] They found that ceasing tax credits and the ethanol tariff or removing mandates can cause a reduction in greenhouse gas emissions, but this conclusion depends on many factors.[103] More recently, Wang used economic models that integrate the agriculture, forest and transportation fuel sectors to examine the short-run and long-run effects of the RFS on agricultural and forest biomass, food, fuel, wood markets, and land use change.[104] His results concluded that, first, the RFS would lead to the production of approximately 1600 billion liters of corn ethanol over the 2010–2035 periods, and, after year 2025, energy crops and crop residues will play the leading role in cellulosic feedstocks production.[105] Second, the author concluded that the production of cellulosic feedstocks biofuels will not cause significant land use change between and within agricultural and forest sector as compared to a situation without a biofuel policy.[106] Third, the author reckons that the total annual GHG flux under the RFS program in 2035 will be improved by 6.9%, together with social welfare increases by 4% relative to situations where a biofuel policy does not exist.[107] Thus, in regard to GHG emissions, while the "RFS slightly increases GHG flux in forest sector due to higher rate of land deforestation, the total annual GHG flux is projected to be improved by year 2035 because of increased soil carbon sequestration in energy crops and avoided emissions from burning of fossil fuels."[108]

Second, studies have found that the RFS program impacts the price of gasoline and other commodities. For instance, McPhail and Babcock studied the effect of the

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[100] *Id.* at 366.

[101] Wyatt Thompson et al., *Effects of US Biofuel Policies on US and World Petroleum Product Markets with Consequences for Greenhouse Gas Emissions*, 39 ENERGY POL'Y 5509, 5509−11 (2011).

[102] *Id.* For example, biofuel trade and compliance costs.

[103] *Id.* at 5517.

[104] Weiwei Wang, *Energy Crops vs. Forest Biomass for Meeting the Renewable Fuel Standard: Implications for Land Use and GHG Emissions*, at 3 (May 5, 2016) (unpublished research paper, University of Illinois), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2776426 [https://perma.cc/N9N5-XZFP].

[105] *Id.* at 14.

[106] *Id.*

[107] *Id.* at 13–14.

[108] *Id.* at 14.

U.S. ethanol policy on the price variability of gasoline in the U.S.[109] The authors contend that the RFS mandates and the blend wall reduce the price elasticity of demand for gasoline and corn, thereby increasing their price variability in the event of shocks, and policy actions should take this fact into consideration.[110] Similarly, Thompson et al. analyzed the petroleum and petroleum product markets and found that terminating mandates, biofuel tax credits, and ethanol tariffs lowered biofuel use, and it could lead to increased use of petroleum in the U.S. and a reduction in petroleum product use in other parts of the world.[111]

Babcock employed simulations under different gasoline prices and ethanol demand elasticities to assess whether the ethanol industry would endure in the absence of a mandate.[112] The author concluded that in the absence of subsidies in the ethanol industry, ethanol would likely not be viable if gasoline prices are low.[113] Additionally, utilizing a VAR model, McPhail argues that biofuels affect the crude oil markets, and, despite the small size of the U.S. ethanol market, the U.S. ethanol market has significant effects on the crude oil market as a whole.[114]

Third, the effects of the RFS policy on agricultural production and markets have also been widely analyzed. As noted, McPhail and Babcock analyzed the corn market and the impacts of the RFS mandates on the demand of corn for ethanol production.[115] The authors argue that ethanol production created a new demand for corn, which, in turn, decreased the price elasticity of corn, increasing its price variability.[116] Miljkovic et al. examined the direct and indirect effects of the ethanol policy on livestock production.[117] The authors examined the interaction between corn, dried distiller's grains, ethanol, and livestock as competition for corn increases.[118] One of their findings was that ethanol policy may indirectly impact cattle production through the influence of the RFS on corn quantity availability.[119] Additionally, in analyzing the impact of the ethanol policy on corn prices, Condon et al. found that a one billion gallon expansion of the U.S. corn ethanol mandate in

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[109] Lihong Lu McPhail & Bruce A. Babcock, *Impact of U.S. Biofuel Policy on US Corn and Gasoline Price Variability*, 37 ENERGY 505, 506 (2012).

[110] *Id.* at 511.

[111] Thompson et al., *supra* note 101, at 5509.

[112] Bruce A. Babcock, *Ethanol Without Subsidies: An Oxymoron or the New Reality?*, 95 AM. J. AGRIC. ECON. 1317, 1322−24 (2013).

[113] *Id.* at 1324.

[114] Lihong Lu McPhail, *Assessing the Impact of U.S. Ethanol on Fossil Fuel Markets: A Structural VAR Approach*, 33 ENERGY ECON. 1177, 1177–78 (2011).

[115] McPhail & Babcock, *supra* note 109, at 507.

[116] *Id.* at 512.

[117] Dragan Miljkovic et al., *Impact of Biofuel Policies on Livestock Production in the United States*, 34 J. POL'Y MODELING 817, 817–19 (2012).

[118] *Id.*

[119] *Id.* at 829.

the year 2015 would lead to up to a 4% increase in corn prices.[120] Finally, Enciso et al. analyzed the impact of eliminating biofuel policies (mandates, tax credits, import and export tariffs) on agricultural price levels and price, and some aspects related to global food security employing a recursive-dynamic, agricultural multicommodity model within a stochastic framework.[121] Their results indicated that while abolishing biofuel policies would have a significant effect on price variability of biofuels, the removal of these policies would have a marginal impact on the variability of agricultural commodity prices.[122]

Lastly, some studies have explored the development of efficiencies in corn ethanol production. For instance, Chen and Khanna considered the role of elements such as economies of scale, cumulative experience, and trade-induced competition from imported ethanol to explain the reduction of processing costs of corn ethanol and increased production volumes in the U.S.[123] Their study suggests that the U.S. corn ethanol production displayed decreasing returns to scale, learning-by-doing played an important role in reducing these processing costs, and imported sugarcane ethanol made the corn ethanol industry more competitive.[124] Moreover, Chen and Önal examined the impact of the implementation of the RFS and Renewable Portfolio Standards on agricultural commodity markets, namely production, consumption, and prices of multiple food and feed crops.[125] Their study has found that the impacts of the implementation of the two policies on agricultural commodity markets, spatial distribution of future cellulosic biorefineries, and regional supply of biomass is highly dependent on the targets set for cellulosic biofuels and bio-power production.[126]

Yet, the existing literature fails to consider how the industry life cycle mediates the effects that the RFS has on the economic sustainability of the U.S. biofuels industry. Every product market has its own PLC, and the ethanol market is no exception. As mentioned above, the PLC is the idea that a product undergoes different stages, from the introduction of the product to growth, maturity, and eventual decline. It makes little sense to mandate demand for products via a policy instrument unless a primary policy goal is to increase the economic sustainability of those products, and thereby help create a lasting market for them. Moreover, the

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[120] Nicole Condon et al., *Impacts of Ethanol Policy on Corn Prices: A Review and Meta-Analysis of Recent Evidence*, 51 FOOD POL'Y 63, 71 (2015).

[121] Sergio René Araujo Enciso et al., *Abolishing Biofuel Policies: Possible Impacts On Agricultural Price Levels, Price Variability and Global Food Security*, 61 FOOD POL'Y 9, 9 (2016).

[122] *Id.*

[123] Xiaoguang Chen & Madhu Khanna, *Explaining the Reductions in US Corn Ethanol Processing Costs: Testing Competing Hypotheses*, 44 ENERGY POL'Y 153, 153–54 (2012).

[124] *Id.* at 158–59.

[125] Xiaoguang Chen & Hayri Önal, *Renewable Energy Policies and Competition for Biomass: Implications for Land Use, Food Prices, and Processing Industry*, 92 ENERGY POL'Y 270, 271 (2016).

[126] *Id.* at 276.

ethanol market has existed since 1979, and mandating demand might produce distinct effects in different stages of its PLC.[127]

As such, it is of the utmost importance to explore the impact of the RFS on production efficiencies within the U.S. biofuels industry at different stages of its PLC in order to evaluate the effectiveness of this policy instrument. That is the focus of this Article.

IV. THE PRODUCT LIFE CYCLE MODEL APPLIED TO THE RENEWABLE FUEL STANDARD

So far we have provided a general background of the ethanol market and some government subsidies and tax programs that have positively impacted its development. We then delved into the important features of the RFS program, and presented information about the price of gasoline vs. the price of ethanol, the production capacity of ethanol plants, and the expansion of the industry. In Part III, we examined some of the different studies analyzing the diverse economic and environmental impacts of the RFS policy. We have found that the existing literature has not considered the actual effects of the economic viability of the RFS policy. In this Article, we raise an important question that no other study has investigated so far.

In this section, we will first provide a brief explanation of the theoretical model used in our study and important premises to understanding the significance of our work. Next, we will delve into our economic model that will be used to evaluate the data and draw important conclusions from empirical evidence in the ethanol industry.

A. The Theoretical Model: The Product Life Cycle and Product Innovation

Our empirical analysis employs the insights of the product life cycle from Gort and Klepper,[128] and the PLC framework developed by Klepper,[129] to investigate and better understand how the ethanol industry evolved from its nascent stage to a mature stage before and after the enactment of the RFS. For that reason, a brief explanation

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[127] *See* Hyunok Lee, *Ethanol's Evolving Role in the U.S. Automobile Fuel Market*, *in* INDUSTRIAL USES OF AGRICULTURAL MATERIALS: SITUATION AND OUTLOOK REPORT 49–54, ECON. RESEARCH SERV., U.S. DEP'T AGRIC., IUS-1, June 1993, https://www.ers.usda.gov/webdocs/publications/ius1/33111_ius1_002.pdf?v=41471 [https://perma.cc/A4GH-KN3N] (noting that major development of ethanol fuel in the United States did not occur until the late part of the 1970s, with the two oil crisis, the passage of the Clean Air Act in 1977 and the 1978 Energy Tax Act).

[128] *See generally* Michael Gort & Steven Klepper, *Time Paths in the Diffusion of Product Innovations*, 92 ECON. J. 630 (1982) (measuring and analyzing the diffusion of product innovations).

[129] *See generally* Steven Klepper, *Industry Life Cycles*, 6 INDUS. & CORP. CHANGE 145 (1997) (discussing the product life cycle and its applicability to many industries).

of the Gort-Klepper PLC work and the model developed by Klepper is imperative to understanding our arguments below.

Gort and Klepper documented the development of forty-six products in connection with their price, output, sales, and change in number of firms (net entry) over the life of each product.[130] The authors found evidence that different manufacturing industries follow similar life cycle phases.[131] Their study drew attention to five distinguishable stages in the evolution of the product market, and the authors studied prices and firms across these stages.[132]

In the first stage, a new product is first introduced into the market, and this stage ends with a period of new firms rapidly entering the market for this new product.[133] In the second stage, Gort and Klepper found evidence of a sharp growth in the number of firms.[134] This stage is commonly followed by a period in which the number of firms in the market levels out.[135] In the third stage, the number of new firms is close to the number of exiting firms, which means that the actual net entry in this period is close to zero.[136] The next stage is characterized by a sharp decline in the number of firms. In the authors' words, this fourth stage is a period of "negative net entry."[137] The exit rate eventually slows, and the market reaches stabilization in the last stage, in which there is almost no new entry.[138]

In summary, Gort and Klepper studied the evolution of industry structure by analyzing a broad range of products. Their work suggests that many of the attributes of the PLC model may be found across different industries.[139] New entrants are generally concentrated in the early stage; product innovation reaches its highest rate early; productivity tends to decline over time; mass exits (shakeouts) are common; and early entrants tend to dominate their respective markets.[140]

In light of Gort and Klepper's work, our model is based on the very well-known contribution of Klepper to PLC theory.[141] Klepper created a dynamic evolutionary model to analyze the different stages of the PLC in an industry. Klepper's model produced results that are in line with the empirical observations of the PLC. Klepper first emphasizes six regularities concerning how entry, market structure, technological change, and exit vary through the different stages of the PLC. First, as described above, at the beginning stage of an industry, the number of entrants may

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[130] *See* Boyan Jovanovic, *Michael Gort's Contribution to Economics*, 1 REV. ECON. DYNAMICS 327, 328 (1998).
[131] *See* Gort & Klepper, *supra* note 128, at 630−31.
[132] *See id.* at 631.
[133] *Id.*
[134] *Id.*
[135] *Id.*
[136] *Id.*
[137] *Id.*
[138] *Id.*
[139] Klepper, *Industry Life Cycles*, *supra* note 129, at 168.
[140] *Id.*
[141] *Entry, Exit, Growth, and Innovation*, *supra* note 28, at 562.

rise, but this number tends to decline over time until the number of new entrants becomes small or zero.[142] The frequency of change of the market shares of the largest firms in an industry declines, leading to the stabilization of the industry in terms of leadership.[143]

Another regularity concerns diversity, a measure of the variations of products that compete within a given market. The number of product innovations, and therefore product diversity, tends to be the highest during the period of growth in the number of producers, eventually declining over time.[144] Moreover, producers tend to allocate increasing amounts of effort to the process and making of products than to product innovation.[145] Finally, Klepper observed that during the period where there is a growth in the number of producers in the industry, the most recent entrants are responsible for a very large share of product innovations.[146] These regularities provide the cornerstone for the author's theoretical analysis.

The key topic of Klepper's work is analyzing industry evolution when innovation is present and influencing the industry's size, entry, and shakeout patterns through changes in the production process.[147] In the beginning of each of the PLC stages, at the firm-level, firms have different choices and their decisions are based on their expected profit. Incumbents must decide whether they remain in or exit the market while potential entrants must resolve whether or not they will enter the market. The market grows through the entry of new firms. All firms are price takers, meaning that they produce a standard product, and the price clears the market.[148]

Klepper's first premise is that the demand of a product is the incentive for product and process innovation.[149] The latter of the two, process innovation, is determined by the total demand for the firm's product. Process innovation is designed to lower a firm's average cost of production.[150] The greater the demand for the product, the greater the potential return of process innovation. Product innovation, on the other hand, is generally designed to attract new buyers.[151] While new products appeal to all buyers, the assumption is that only new buyers may be willing to pay for the price increase.[152] Second, Klepper affirms that firms have

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[142] *Id.* at 564.

[143] *Id.*

[144] *Id.* at 565.

[145] *Id.*

[146] *Id.*

[147] *Id.* at 563; Klepper, *Industry Life Cycles*, *supra* note 129, at 165 (stating that "for a product to be deemed as experiencing a shakeout, the fall in the number of firms had to be pronounced (at least 30% from the peak) and sustained (not rising subsequently to 90% of the peak)").

[148] *Entry, Exit, Growth, and Innovation*, *supra* note 28, at 566.

[149] *Id.*

[150] *Id.* at 565.

[151] *Id.*

[152] *Id.* at 566.

different skills and capabilities that govern the type and effectiveness of their innovation efforts.[153] New firms must decide if their product development skills are sufficient to jump in and earn a profit and to survive given the incumbents' volume-based advantages.

Klepper suggests that firms may take advantage of research and development ("R&D") costs because of their size, and their incentives and types of product innovations may shift internally as firms grow larger.[154] Therefore, Klepper's model is relevant for analyzing the RFS program because it introduced the idea that the historical sequence of events in the introduction of a new product is a critical determinant of the final structure of the new product market.[155] The development of the ethanol market, from its nascent to its more recent mature stage, closely followed the pattern of the PLC model.

In conclusion, Klepper's findings guide our analysis and help us to understand how the ethanol market efficiently and sustainably evolved from birth to maturity, including the period defined by the presence of the RFS policy mandating minimum biofuel consumption.

B. The Ethanol Industry Under the Lens of the Product Life Cycle Model

Gort and Klepper define a product market at its early growing stage as one in which the product market grows in terms of the number of firms.[156] They define a market as being at its mature stage when sustainable growth is not possible or the market starts to experience shakeout.[157]

As shown in Figure 3 discussed above, both the number of plants and the number of firms in the ethanol market grew consistently prior to 2008, and the number of new entrants slightly stabilized after that date. Hence, in accordance with the different life cycle phases of the PLC model, the ethanol market experienced both its early nascent growing stage and its mature stage after the RFS policy was implemented. Because our data shows that the ethanol market underwent strong expansion after the RFS mandates were implemented, this Article attempts to study whether the policy affected the economic sustainability of the existing U.S. biofuels industry.

For that end, we adapt the PLC model to understand how the mandates may strengthen the growth of the ethanol market in the industry's distinct life cycle stages. A full list of the variables and a complete mathematical explanation of our model may be found in the Appendix.

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[153] *Id.* at 565.
[154] *Id.* at 580.
[155] Gort & Klepper, *supra* note 128, at 630.
[156] *Id.* at 631.
[157] *Id.* at 633.

1. Preliminary Assumptions Under Our Model of Large-Scale Mandatory Demand

As stated above, Klepper presents a complete model showing trends along the PLC, demonstrating that, over time, increasing production efficiency cannot catch up with the declining price pattern driven by exogenous factors that are not controlled by individual firms.[158] As such, product markets eventually will stop growing with increasing production efficiency.[159] We adopt the framework introduced by Klepper for two reasons. First, ethanol producers have limited control over the price of their product. Second, this study attempts to answer how the RFS mandates impact the ethanol market at different stages of its PLC. Thus, we modify the model assumptions to fit the characteristics of the ethanol market.

In order to simplify the model, we consider aggregated production decisions at the firm level. This enables us to focus on how firms make decisions according to market competition and changes in policy. We will discuss within-firm decision making in the empirical section. The plant-level growth pattern will be investigated empirically for a comparison with the firm-level production decision. It is important to understand the two channels through which an industry expands: (1) expansion of existing firms, and/or (2) entry of new firms.[160] Since a firm can operate one or multiple plants, it can also grow at the firm level by increasing the production capability of existing plants, constructing new plants, or adding plants through acquisition. This means that an industry can expand without an actual increase in the number of new players in the industry.

All decisions made by a firm, especially whether to enter or remain in the market, are presumed to be made based on the firm's expected profits.[161] The expected profit function is a function of the sale price and output of the firm minus the cost to produce the product, which accounts for production efficiency and for monitoring and managing the operations of its opponents.[162]

As is to be expected, a firm would behave in a manner so as to maximize the expected profit function.[163] When a firm decides to enter the market, it must determine whether its investment capabilities are sufficient to enter the market and earn a profit. The firm's production efficiency is considered when defining the expected profits of a firm. A greater production efficiency level indicates a higher

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[158] *Entry, Exit, Growth, and Innovation*, *supra* note 28, at 564.

[159] *Id.* at 580 (noting that the number of product innovations will decline as exit occurs and the number of firms falls).

[160] *Id.* at 564−65.

[161] WOLFRAM ELSNER ET AL., THE MICROECONOMICS OF COMPLEX ECONOMIES: EVOLUTIONARY, INSTITUTIONAL, NEOCLASSICAL, AND COMPLEXITY PERSPECTIVES 118 (2015).

[162] *See infra* Part App. (Equation 1).

[163] *See* VICTOR J. TREMBLAY & CAROL HORTON TREMBLAY, NEW PERSPECTIVES ON INDUSTRIAL ORGANIZATION: WITH CONTRIBUTIONS FROM BEHAVIORAL ECONOMICS AND GAME THEORY 128–36 (2012) (noting that a firm must select the combination of inputs that minimizes its production costs so that it can maximize its profits).

efficiency, in which the production efficiency level is, in turn, determined by the latest technology available for investment when a firm decides to enter the market.

This assumption fits well in the ethanol industry since the industry does not typically have R&D sectors within producing firms.[164] The R&D usually happens upstream and the latest technology is available for all firms willing to invest in it.[165] Because the technology keeps evolving, new entrants invest in the newest technology and are able to produce more efficiently in terms of marginal cost with their production efficiency level.[166] The expense for the latest technology, however, is not trivial and, for that reason, we assume that incumbents do not upgrade their technology. As such, new entrants are equipped with the latest technology and are capable of more efficient production. This assumption will be considered in the production function of new entrants.

However, in accordance with the PLC stages described above, this pattern of innovation usually slows down after the PLC enters the mature stage,[167] and thus new entrants' relative advantage in production efficiency also decreases based on their entry timing. Besides the production cost, we also take into account the firm's cost of monitoring and managing the operations and innovations of its opponents. In order to simplify this model, a constant input cost c is assumed in the expected profit function.

The ethanol product price is a function of the demand for ethanol, the price of gasoline, and the number of competitors in the market.[168] The market demand at a specific time is fulfilled by the total supply of all firms.[169] This total supply is the summation of the supply of every individual firm in the market. Because the price

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[164] *See DOE Recommits to Public-Private Research & Development for Clean Fuels in Its 2015 Budget*, ENVTL. & ENERGY STUDY INST. (Apr. 18, 2014), http://www.eesi.org/articles/view/doe-recommits-to-public-private-research-development-for-clean-fuels-in-its [https://perma.cc/4UPW-V5ZQ] (discussing public-private research & development for clean fuels and noting that in this area "the government invests in high risk research and development that has great potential but is of little interest for private investors because it seems too risky"); *see also* Rupa Karmarkar-Deshmukh & Carl E. Pray, *Private Sector Innovation in Biofuels in the United States: Induced by Prices or Policies?*, 12 AGBIOFORUM 141, 143 (2011) (noting that few firms disclose how much R&D they perform on biofuels).

[165] Daniel J. Wilson, *Is Embodied Technology the Result of Upstream R&D? Industry-Level Evidence*, 5 REV. ECON. DYNAMICS 285, 288 (2002) (concluding that embodied (investment-specific) technology is the result of upstream R&D, meaning that "R&D done 'upstream' by producers of capital goods is responsible for the measured productivity growth of 'downstream' customer industries").

[166] ELSNER ET AL., *supra* note 161, at 167 (defining marginal costs as reflecting "the amount by which a firm's cost changes if the firm produces one more unit of output").

[167] Gort & Klepper, *supra* note 128, at 631 (explaining that the period preceding the time an industry reaches maturity is characterized by negative entry and, consequently, reduced competition and innovation, inducing the obsolescence of the product).

[168] *See infra* Part App. (Equation 2).

[169] *See infra* Part App. (Equation 3).

of ethanol is highly correlated to the price of gasoline, we assume that the ethanol price at a certain time is a function of the price of the gasoline at that same time. In addition to the effect from the changes of gasoline price, industry evolution theory suggests that price declines with growing demand over time due to competition among firms, which also results in increasing production efficiency at the industry level.[170] In the long run, inefficient firms would be driven out of the market if their expected profit is negative, and then the price would stay stable, *ceteris paribus*.[171]

2. A Simple Model of Large-Scale Mandatory Demand

We solve a firm's profit maximization problem with respect to the firm output capacity and its first order condition (i.e., setting equal to zero the derivative of the firm output capacity since it is the function being maximized). We first derived the optimal capacity of a firm by considering that the marginal costs increase with increases in the firm output capacity and by keeping the marginal revenue as a constant. The marginal costs increase with the increase in the firm output capacity because, at a certain production level, producing one more unit of output will eventually cost more.[172] This increase in production cost may be due, among other things, to inputs being used less effectively. For that reason, marginal costs increase. The marginal cost and the firm's optimal capacity are presented in the Appendix.[173]

Substituting the optimal capacity function into the expected profit function discussed above, we find that firms would make an entry decision if the expected optimal profit is greater than zero.[174] The exit decision, on the other hand, is based on the zero profit condition, and firms exit if they expect a zero or negative profit. An inefficient firm with a smaller production efficiency level cannot compete with more efficient firms. In other words, less efficient firms will be run out of the market, and only firms that can economically survive the competition will remain in the market.

In the ethanol market, market demand is mandated in each period, which causes a change in demand.[175] We define the ratio of current demand to the previous period's demand, where the mandated growth rate is always positive, implying that the ratio of current to past demand is greater than unity.[176] This positive, growing

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[170] Rajshree Agarwal, *Evolutionary Trends of Industry Variables*, 16 INT'L J. INDUS. ORG. 511, 521 (1998); *see Entry, Exit, Growth, and Innovation*, *supra* note 28, at 570 ("In order for every firm that remains in the market to expand its market share, some firms must exit in every period. This will occur only if price falls over time.").

[171] *See Entry, Exit, Growth, and Innovation*, *supra* note 28, at 566 (noting that firms are price takers and all their decisions are made to maximize profits and that the absence of profit will drive a firm out of the market).

[172] ELSNER ET AL., *supra* note 161, at 110.

[173] *See infra* Part App. (Equations 4–5).

[174] *See infra* Part App. (Equation 6).

[175] RFS OVERVIEW AND ISSUES, *supra* note 4, at 1−3.

[176] *See infra* Part App. (Equation 7).

market demand creates profitable opportunities for new entrants to act opportunistically by taking advantage of the gap between growing demand and existing supply. That is because the incumbents deviate from their optimal production capacity by hesitating to increase production capacity and drive prices down.

Thus, we expect an increasing number of firms in the market with the growth of the mandated demand stimulating market demand. However, as explained in section IV.A above, when the PLC reaches a mature stage, new entrants no longer have a competitive advantage in terms of production efficiency. New entrants do not have this competitive advantage because the technology has been developed and is common to all market entrants. When the PLC reaches a mature stage, prices stabilize.[177] As such, there are reduced opportunities for new entrants to act opportunistically, which would make the mandated demand attract fewer new entrants now that the market has reached its mature stage.

Two results would reflect the nature of this model. The first result shows that the mandated demand incentivizes new entry, but the growth of entry is at a declining rate. The growing market demand creates profitable opportunities for new entrants. Nevertheless, as noted, when the PLC enters a mature stage, these new entrants no longer have a competitive advantage in terms of production efficiency. That is because the technology that once was their advantage has now become the standard and is common to all market participants.

The second result shows that new entrants create more competition, thereby bringing the price down. In this case, the demand for ethanol shifts up, incentivizing new entry into the market in the early stage. Because new entrants hold the latest technology, they are able to produce at a lower marginal cost and then increase their market share through price competition.[178] These new market entrants are thus able to gain market share by offering lower prices. The ethanol price would be reduced as a result of competition, and the price reflects a decreasing pattern along the PLC. Hence, new entry will stir up competition and bring prices down.

Based on these first and second results, the optimal capacity of the incumbents needs to be reduced in response to the declining price pattern because the slope of the profit versus price curve is positive,[179] and a declining price pattern produces declining profits. This decline in profits would call for the capacity to be reduced and, thus, the optimal capacity of the incumbents follows the declining price. If all incumbents try to maintain their capacity at the now lower optimal level, a gap would be generated between supply and demand. New market entrants, with their improved technologies and lower production costs, would be attracted to the market to fill the gap between supply and demand, creating a higher level of competition that would

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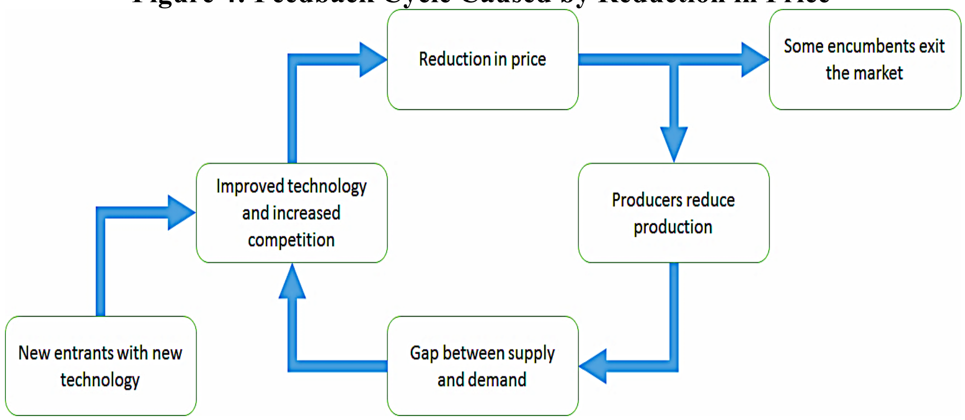
[177] *Entry, Exit, Growth, and Innovation*, *supra* note 28, at 564.

[178] TREMBLAY & TREMBLAY, *supra* note 163, at 14 ("In industrial organization, a central policy interest relates competition and efficiency. When inadequate competition leads to market power, price exceeds marginal cost and markets are statically inefficient.").

[179] *See infra* Part App. (Equation 8).

drive the price even lower. This cycle, initiated by the reduction of price, is illustrated in Figure 4.

Figure 4: Feedback Cycle Caused by Reduction in Price



As such, the decision to maintain an optimal capacity would eventually result in the exit of some incumbents. In order to stay in the market, the remaining incumbents must deviate from their optimal production by overproducing where, because of the artificial demand created by a mandate, the actual production,[180] is higher than the optimal production.[181]

It is important to note that the operational cost of monitoring and managing in our model is assumed to be a fixed cost. Thereby, an increase in production would lower the average fixed cost to thus develop economies of scale. Therefore, even though the deviation from the optimal production level would result in higher marginal costs than the constant marginal revenue, incumbents still benefit from preventing the entry of new competitors and developing economies of scale, as long as incumbents still make a nonnegative expected profit.

Consequently, incumbents deviate from the optimal production rate to seek long-term survival in the ethanol market, and their average expected profit is a function of the price of ethanol minus the marginal costs of production and the average fixed costs ("AFC").[182] The AFC of a firm is the firm's cost of monitoring and managing the operations of its opponents divided by the firm's output capacity at a certain time.[183] As explained above, based on the assumptions in our model, the marginal cost increases with the firm's output capacity[184] while the average fixed cost decreases with an increase in the firm output capacity.[185]

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180 *See infra* Part App. (Variable "y_{it}").
181 *See infra* Part App. (Variable "$y_{it}{}^*$").
182 *See infra* Part App. (Equation 9).
183 *See infra* Part App. (Equation 10).
184 *See infra* Part App. (Equation 11).
185 *See infra* Part App. (Equation 12).

Finally, we apply the cost-benefit analysis and derive the firm capacity expansion decision.[186] The pattern of production capacity would mirror the concave trend of entry discussed above because demand encourages entry, but the entry grows at a declining rate. The negative second derivative of the price of ethanol with respect to production[187] implies decreasing returns to further capacity expansion. Production capacity also has a negative second derivative, and thus we can derive two hypotheses:

Hypothesis 1: Production capacity increases with the increasing mandated demand. As proved above, an increase in the mandated demand will increase the production capacity.

Hypothesis 2: Production capacity increases at a decreasing rate along the product life cycle. Nevertheless, this increase in production capacity will occur at an ever-decreasing rate over the PLC. The first mandated demand will increase the production capacity by a great deal. The second mandated demand will also increase the production capacity but to a lesser degree. Subsequent increases in mandated demand will become increasingly ineffective at generating production capacity increases.

In our model, a firm can increase its production efficiency by increasing its capacity to compete with the new entrants that invest in the latest technology. Increasing demand encourages market competition by incentivizing capacity expansion and new entrants to the market, where only efficient firms will remain as competition increases. Because technology emerges and stabilizes after the PLC enters the mature phase, the mandated demand is effective in promoting economies of scale only in the nascent stage of PLC. A mandated demand encourages firms to expand production capacity and promotes entry of new firms with new technology. Price competition causes costs to be driven down, and then the market is no longer able to benefit from the new technologies that new entrants would bring to the market since decreased prices deter new firms from entering the market. Thus, once the market reaches a level where only efficient firms remain and competition ceases, an increase in mandated demand will be less effective in promoting economies of scale and the development of new technologies compared to how effective it was during the nascent stage of the industry.

V. EMPIRICAL ANALYSIS AND IMPLICATIONS

We will now utilize our model of large-scale mandatory demand described in the previous section to analyze industry data and examine the production capacity of first-generation ethanol plants in the U.S. Our objective is to determine the actual impact of the RFS policy in the ethanol industry through the lens of the PLC model. We find empirical evidence indicating that the RFS program stimulates the efficient development of the biofuels industry during the early growing phase in the PLC.

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[186] *See infra* Part App. (Equation 13).
[187] *See infra* Part App. (Equation 14).

A. Data/Methodology on the Ethanol Industry

We gathered data on the characteristics of 216 ethanol production facilities that are listed in the Ethanol Produce Magazin[188] and the Renewable Fuels Association's ("RFA") Annual Industry Outlook from 2000 through 2013.[189] The facility level data are used for the plant-level analysis. Each plant in our data set is located in the United States. Of the 216 ethanol plants, 195 plants produce corn-based ethanol, and twenty-one plants use potato or beverage waste as inputs for ethanol production.[190] These plants are operated by 177 corporate firms. These firms produce ethanol that only qualifies as a basic renewable fuel for purposes of satisfying the RFS mandates.

Plant and firm capacity are important research variables for our empirical analysis. We gathered information on these variables from the RFA's Annual Industry Outlook and supplemented it with information published in Ethanol Producer Magazine. The time unit in our empirical analysis is one year, and each firm is treated as entering the ethanol market in the year it first registered with the relevant Secretary of State. Since we gathered data at the plant level, we used the information provided in OneSource.com[191] and Capital IQ[192] to identify the corporate tree for each ethanol plant. This information allows us to keep track of the firm growth with ownership changes of ethanol plants.

To make our empirical analysis as precise as possible, we also collected information on the RFA Annual Industry Outlook from 2000 through 2013 and Ethanol Producer Magazine about plant location,[193] total number of ethanol plants in a given state, plant age, the U.S. gasoline price, and the U.S. corn price. Information about the total number of ethanol plants and capacity are obtained from the RFA's Annual Outlook,[194] while data on plant age was sourced from the information in the data set derived from Secretary of State Websites.[195] The corn

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[188] *U.S. Ethanol Plants*, ETHANOL PRODUCER MAG. (Jan. 23, 2016), http://www.ethanolproducer.com/plants/listplants/US/Existing/Sugar-Starch/ [https://perma.cc/JQ8B-XZ84].

[189] *Annual Industry Outlooks*, RENEWABLE FUELS ASS'N, http://www.ethanolrfa.org/resources/publications/outlook/ [https://perma.cc/R3DV-TMT4] (providing the Annual Industry Outlook from 2002–2015).

[190] *See U.S. Ethanol Plants*, *supra* note 188; *see also Annual Industry Outlooks*, *supra* note 189.

[191] *See generally The Avention OneSource Advantage*, AVENTION, https://www.avention.com/onesource-advantage [https://perma.cc/SL77-RY6J] (explaining the tools utilized to help with data collection on ethanol plants).

[192] *See generally S&P Capital IQ Platform*, S&P GLOBAL, http://marketintelligence.spglobal.com/ [https://perma.cc/D7GF-2Y9K] (showing company information regarding the platform utilized to help with data collection on ethanol plants).

[193] *See Annual Industry Outlooks*, *supra* note 189; *U.S. Ethanol Plants*, *supra* note 188.

[194] *Annual Industry Outlooks*, *supra* note 189.

[195] The empirical research covered all 50 Secretary of State websites, and the data used in the article is from 25 of them (AZ, CA, CO, GA, IA, ID, IL, IN, KS, KY, LA, MI, MN, MO, MS, ND, NE, NM, NY, OH, OR, PA, SD, WI, WY).

price came from the U.S. Department of Agriculture,[196] and the gasoline price from the Nebraska Ethanol Board.[197]

Agarwal suggests that the age of a product market and its quadratic form can be used to capture the industry life cycle phase effect.[198] The ethanol industry in the United States dates back to 1979,[199] so we define the U.S. ethanol industry's age as the amount of time since 1979.

Because the RFS mandated demand differs from year to year, we use a mandate variable, which represents the volume of the RFS mandates that can be satisfied with traditional renewable fuels (i.e., the category of fuel produced by all plants in our data set). The mandate variable equals zero when the RFS was not enacted.

B. Results and Discussion: The Impact of Demand on the Ethanol Industry's Production Capacity

In our empirical analysis, we answer the question of whether the RFS helps to improve economies of scale by investigating the impact of its mandated demand on production capacity. We determine the firm's optimal capacity by taking the natural logarithm of both sides of the firm's optimal capacity[200] when it enters the market.[201] Nevertheless, the incumbent's capacity deviates from the optimal level because of the growing mandated demand and the evolving PLC. Thus, we included the PLC effect in our empirical model and the plant/firm capacity in the empirical estimation.

The right hand side of Equation 15 is treated as a constant term, and the cost is measured by the input price (i.e., price of corn). We decomposed the ethanol product price[202] into three components: (1) a large-scale mandatory demand, (2) gasoline price, and (3) local competition (the number of ethanol plants within the same state). The natural log of corn and gasoline prices is taken and are lagged by one year to avoid endogeneity.

Our empirical model is illustrated in the Appendix.[203] The empirical result shows statistical evidence that a mandated demand positively correlates to capacity at both the production plant and firm level. However, the result does not hold when the sample is limited to the mature stage of PLC, as will be shown in Table 1. We

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[196] *See Feed Grains Database*, U.S. DEP'T AGRIC., ECON. RESEARCH SERV., http://www.ers.usda.gov/data-products/feed-grains-database.aspx [https://perma.cc/R8HB-SYCG].

[197] *See Ethanol and Unleaded Gasoline Average Rack Prices*, OFFICIAL NEB. GOV'T WEBSITE, http://www.neo.ne.gov/statshtml/66.html [https://perma.cc/7XQR-VYLJ] (last updated Jan. 4, 2017).

[198] *See* Agarwal, *supra* note 170, at 514–20.

[199] *See Ethanol History - From Alcohol to Car Fuel*, ETHANOL HISTORY, http://www.ethanolhistory.com/ [https://perma.cc/8YWM-8877] (noting that in 1979, the Amoco Oil Company started marketing alcohol-blended fuels).

[200] *See infra* Part App. (Equation 5).

[201] *See infra* Part App. (Equation 15).

[202] *See infra* Part App. (Equation 2).

[203] *See infra* Part App. (Equation 16).

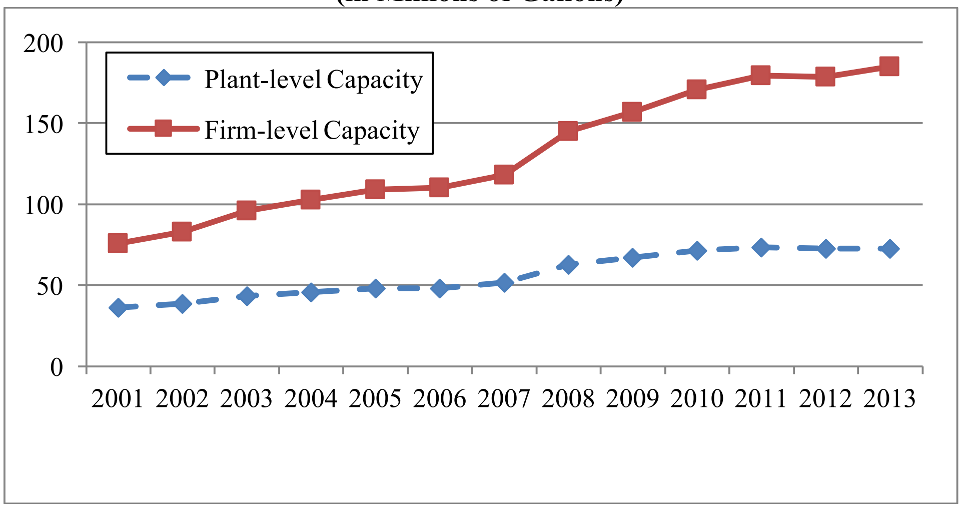
admit that our finding does not directly answer whether a large-scale mandatory demand regime in practice helps to improve the efficiency of biofuel production. This is due to limited data concerning plant-level production *costs*, which are not currently available and is unlikely to be available in the near future due to their potentially proprietary nature.

1. A Preliminary Analysis: The Product Life Cycle

Two preliminary tests for the first and second propositions explained above confirm the appropriate economic model assumption in our study. The concave-down trend of entry growth at both the firm and plant level after the enactment of the RFS2 in 2007, as shown in Figure 3, supports the first proposition that the mandated demand incentivizes new entry, but the growth of entry is at a declining rate. The declining pattern of the ratio of ethanol price to gasoline price in Figure 2 is also consistent with the prediction of the second proposition.

As previously mentioned, there are two channels through which an industry expands: (1) expansion of existing plants, and/or (2) construction of new plants. The growth patterns of the average plant-level and firm-level capacity are plotted in Figure 5, and the growth of the average firm-level capacity is steeper than the growth of plant-level capacity. Figure 5 shows that the firms are acquiring more plants to a greater degree than individual plants are growing in size because the firm-level capacity has increased, but the plant-level capacity has essentially remained the same.

Figure 5: Plant- and Firm-Level Capacity Patterns (in Millions of Gallons)

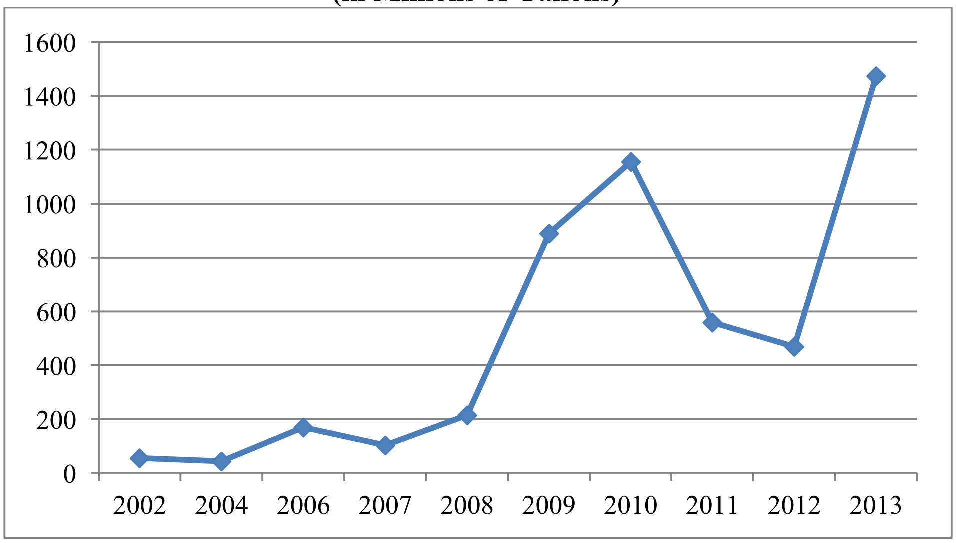


Source: Renewable Fuels Association

During the shakeout stage in the PLC, the period in which a large number of competing firms exit the market after the rapid growth and overexpansion of an industry, efficient firms further develop their economies of scale and inefficient firms leave, which sometimes involves resource reallocation in the form of M&A.[204] Figure 6 presents the acquisition activities (in millions of gallons of capacity) in the ethanol market. Increasing M&A activities are found during 2008–2010 and 2012–2013.

[204] *See Entry, Exit, Growth, and Innovation*, *supra* note 28, at 579 (arguing that the firms that grow and continue during the shakeout stage are the better innovators).

Figure 6: Capacity Acquisition Pattern (in Millions of Gallons)



Source: Renewable Fuels Association

The first increasing pattern can be explained by the 2008 recession. The distressed economy forced inefficient firms to leave, and efficient firms took over the ownership to develop economies of scale and sustain the growth of the ethanol market. The increasing acquisition activity in 2013 might be a result of the economic recovery from the 2008 recession, or it may also be the result of the rise of oil prices. In February 2009, oil was $43.66 a barrel and by 2013, oil was around $100 a barrel.[205]

In 2013, there were four acquisitions involving facilities which had been inactive since 2009 at a capacity of 133 million gallons, despite the fact that new plant operations contributed 115 million gallons, and existing plant expansion contributed 97.74 million gallons to the growth of the U.S. ethanol production capacity that year. Since in our model we consider that the ethanol price is tied to the price of gasoline, this can also be a reason for those facilities to be reactivated. The exemption from the 20% lifecycle GHG threshold requirement for the facilities constructed prior to December 19, 2007, (the date of enactment of the Energy Independence and Security Act) may explain why firms were incentivized to acquire inactive facilities rather than building new plants.[206]

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[205] *See Crude Oil Prices – 70 Year Historical Chart*, MACROTRENDS, http://www.macrotrends.net/1369/crude-oil-price-history-chart [https://perma.cc/DWU8-5K33].

[206] *See Renewable Fuel Standard*, CTR. FOR CLIMATE & ENERGY SOLUTIONS, http://www.c2es.org/federal/executive/renewable-fuel-standard [https://perma.cc/R89Z-CM32] (noting that the Grandfather Clause provides that "renewable fuel from existing facilities, which commenced construction on or before December 19, 2007, is exempt from the percent reduction from displaced gasoline/diesel for 'renewable fuel'").

2. *The Effects of the Renewable Fuel Standard on the Ethanol Plant Capacity*

Our model presents evidence that is consistent with the RFS mandated demand encouraging firms to expand production capacity and thus leading to economies of scale at the early growing phase in the PLC. We examine whether the RFS positively impacts the growth of plant-level and firm-level capacity via panel data analysis that controls for firm/plant random effects. In this Article, we adopt the Ordinary Least Squares ("OLS") method.[207] A regression is generally used when attempting to predict values of the dependent variable from independent variables.[208] Hence, we have a dependent variable that we would like to understand and independent variables which will be used to make predictions for the dependent variable.[209]

In our case, plant capacity and firm capacity are the primary dependent variables used to compare the effects of the RFS on ethanol plants and firms. The independent variables are corn price, gasoline price, number of ethanol plants within a state, and the mandated demand level (RFS mandate). The age of the ethanol market and its square are used to capture the effect of the different stages of the PLC. Firm age is used as a control variable to control for heterogeneous firm characteristics. The results of the OLS regression performed on these variables is presented in Table 1.

[207] *See Ordinary Least Squares Linear Regression: Flaws, Problems and Pitfalls*, CLOCKBACKWARD ESSAYS (June 18, 2009), http://www.clockbackward.com/2009/06/18/ordinary-least-squares-linear-regression-flaws-problems-and-pitfalls/ [https://perma.cc/QDT4-KGL8].

[208] *See id.*

[209] *See id*. In a linear regression such as the OLS, the assumption is that the dependent variable is fundamentally a linear function of the independent variables. *Id.*

Table 1: Random-effect OLS Regression Using the Plant Capacity as the Dependent Variable (DV)

	DV: ln(Plant Capacity)			DV: ln(Firm Capacity)		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
RFS Mandate		0.0140**	0.0257		0.0201**	0.0626
		(0.0047)	(0.0417)		(0.0074)	(0.0630)
Lagged Corn	0.0537	0.0314	-0.0277	0.1306*	0.0966+	0.0129
Price	(0.0355)	(0.0362)	(0.0388)	(0.0571)	(0.0582)	(0.0586)
Lagged Gasoline	-0.0524	-0.0364	0.0318	-0.0936+	-0.0733	0.087
Price	(0.0325)	(0.0328)	(0.0647)	(0.0530)	(0.0532)	(0.0980)
Number of Plants	0.0962***	0.0650*	0.1697***	0.1071**	0.065	0.4093***
in State	(0.0249)	(0.0269)	(0.0429)	(0.0372)	(0.0400)	(0.0544)
Age	0.1605***	0.1083*	0.2112***	0.1620*	0.0993	0.1730***
	(0.0414)	(0.0448)	(0.0081)	(0.0662)	(0.0698)	(0.0109)
Age^2	-0.0023**	-0.0017*	-0.0033***	-0.0022*	-0.0016	-0.0035***
	(0.0007)	(0.0007)	(0.0006)	(0.0011)	(0.0011)	(0.0009)
Firm Age	-0.0135	-0.0053	-0.0569*	0.034	0.0487	0.0870*
	(0.0258)	(0.0259)	(0.0275)	(0.0422)	(0.0424)	(0.0398)
Constant	0.7576	1.7451*		0.5046	1.7311	
	(0.6005)	(0.6836)		(0.9601)	(1.0569)	
Observations	1392	1392	884	1010	1010	613
Group	216	216	198	177	177	155
R^2	0.2071	0.1861	0.1642	0.1453	0.1146	0.1055

Notes: The numbers in parenthesis are the standard error. $^{+}P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

The results of analyzing the firm capacity are reported in the first three columns of Table 1. Model 1 consists of all variables except the mandatory demand of the RFS. Differently, Models 2 and 3 include the RFS mandate as an independent variable, where Model 3 analyzes only post-2008 data in order to investigate the effect of the RFS on plant capacity after the PLC enters the mature stage. In Model 2, the value of 0.0140 with $P < 0.01$ suggests that the RFS mandate has a statistically significant positive effect on the plant capacity, and is associated with a 1.4% increase in plant capacity.

When looking at the post-2008 data of Model 3, the RFS is no longer associated with a statistically significant effect on plant capacity. We find that the PLC variables of number of plants and market age have a statistically significant positive relation with plant capacity in Models 1–3, but the RFS mandate no longer posits significant impact on expanding plant capacity in Model 3. The corn price and the gasoline price do not have a significant effect on the plant capacity for any of the first three models. The two variables that are associated with an effect on the plant capacity in the mature stage of the ethanol market are the number of plants in a state and the age of the market, i.e., the PLC variables. These two variables are associated with a plant capacity increase of 16.97% and 21.12%, respectively, at the $P < 0.001$ confidence level.

The positive correlation between the number of plants in a state and plant capacity suggests that increasing the number of plants might raise the competition among firms. In turn, the increased competition among firms encourages the development of economies of scale by expanding capacity so that they can survive in the competitive market. Our findings demonstrate that, while the RFS was associated with a positive effect on ethanol plant capacity during the ethanol market's nascent stage, it appears that the RFS cannot be associated with an effect on plant capacity with any statistical significance after 2008 when the ethanol market entered its mature stage.

In Models 4, 5, and 6, we investigate which independent variables are associated with a growth in firm capacity. As was the case for Model 1, Model 4 does not include the RFS mandate as an independent variable. The RFS mandate is an independent variable in Models 5 and 6, and Model 6 analyzes only post-2008 data from the mature stage of the ethanol industry. We still observe statistically significant effects of the RFS mandated demand on firm capacity until the ethanol market enters its mature phase in Model 6.

Similar to the results found when examining plant capacity, if we ignore the effects of the RFS, the number of plants in a state and the age of the market are associated with statistically significant growth effects on firm capacity. This statistical significance no longer exists for those PLC variables when the RFS is included as an independent variable in Model 5. The data of Model 5 suggest that the RFS mandates can be associated with a 2.01% increase in firm capacity at the $P < 0.01$ confidence level. Moving on to the mature stage of the ethanol market in Model 6, the RFS mandate is no longer associated with any statistically significant effect on the firm capacity. Instead, the number of plants per state and the market age can be associated with 40.93% and 17.30% increases in the firm capacity, respectively, at the $P < 0.001$ confidence level.

Once again, our data reinforces the fact that while the RFS was associated with a statistically significant increase in the firm capacity, it cannot be associated with any statistically significant effects on the firm capacity after the mature stage of the PLC was entered. Our empirical findings underscore the robustness of the implications derived from our theory.

C. Discussion: Policy Implications

Our results and analysis, using the first-generation ethanol industry as our study subject, show that mandated demand has had an influence on developing economies of scale by incentivizing more new entry. Nonetheless, it must be noted that the policy is only effective at the early growing stage of the product life cycle. As such, if a de facto goal of the RFS is to create a viable and sustainable biofuels industry, our analysis and results show that it is helping to effectuate these goals only when the policy is enacted in the nascent stage of the PLC of the ethanol market.

As noted above, Chen and Khanna found that U.S. corn ethanol production exhibits diseconomies of scale at the industry level.[210] Our plant-level and firm-level empirical analyses do not show any contradiction. In fact, considering the new-entry effects and the learning-by-doing ("LBD") effects suggested by Chen and

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[210] *See* Chen & Khanna, *supra* note 124, at 157.

Khanna,[211] it is not surprising to observe diseconomies of scale at the industry level with the presence of plant-level economies of scale. The importance of LBD indicates the inefficiency of new entrants. It is in line with our assumption that firms develop economies of scale by lowering average production cost through the expansion of production capacity. When an increasing number of incumbents is a normal characteristic of the nascent biofuel market, industry-level diseconomies of scale might result from the reduced average efficiency caused by new entrants. Hence, there is no contradiction to observe the coexistence of the plant-level economies of scale and the industry-level diseconomies of scale.

Additionally, the U.S. Tax Code might also have some effect on ethanol plant capacity trends for the period analyzed in this Article. Although the provision expired on December 31, 2011, a small ethanol producer tax credit used to be in place that provided preferential tax treatment for ethanol plants with lower production capacities.[212] Specifically, from 1990–2005, ethanol producers with a production capacity of less than thirty million gallons per year ("mgy") (i.e., "small ethanol producers" for purposes of the U.S. Tax Code) were eligible to receive a $0.10 per gallon tax credit for their first fifteen million gallons of ethanol production.[213] Accordingly, eligible small ethanol producers could receive a tax credit worth up to $1.5 million per year. In 2005, the Tax Code was amended to redefine a "small ethanol producer" as one whose production capacity is less than sixty mgy.[214] Until its expiration at the close of 2011, the value of the tax credit remained the same with a maximum value of $1.5 million per year.[215] As such, it would appear that: (1) from 1990–2005, firms generally had a tax incentive to build plants with capacities of less than thirty mgy; and (2) from 2006–2011, firms generally had a tax incentive to build plants with capacities of less than sixty mgy. However, our empirical analysis indicates that plants and firms tend to grow with the implementation of the RFS in spite of the tax credit incentives for small producers. Thus, the benefits from economies of scale seem more attractive than tax credits.

That being said, there are a few limitations to the empirical analysis in this study. First, since our sample includes only ethanol plants that we observed entering the market in 2000 or later, our conclusions do not apply to plants that entered the market prior to 2000. Moreover, information about production cost and R&D investment could further assist us in directly testing the effect of economies of scale. However, gathering such information remains a challenge.

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[211] *See* Chen & Khanna, *supra* note 124, at 153−54.

[212] *See* 26 U.S.C. § 40(b)(4)(A) (2012).

[213] Alicia Sue Rosburg, Essays Concerning the Cellulosic Biofuel Industry, at 9 (2012) (unpublished Graduate Theses and Dissertations, Paper 12725, Iowa State University), http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=3732&context=etd [https://perma.cc/XV5P-X7HS].

[214] 26 U.S.C. § 40(g)(1) (2012).

[215] *See* 26 U.S.C. § 40(b)(4)(C) (2012) (noting that fuel production is limited to 15,000,000 gallons for any producer with the tax credit equal to $0.10 per gallon).

Despite the benefits of the RFS mandates at the early stage of the ethanol industry, a large-scale mandatory demand regime also has several theoretical disadvantages. By its very nature, the RFS program creates an excess demand for biofuels above what the market forces of supply and demand would otherwise determine.[216] Moreover, simple economic theory predicts that excess demand encourages new entrants to act opportunistically, which could cause incumbents to expand production capacity to deter entry.[217] In addition, the RFS will generate additional demand for biofuel feedstock, which will likely cause the price of inputs for biofuel production to rise, although this Article does not intend to comment on the food versus fuel debate.[218] Our empirical finding corroborates our model implication and suggests that the RFS program incentivizes the efficient development of an economically sustainable biofuels industry during its nascent PLC phase.

Finally, the fact that the RFS mandates for advanced and cellulosic biofuels increase disproportionately to its mandate for basic renewable fuel (i.e., first-generation ethanol) indicates an ultimate policy goal of incentivizing their use over first-generation biofuels.[219] Unfortunately, it remains unanswered whether or not the RFS will produce the same results for the second-generation biofuels industry that we have seen for the first-generation ethanol industry. The difficulty in extrapolating our results to the second-generation biofuels industry stems from the fact that it is at a different stage of its product life cycle. When the RFS was first implemented, first-generation ethanol was already being produced at large-scale commercial facilities through proven conversion technologies.[220]

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[216] *See* Richard Webb, *The Economic Effects of an Ethanol Mandate*, Australian Parl. Paper No. 18 2007–08 (January 22, 2008).

[217] *See* Mike Fusillo, *Excess Capacity and Entry Deterrence: The Case of Ocean Liner Shipping Markets*, 5 MAR. ECON. & LOGISTICS 100, 100–02 (2003).

[218] *See* John M. Urbanchuk, *The Renewable Fuel Standard and Consumer Food Prices*, ABF ECON. (Jun. 7, 2013), http://ethanolrfa.3cdn.net/281d77a62939896ba8_8nm6bevpj.pdf [https://perma.cc/36UH-5TAR] (discussing the impact of the RFS and biofuel mandates on food prices); *see also* Brent J. Hartman, *The Renewable Fuel Standard: Food Versus Fuel?*, 65 ME. L. REV. 525, 547 (2011) (arguing that the RFS policy does not require only feedstocks that are traditionally used for food and feed, but rather, there are many opportunities for non-food feedstocks that can be advanced).

[219] *See* Phil Ciciora, *Study: Renewable Fuel Standard Needs to be Modified, Not Repealed*, ILL. NEWS BUREAU (Oct. 14, 2003 9:00 AM), https://news.illinois.edu/blog/view/6367/204722 [https://perma.cc/VWY3-7HXQ] (noting that the crucial goal of the RFS is "to incentivize the increased commercialization of second-generation biofuels, such as cellulosic biofuels that do not rely on food-related feedstocks for their production").

[220] *See* Ned Stowe, *Issue Brief: Requests to Waive the Renewable Fuel Standard in the Aftermath of the 2012 Heat Wave*, ENVTL. & ENERGY STUDY INST. (Sept. 20, 2012), http://www.eesi.org/papers/view/issue-brief-requests-to-waive-the-renewable-fuel-standard [https://perma.cc/45GV-7765] (noting that first-generation corn ethanol was produced at commercial scale before 2005).

In contrast, the first wave of commercial-scale second-generation biofuel production facilities is only now being built and their conversion technologies have yet to be proven on a commercial scale.[221] As such, we would not expect the RFS to have similar effects on the second-generation biofuels industry until it has reached the same product life cycle point as the first-generation ethanol industry when the RFS was put in place. The policy implication of this is that it might be prudent to keep alternative policy instruments (e.g., tax incentives, loan guarantees, R&D grant funding, etc.) in place to continue incentivizing the development of the second-generation biofuels industry. Once it reaches a later stage in its product life cycle, we could then begin to see the RFS have similar effects on the second-generation biofuels industry as we have seen it have on the first-generation ethanol industry.

VI. CONCLUSION

This Article sought to improve the understanding of the economic implications of the RFS program to the different stages of the biofuels industry. In this Article, we analyzed how the RFS mandates impact the ethanol market at the different stages introduced by the PLC model. We show that the mandatory demand regime implemented via the RFS program has been an effective policy instrument to promote the nascent first-generation ethanol industry.

Our model suggests that ethanol mandates positively correlate to capacity at both the plant and firm level at the early growing stage of the product life cycle of the ethanol market. In other words, after the industry overcomes its early growing stage, mandated demand does not favor production-related economies of scale. According to our findings, the ethanol industry witnessed a steady growth in the number of firms and plants during the first years the RFS was implemented. The mandated demand, at this stage, helps to develop competition by promoting new entry and capacity expansion. Consequently, our findings suggest that the first-generation ethanol industry tended to grow with the implementation of the RFS policy because mandated demand had an influence on developing economies of scale by incentivizing more new entry.

On the other hand, our empirical analysis has also found that, after 2008, the industry growth slowed. That is because, despite the fact that we expect an expansion in the number of firms as the mandated demand grows, the new entrants in the mature stages of the PLC do not posit significant competitive advantage in terms of production efficiency. Hence, we conclude that mandates are effective in promoting economies of scale in the biofuel market only in the nascent stage of its PLC.

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[221] JOERN HUENTELER ET AL., *Commercializing Second-Generation Biofuels: Scaling Up Sustainable Supply Chains and the Role of Public Policy*, BELFER CTR. FOR SCI. & INT'L AFFAIRS, Harvard Kennedy School (Nov. 13–14, 2014), http://belfercenter.ksg.harvard.edu/files/commercializing-2ndgen-biofuels-web-final.pdf [https://perma.cc/N56K-MNS8] (noting the benefits of second-generation biofuels and discussing the challenges to commercialization of second-generation biofuels in the U.S.).

Consequently, the RFS mandated demand regime is not as effective after the market becomes mature. Given the "blend wall" and the ineffectiveness of the RFS policy after 2008, we suggest that policy makers reconsider the policy instrument in further promoting the ethanol industry. By implication, as noted earlier in this Article, it is possible that the RFS could have these similar effects on the nascent second-generation biofuels industry once it too reaches significant production at commercial scale. Moreover, policy makers might need to consider alternative policy instruments in responding to different stages of the product life cycle in the biofuels industry.

APPENDIX: A PRODUCT LIFE CYCLE MODEL OF THE IMPACT OF THE RENEWABLE FUEL STANDARD ETHANOL MANDATE

The following table shows the list of variables used in our model:

Variables	
Variable	**Notes**
i	Firm, subscript
t	Time, subscript
P_t	Price of ethanol at a certain time or marginal revenue
y_{it}	Firm's output capacity (at a certain time)
k_{it}	Quantity of input
A_i	Firm's production efficiency level assumed to be exogenously given
$P_{Gasoline,t}$	Price of gasoline (at a certain time)
F	Firm's cost of monitoring and managing the operations of its opponents
c	Input cost (constant)
n_t	Number of firms
Q_t	Market demand (at a certain time)
n_t	Number of firms
$\sum_{i=1}^{n_t} y_{it}$	Accumulated supply of all firms
β_t	Mandated growth rate
π_{it}	Firm's profit (at a certain time)

The following mathematical explanation describes our theoretical model.

Klepper presents a complete model showing regularities along PLC. He shows that over time, increasing production efficiency cannot catch up with the declining price pattern driven by exogenous factors that are not controlled by individual firms. As such, product markets eventually will stop growing with increasing production efficiency.

We modify the PLC model assumptions to fit the characteristics of the ethanol market. The expected profit function of firm i is $E(\pi_{it}) = E[P_t y_{it} - c_t k_{it} - F]$, s.t. $y_{it} = A_i {k_{it}}^{\alpha}$, where $0 < \alpha < 1$. P_t and y_{it} are the price and firm i's output capacity at time t. k_{it} is the quantity of input (Equation 1). A_i shows firm i's production efficiency level and it is assumed to be exogenously given. Greater A_i indicates higher efficiency, and A_i is determined at the latest technology level available for investment when firm i decides to enter the ethanol market. The technology keeps evolving, and new entrants are able to produce more efficiently with a higher A_i in their production function. However, the pattern of innovation usually slows down after the PLC enters the mature stage, and thus new entrants' relative advantage in production efficiency also decreases based on their entry timing.

In addition to the production cost, F is the firm's cost of monitoring and managing the operations of its opponents. In order to simplify this model, a constant input cost, c, is assumed in the expected profit function.

The ethanol product price, $P_t = P_t(Q_t, P_{Gasoline,t}, n_t)$, is a function of demand, the price of gasoline, and the number of manufacturers (Equation 2). The market demand at period t, Q_t, is cleared by the accumulated supply of all firms, $\sum_{i=1}^{n_t} y_{it}$, where n_t is the number of firms (Equation 3). Because the ethanol price and the gasoline price are highly correlated, we assume that P_t is a function of $P_{Gasoline,t}$. In addition to the effect from the changes of gasoline price, industry evolution theory suggests that price declines with growing demand over time due to competition among firms, which also results in increasing production efficiency at the industry level. In the long run, inefficient firms would be driven out of the market if their expected profit is less than zero. Price would then stay stable, *ceteris paribus*.

We solve a firm's profit maximization problem with respect to y_{it}, and the first order condition for y_{it}. The marginal cost, $c_t\ \alpha^{-1} A_t^{-1/\alpha}\ y_{it}^{(1-\alpha)/\alpha}$, increases with y_{it}, while the marginal revenue, P_t, is a constant (Equation 5). As such, we can derive the optimal capacity,

$y_{it}^* = \left(\frac{\alpha\ A_t^{1/\alpha}\ P_t}{c_t}\right)^{\frac{\alpha}{1-\alpha}}$ (Equation 5).

Substituting y_{it}^* into the expected profit function and then firms would make an entry decision if the expected optimal profit, $E(\pi_{it}|y_{it}^*)$, is greater than zero (Equation 6). The exit decision, on the other hand, is based on the zero profit condition, and firms exit if they make a negative profit. An inefficient firm with smaller A_i cannot compete with efficient firms. Therefore, only firms that can economically survive the competition would remain in the product market.

In the ethanol market, market demand is mandated in each period, which causes a change in demand. We define $Q_t/Q_{t-1} = 1 + \beta_t$, where β_t is the mandated growth rate of the total quantity demanded and is always positive (Equation 7). The growing market demand creates profitable opportunities for new entrants to act opportunistically when the incumbents hesitate to increase production capacity by deviating from their optimal production capacity. Thus, we expect an increasing number of firms with the growth of the mandated demand. However, when the PLC turns to the mature stage, new entrants no longer have a great competitive advantage in terms of production efficiency, A_i, because the technology emerges. As such, reduced opportunities would make the mandated demand attract fewer new entrants as the market emerges. Two results would reflect the nature of the model.

Lemma 1: The mandated demand incentivizes new entry, but the growth of entry is at a declining rate.

The growing market demand creates profitable opportunities for new entrants. Nevertheless, as noted above, when the PLC enters a mature stage, these new entrants no longer have a competitive advantage in terms of production efficiency.

That is because the technology that once was their advantage has now been developed and is common to all market participants.

Lemma 2: New entry results in more competition, thus bringing the price down.

The demand shift would cause the change of price. Because new entrants hold the latest technology, they are able to produce with a lower marginal cost and then gain their market share through price competition. Thus the ethanol price would be cut as a result of rivalry, and the price reflects a decreasing pattern along the PLC.

Based on Lemmas 1 and 2, the optimal capacity of the incumbents needs to be reduced in response to the declining price pattern ($\because dE(\pi_{it}|y_{it}{}^{*})/dP_t > 0$) (Equation 8). If all incumbents try to maintain their capacity at the optimal level, the released market share would attract more new entrants and, later, a higher level of competition would drive the price even lower. As such, the decision to maintain an optimal capacity would eventually result in the incumbents' exit.

Thus, in order to stay in the market, incumbents must deviate from their optimal production capacity, where the capacity $y_{it} > y_{it}{}^{*}$. Because the operational cost of monitoring and managing in our model is assumed to be a fixed cost, an increase in production would lower the average fixed cost to thus develop economies of scale. Hence, even though the deviation from the optimal production level would cause higher marginal costs than the constant marginal revenue, incumbents still benefit from deferring entry and developing economies of scale, so long as incumbents still make a nonnegative expected profit.

Incumbents deviate from the optimal production rate to seek long term survival in the ethanol market, and their average expected profit: $AP_{it} = \frac{E(\pi_{it})}{y_{it}} = E[P_t - \alpha MC_{it} - AFC_{it}]$ (Equation 9), where $AFC_{it} = \frac{F}{y_{it}}$ (Equation 10). Based on the assumptions in our model, the marginal cost increases with y_{it}, $\frac{dMC_{it}}{dy_{it}} > 0$ (Equation 11), and the average fixed cost decreases with y_{it}, $\frac{dAFC_{it}}{dy_{it}} = \frac{d(\frac{F}{y_{it}})}{dy_{it}} < 0$ (Equation 12). We apply the cost-benefit analysis, and derive the firm capacity expansion decision when $\frac{dAP_{it}}{dy_{it}} = -\frac{c}{\alpha} A_i{}^{-\frac{1}{\alpha}} y_{it}{}^{\frac{1-\alpha}{\alpha}} + F y_{it}{}^{-2} > 0$ (Equation 13). The pattern of production capacity would mirror the concave down trend of entry growth because of Lemma 1 and the second derivative, $\frac{d^2 AP_{it}}{dy_{it}{}^2} < 0$ (Equation 14), which implies decreasing returns to capacity expansion. Thus we can derive the following two propositions.

Hypothesis 1: Production capacity increases with the increasing mandated demand.

Hypothesis 2: Production capacity increases at a decreasing speed along the product life cycle.

In our model, a firm can increase its production efficiency by increasing its capacity to compete with the new entrants that invest in the latest technology. Increasing demand encourages market competition by incentivizing capacity expansion and new entry, and only efficient firms survive after competition. Because technology emerges after the PLC turns to a mature phrase, the mandate demand is effective in promoting economies of scale only in the nascent stage of PLC.

Finally, in our empirical analysis, we answer the question of whether the RFS helps to improve economies of scale by investigating the impact of its mandated demand on production capacity. Taking the natural logarithm of both sides of Equation 5 yields:

$$\ln(y_{it}{}^{*}) = \left(\frac{\alpha}{1-\alpha}\right)\left[\left(\ln A_t{}^{1/\alpha} + \ln\alpha\right) - \ln c_t + \ln P_t\left(Q_t, P_{Gasoline,t}, n_t\right)\right]$$

(Equation 15).

Equation 15 shows a firm's optimal capacity decision when it enters the market. However, the incumbent's capacity deviates from the optimal level for the growing mandated demand and the evolving PLC. Thus, we included the PLC effect in our empirical model. We consider the plant/firm capacity in the empirical estimation. At the right hand side of Equation 15, $(\ln A_t{}^{1/\alpha} + \ln\alpha)$ is treated as a constant term, and the cost is measured by the input price (i.e., corn price). We decompose the price, $P_t\left(Q_t, P_{Gasoline,t}, n_t\right)$, into three components: (1) a large-scale mandatory demand, (2) gasoline price, and (3) local competition (number of ethanol plants within the same state). The corn and gasoline prices are taken natural log and are lagged by one year to avoid endogeneity.

Therefore, our empirical model is as follows:

$$\ln y_{it} = \beta_0 + \beta_1\, RFS + \beta_2 \ln c_t + \beta_3 \ln P_{Gasoline,t} + \beta_4 \ln n_t + \beta_5\, Age + \beta_6\, Age^2$$

(Equation 16).

The empirical result shows statistical evidence that a mandated demand positively correlates to capacity at both plant and firm level. However, the result does not hold when the sample is limited to the mature stage of PLC. We admit that our finding does not directly answer whether a large-scale mandatory demand regime helps to improve the efficiency of biofuel production in practice. This is due to limited data concerning plant-level production costs, which is not currently available and is unlikely to be available in the near future.