CHOICES
The magazine of food, farm, and resource issues
1st Quarter 2014 • 29(1)

A publication of the
Agricultural & Applied
Economics Association

AAEA
Agricultural & Applied
Economics Association

Technology Forcing and Associated Costs and Benefits of Cellulosic Ethanol

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JEL Classifications: Q2, Q13, Q16, Q42
Keywords: Cellulosic Biofuel, Renewable Fuel Identification Numbers, Renewable Fuel Standard, Technology Forcing

Technology Forcing in Environmental Policy

Technology forcing regulations (policies) have long been used in environmental economics. To evaluate the technology forcing impacts of the RFS, it is important to address two questions: First, what is technology forcing and what is it designed to achieve? Second, why and how did it originally come about in the air quality arena, and what is the underlying economic rationale?

Technology forcing is a regulatory strategy that establishes currently unachievable and uneconomic performance standards to be met at some future point in time. The legislation or regulatory rules also set a defined time period for achieving these performance standards as well as intermediate or annual progress that must be demonstrated. In cases where the standards are not achieved in a timely fashion, fines are assessed or permits have to be purchased. Basically, technology forcing sets regulatory standards and provides incentives for achieving the standards or disincentives for not achieving them. In many respects it is analogous to a cap-and-trade system with phased-in or more restrictive emissions caps over time.

The origin of technology forcing in air quality control goes back to the 1960s. California and the U.S. government had been following what was referred to as "technology following" with respect to air quality regulations. California, the state with the worst air quality, required automobile pollution control devices be installed on new vehicles after two developers demonstrated their devices could meet specified emission levels at reasonable costs. This approach provided a disincentive for automakers to divulge development of their own control efforts until two others were certified (Miller and Solomon, 2009), and it led to collusive behavior both in limiting device development and overstating time needed to meet emission standards. The California experience led to adoption of technology forcing for auto emissions control.

Similarly, low private investment in air emissions control technology research, development, and demonstration led Congress to design the Clean Air Act Amendments (CAAA) of 1970 to: (1) stimulate private investment that would help meet new emission source performance standards, and (2) allow the states to require existing emission sources to meet technically or economically infeasible emission limitations as part of state implementation plans (*Yale Law Journal*, 1977). Further, the U.S. Supreme Court in *Union Electric C. v. EPA (1976)* found that Congress intended the 1970 amendments to induce rapid improvements in air pollution control technology, or technology forcing, and affirmed the states' authority to set such standards as well.

Technology forcing involves two policy challenges: First, who sets the performance standards and how do they forecast potential technology improvements in setting standards or targets? At the Federal level, this will be Congress and the Environmental Protection Agency (EPA) in the renewable fuel and air quality arena. Second, what is the enforcement mechanism and how stringent will the enforcement process be? Gerard and Lave (2005) discuss how these challenges were addressed in implementation of air quality policies and how they helped explain the success of technology forcing with respect to efficiency, industry costs of non-compliance, waivers, delays in implementation, and political deterioration (reduction) of performance standards. Further, Gerard and Love point out how these factors may create significant "policy risk," and disincentives for investors to develop new technologies when not designed or implemented appropriately. This is an important concern in the implementation of the RFS.

RFS Technology Forcing and Commercialization of Cellulosic Biofuel

Biofuel made from renewable resources offers an alternative fuel to petroleum. To encourage production and consumption of biofuel, Congress passed the initial Renewable Fuels Standard (RFS) as part of the Energy Policy Act of 2005. The RFS applied only to conventional ethanol biofuel and had a 2012 target of 7.5 billion gallons per year (bgy). As part of the 2007 Energy Independence and Security Act (EISA), Congress established the RFS mandate that required 36 bgy of biofuel by 2022. The EISA mandated conventional ethanol at 15 bgy, biodiesel production at 1.0 bgy, cellulosic ethanol at 16 bgy, and advanced biofuel at 4 bgy with annual targets over the intervening years. It is important to note that Congress, through the EISA, legislated the annual and 2022 mandates, and EPA is responsible for the rules implementing the mandated levels. EPA also established a separate Low Carbon Fuel Standard (LCFS) for each biofuel subcategory, ranging from a 20% reduction relative to gasoline for conventional ethanol to a 60% reduction of CO_2 emissions for cellulosic ethanol (U.S. EPA, 2010).

The annual mandates, unless waived or reduced by EPA, determine the number of gallons of biofuel from each category that need to be blended that year. Compliance with the mandate falls to oil refineries and is enforced through Renewable Identification Numbers (RINs). One RIN record is associated with each gallon of biofuel. If oil refineries do not have sufficient RINs relative to their liquid fuel sales, they need to purchase additional RINs in the market to make up the difference. The market clearing process determines the price of RINs. If the annual blending mandate (original or as adjusted by EPA) has been met, then the price of RINs should fall to zero. The RFS provides annual mandate quantities for each biofuel category. EPA does annual evaluations and is allowed revisions to prevent costly investment. When a portion of the biofuel mandate is waived, EPA is required to make waiver credits available to meet the revised mandated volumes in lieu of blending biofuel.

Technology forcing typically improves efficiency over government incentive programs that provide loans, technology grants, interest subsidies, output tax credits, loan guarantees, and other incentives. Why? Although the government may pick the biofuel categories, it does not pick the "winners" (e.g., companies, technologies, and feedstock) in terms of what technology platforms are researched and developed. These decisions are made by firms that compete in a market environment that can more efficiently supply the targeted product. For example, biofuel processors compete with each other to find the most efficient conversion technologies and feedstock producers compete to supply the least cost feedstock input. Unlike the government providing grants, subsidized loans, and other incentives to develop renewable energy and emissions control technologies, the government sets the targets and lets the market derive an efficient solution or get "the biggest bang for the buck" in biofuel supply. Ultimately, this approach should lead to renewables competing with petroleum products, especially with increasing oil prices over time. At the same time, this statement assumes: (1) that other government incentives (e.g., tax credits, subsidies) to oil companies are not distorting market prices, and (2) that biofuels are able to satisfy the mandated RFS targets on a competitive basis. Possibly because of regional equity (e.g., rural income and development) and environmental impacts, separate mandates for biofuel categories were specified in the EISA as discussed above. RFS program efficiency could be improved if biofuel categories (i.e., feedstock sources and conversion technologies) were competitively designed.

Historical Biofuel Policy

Duffield, Xiarchos, and Halbrook (2008) provides a historical review of modern biofuel policy. Biofuel policy really has its origin in the National Energy Policy Act (1978) that established a $0.40/gal excise tax credit for fuels containing at least a 10% ethanol blend. The Energy Security Act of 1980 offered insured loans to small ethanol plants and subsequent acts provided grants, loans or guarantees, and other incentives. In 1988, Congress passed the Alternative Motor Fuels Act that provided credits to automakers producing cars running on alternative fuels such as E85 in meeting Corporate Average Fuel Economy, or CAFÉ, standards. The CAAA of 1990 established the Oxygenated Fuels Program and the Reformulated Gasoline Program. Both programs required that oxygen be added to gasoline, and ethanol was an alternative for meeting the oxygen requirement. The 2002 Farm Security and Rural Investment Act created a number of incentives to promote production and consumption of bioenergy and bioproducts. These incentives increased conventional ethanol demand and helped the industry develop a technology base for rapid expansion. Yet, these incentives did not make ethanol competitive on a gasoline equivalent basis in the market. The industry produced only 1.6 bgy of ethanol in 2000 and 13.3 bgy by 2010. What really drove biofuel industry development in the 2000s beyond legislated ethanol demand and policy incentives were higher oil prices (Andrian and Miranowski, 2009; and Aukayangul and Miranowski, 2010).

Prior to the RFS, similar government incentives (loans, grants, feedstock incentives, and excise tax credits) were used to spur cellulosic technology development in the 1970s and in the 2000s (National Academy of Sciences, National Academy of Engineering, and the National Research Council (NAS-NAE-NRC), 2009). Except for short run, oil supply interruptions and high oil prices, research and development in cellulosic biofuel technologies were limited until the EISA was passed in 2007. As a result, substantial progress has been made in research, development, and commercialization.

Benefits Associated with the RFS Mandate?

The benefits discussed in the EISA 2007 of the RFS include energy security gained from having a domestic source of renewable liquid transportation fuel, an associated reduction in greenhouse gas (GHG) emissions, and enhanced rural incomes, employment, and economic development. Typically, the critique of the RFS centers on a few key issues: (1) the need of energy security in an era of gas and oil fracking and declining domestic liquid fuel consumption, (2) what biofuel costs relative to greenhouse gas (GHG) emissions reduction, and (3) unlike the CAAA, technology forcing biofuel policies will not bring growth and prosperity because biofuel will substitute for domestic fossil fuel activities. In the short run, biofuel expansion may compete with domestic fossil fuels in the market and even lead to contraction in some of the fossil fuel sectors. At the same time as a society, we live and participate in a global energy market where oil prices are largely determined by global oil supply and demand.

What are the economic benefits associated with the RFS mandate? This is truly one of those questions with an “it depends” answer. Benefits depend on which crude oil price (i.e., current or longer run) is used because gasoline, diesel, and biofuel are a function of oil prices. The benefits of the biofuel substitute increase and decrease with petroleum prices. If long run oil price is sustained at $150/bbl as forecast by the U.S. Energy Information Agency (EIA) (2014) for 2035, many cellulosic and advanced biofuels will become competitive with gasoline and diesel as long as blending constraints are not imposed (Miranowski and Rosburg, 2013; Rosburg and Miranowski, 2011; and National Resource Council (NRC), 2011). Alternatively, if current oil price is sustained in the long run, then biofuel becomes more costly to blend. Furthermore, the multi-objective nature of the legislation creates an important attribution problem in measuring and comparing “efficiency” versus “distribution” benefits.

The benefits of domestic energy security are difficult to measure. Energy security is a long run issue. Even if we have positive short run supply shocks (e.g., fracking gas and oil) and short run decreases in domestic consumption, global energy markets will drive energy prices and price volatility. The less dependent we are on global petroleum markets the better able the United States will be to deal with global oil shocks and potential supply interruptions.

The rural development impacts of biofuel have created significant employment and economic growth in rural regions with excess feedstock supplies, like the Midwest, as discussed in Miranowski et al. (2010) and Brown, Weber, and Wojan (2013). At the same time, these impacts may be more intermediate run and the livestock sector may have been disadvantaged by the competition for feedstock from biofuel expansion in the short run. Furthermore, the net economic benefits to the region in the longer run may be different than the private benefits of employment and income growth.

What are the potential carbon savings or how does the cellulosic ethanol footprint compare with that of gasoline? Although there is much conflict in the literature over the carbon savings associated with biofuels (NRC, 2011), the most frequently reported estimates are based on the GREET model. Rosburg and Miranowski (2011) used the GREET 1.8 version from the Center for Transportation Research, Argonne National Laboratory. These were derived by comparing total GHG emissions per mile for both conventional gasoline and cellulosic ethanol. They assumed biomass ethanol yield—70 gal/ton; ethanol fuel efficiency—23 MPG; and gasoline fuel efficiency—23 MPG in 2009 based on default options. The reductions in GHG emissions relative to gasoline-fueled vehicles ranged from 84% to115% over all cellulosic feedstock with corn stover at 89% and switchgrass at 84%. In terms of tons of GHG savings per ton of feedstock, these estimates ranged from 0.79 to 1.09 tons CO_2e reduction per ton feedstock with corn stover at 0.85 and switchgrass at 0.80. These numbers imply a substantial cellulosic ethanol reduction relative to gasoline.

Supply Costs of Cellulosic Ethanol Production Under the RFS Targets

I will consider two types of cellulosic biofuel costs. These data are similar, but derived under different assumptions. One approach is to consider the long run average supply cost for different cellulosic feedstock in different production regions. It is necessary to use comprehensive accounting of all feedstock supply costs including establishment, production, and land opportunity costs; harvest and storage costs; and transportation and delivery to the biofuel processing plant. Such estimates from NRC (2011) and Rosburg and Miranowski (2011) are used in this example for illustrative purposes, but similar estimates are reported in other studies using comprehensive cost estimates (Miranowski and Rosburg, 2013). Estimates for feedstock delivered to the biofuel plant range from about $75/ton for wheat straw and forest residues to about $89/ton for corn stover and farmed trees to about $98/ton for switchgrass in the lower cost production regions. Assuming a 70 gal/ton biofuel conversion rate, feedstock costs will be from $1-2/gal of biofuel depending on the feedstock used. Further, to supply the RFS mandated cellulosic biofuel levels will require a combination of feedstock. Assuming a long-run oil price of $100/bbl, the gap between what the biofuel producer can pay for feedstock and what the feedstock seller must have to breakeven is about $0.85-1.50/gal or $60-100/ton assuming a 70gal/ton biomass conversion rate.

There have been a number of estimates of the average costs of supplying cellulosic ethanol from different cellulosic feedstock but few supply or marginal cost curve estimates for supplying different quantities of cellulosic ethanol to the fuel market. Rosburg, Miranowski, and Jacobs (2013) estimated the supply cost of meeting the 2016 RFS.2 cellulosic ethanol requirement of 4.25 billion gallons using sustainably-harvested corn stover and switchgrass feedstock. If the industry is scaled-up commercially, they found that the 4.25 bgy could be produced at an ethanol price under $3.50/gal, or a wholesale gasoline-equivalent price $5.15/gal. Additionally, cellulosic ethanol would be cost competitive with gasoline at $150/bbl oil price. If the cellulosic ethanol industry were further scaled-up with assumed technology, it could produce about 12 bgy of cellulosic ethanol at a wholesale ethanol price of $4.00/gal. At the same time, technology should improve significantly over time and reduce cellulosic ethanol costs significantly. It is important to note that these estimated costs are calculated absent any cellulosic biofuel incentives, such as the producer tax credit of $1.01/gal and the Biomass Crop Assistance Program (BCAP) feedstock subsidy, which could substantially reduce these costs. Similar estimates have been developed in similar studies (e.g., Chen, Huang, and Khanna, 2012).

How do supply costs translate into implicit carbon cost per ton of CO_2e reduction? First, implicit carbon reduction cost estimates, like all biofuel benefit estimates, are a function of the price of oil. Second, as indicated above, the RFS.2 costs/benefits cannot be attributed exclusively to carbon reduction. That said, if we did attribute RFS.2 program costs exclusively to carbon reduction and considered crude oil prices of $100/bbl and $150/bbl, what would it cost per ton of carbon reduced? Using a different analysis and assumptions than those used above, Rosburg and Miranowski (2011) estimated an upper bound for implicit carbon costs (or prices) per ton of CO_2e reduction from $0-10/metric ton (MT) CO_2e at $150/bbl oil and $140-200/MT CO_2e at $100/bbl oil. Assuming all these costs are attributable to carbon reduction with a long run oil price of $150/bbl, the implicit carbon reduction costs are insignificant and well below carbon prices suggested in the climate change literature. If current oil prices prevail in the long run, then program costs are significantly higher, attributing all program costs to carbon reduction.

Technology Forcing: Rapid Technology Improvement vs. Uncertain Development

When the RFS was passed, conventional ethanol and biodiesel were established industries and well on their way to reaching the original 15 bgy and 1 bgy targets. The opposite was true of cellulosic ethanol and advanced biofuel. It is accurate to say that technology forcing induced rapid improvements in biofuel production technology given the industry's technology base when the EISA was passed in 2007. Although there were demonstration plants for cellulosic conversion operational at the end of 2013 and commercial plants under construction, the first viable commercial plants are expected to begin operation in 2014. Further, the capital investment and plant build-out required by 2022 were not achievable for the cellulosic ethanol industry. The National Academy of Sciences, National Academy of Engineering, and the National Research Council (NAS-NAE-NRC) study (2009) concluded that even assuming a robust commercial cellulosic conversion technology was available by 2015, the cellulosic plant capacity build rate would have to be double the build rate for conventional ethanol to produce 16 bgy by 2022. Further, the National Resource Council (NRC) study (2011) on economic and environmental impacts of the RFS mandates found that without major conversion and feedstock technology breakthroughs, high oil prices, or high carbon prices, it will likely not be possible to meet the 2022 cellulosic biofuel mandate and these conclusions are supported by more recent data (U.S. EPA, 2013).

A sustainable biomass feedstock and cellulosic biofuel market requires stable and predictable energy policy if investors are to assume the technology and capital risks involved. It is reasonable to assume that uncertainty over political sustainability and enforcement of the RFS, appropriate and viable, commercial technology, and feedstock supply chain development have all slowed cellulosic biofuel industry development. The current EPA proposed rule change on *2014 Standards for the Renewable Fuel Standards Program* (U.S. EPA, 2013) only increases the policy risk of investing in cellulosic feedstock, conversion technology, and scaled-up commercialization of the industry.

Modifying RFS to Improve Program Efficiency and Effectiveness

Congress prescribed RFS biofuel mandates for good reason—to achieve energy security, improve rural well-being, and reduce GHG emissions. The approach is consistent with the original "technology forcing" approach under CAAA of 1970. Given the state of the cellulosic feedstock supply chain (i.e., largely undeveloped) and conversion technology to commercially produce cellulosic ethanol (i.e., largely bench science without scaling-up to pilot and commercial plants) when the EISA was passed, it was nigh impossible to have a commercial industry operational in 10 years. The targets were unrealizable in the timeframe established by Congress.

If the mandate is implemented over a more achievable timeframe (e.g., 2030), insuring a reasonable period of commercialization, and mandate enforcement is strengthened, then political and technological risk is reduced. These changes will provide incentives to spur private investment in industry development and growth and continued improvement in both feedstock and conversion technology. As noted earlier, the corn ethanol industry achieved rapid growth and expansion when oil price and feedstock (corn) cost made it less costly to substitute ethanol for petroleum fuel.

Another modification that may improve policy and program efficiency is to remove the biofuel categories. Why pick the winning biofuel subcategory, especially when EPA has also imposed a Low Carbon Fuel Standard on each biofuel subcategory? If our objective is to minimize the total cost of achieving a targeted reduction in CO_2 emissions or increased share of renewable liquid fuels, then the biofuel subcategory classification does not insure a least-cost solution. As in any standard economic problem, loosening one or more constraints never leads to a reduction in program efficiency. If the only goal of the RFS were to reduce GHG emissions, then we should be seeking a least cost reduction of GHG emissions, but RFS goals are more complex.

Another argument against proceeding with implementation of the RFS is that current production of biofuel is already bumping against the "blend wall" in terms of the amount of biofuel that the liquid transportation fuel market can absorb. The "blend wall" is a short run constraint that exists, in part, because it is politically viable. As Babcock and Pouliot (2013 and 2014) demonstrate, E85 (and E15 as well) can provide a safety valve to get us over the "blend wall" hurdle, especially if the gasoline distribution system is willing to make the necessary infrastructure investment. In the long run, even with existing technology and blender pumps, blending larger biofuel quantities should not present a significant challenge.

Relaxing standards and especially enforcement of current RFS provisions will spell disaster for development of a commercial biofuel industry much like occurred in the 1980s. Throughout the RFS era, many have been skeptical of the RFS working, not because technology forcing will not work, but rather, because Congress and the EPA may not have the resolve to enforce the mandate in the long run, thus creating a high political risk factor for investors.

RFS and Nation's Biofuel Commitment

The nation has a choice. If it is not willing to "get market prices right" by internalizing external environmental costs (e.g., carbon taxes, carbon cap-and-trade) and eliminating price distorting tax subsidies (e.g., petroleum tax write-offs, tax credits), then the RFS provides an effective and relatively efficient approach to achieve the articulated energy policy goals.

The nation can follow the more aggressive commitment to the RFS policy to produce renewable fuels to improve energy security, reduce GHG emissions, and enhance rural incomes and development. If the nation is not committed to the EISA goals, it can follow the passive approach that was used historically with ethanol. Even though these programs established a relatively small-scale, corn ethanol industry, it took market forces like high oil prices and low corn prices to scaled-up commercialization of the corn ethanol industry and make it competitive.

During oil crises and shortly thereafter in the 1970s and 2000s, the government, private companies, and the oil industry put substantial research funding into biofuel and other alternative fuels. Yet without sustained support, such as offered by the EISA's RFS, the cellulosic industry will not reach scaled-up commercialization. Although we may be awash in gas and oil from fracking and domestic consumption of gasoline and diesel, are slowly decreasing, we live in a global oil market with growing incomes and population. This is bound to drive oil prices higher in the future and having renewable fuels competing in the marketplace may afford us welcomed energy security and price protection.

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The author wishes to thank Jonathan McFadden, Sebastien Pouliot, Alicia Rosburg, and anonymous referees for helpful comments on an earlier draft of this article.