Some Inconvenient Truths About Climate Change Policy:
The Distributional Impacts of Transportation Policies

Stephen P. Holland,[1,4] Jonathan E. Hughes,[2] Christopher R. Knittel,[3,4] Nathan C. Parker[5*]

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Abstract

Instead of efficiently pricing greenhouse gases, policy makers have favored measures that implicitly or explicitly subsidize low carbon fuels. We simulate a transportation-sector cap & trade program (CAT) and three policies currently in use: ethanol subsidies, a renewable fuel standard (RFS), and a low carbon fuel standard (LCFS). Our simulations confirm that the alternatives to CAT are quite costly—2.5 to 4 times more expensive. We provide evidence that the persistence of these alternatives in spite of their higher costs lies in the political economy of carbon policy. The alternatives to CAT exhibit a feature that make them amenable to adoption—a right-skewed distribution of gains and losses where many counties have small losses, but a smaller share of counties gain considerably—as much as \$6,800 per capita, per year. We correlate our estimates of gains from CAT and the RFS with Congressional voting on the Waxman-Markey cap & trade bill, H.R. 2454. Because Waxman-Markey (WM) would weaken the RFS, House members likely viewed the two policies as competitors. Conditional on a district's CAT gains, increases in a district's RFS gains are associated with decreases in the likelihood of voting for WM. Furthermore, we show that campaign contributions are correlated with a district's gains under each policy and that these contributions are correlated with a Member's vote on WM.

[1]Department of Economics, University of North Carolina at Greensboro. [2]Department of Economics, University of Colorado at Boulder. [3]William Barton Rogers Professor of Energy Economics, Sloan School of Management, Massachusetts Institute of Technology. [4]National Bureau of Economic Research. [5]Institute of Transportation Studies, University of California, Davis.

1 Introduction

Economists often point to Pigouvian taxes and cap & trade programs as the preferred policy tools for reducing externalities. In contrast, to reduce greenhouse gas emissions, policy makers have relied on a number of alternatives that center around either explicit or implicit subsidies. Given the inherent inefficiency of these alternatives, what explains the persistence of these policies in spite of their higher costs? We provide evidence that the answer lies in the political economy of climate change policy.

In the transportation sector, the policies currently in place essentially translate into subsidies for biofuels, most notably ethanol.[1,2] Two major policies exist at the national level: direct subsidies to ethanol and the Renewable Fuel Standard requiring minimum levels of ethanol consumption each year, which we show acts as an implicit subsidy for ethanol. In addition, California recently adopted a Low Carbon Fuel Standard which requires the average greenhouse gas content of fuels to fall over time; Holland, Hughes, and Knittel (2009) show that a LCFS acts as an implicit subsidy for any fuel with a greenhouse gas content below the standard and that a LCFS can be highly inefficient.

We construct a model of advanced biofuels in the transportation sector and compare the equilibrium outcomes across carbon trading (CAT) and the three policy alternatives that currently exist: direct subsidies for renewable fuels (SUBs); renewable fuel standards (RFSs); and low carbon fuel standards (LCFSs). In particular, for each policy, we simulate prices, quantities, changes in farming activity, and changes in private surplus at the county level. Our results represent long run equilibria in the liquid fuels market by exploiting feedstock-specific ethanol supply curves that solve a GIS-based optimal ethanol plant location problem for the US in 2022. Our simulations confirm that the alternatives to CAT are quite costly. Under CAT, average abatement costs are $20 per metric ton of carbon dioxide equivalent ($/MTCO$_2$e). Costs under the alternative policies are substantially higher at $50 to $80 per MTCO$_2$e.[3]

While the alternatives to CAT are more expensive, they differ considerably in both their incidence and the variance in the annual per capita gains and losses across counties. We find that the alternatives to CAT exhibit a feature that make them more amenable to adoption—a right-skewed distribution of annual per capita gains and losses where many counties have small losses, but a smaller share of counties gain considerably.[4] For example, under SUBs we find that 5 percent of

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[1] Prominent policies in the electricity sector, also implicitly or explicitly subsidize low carbon fuels.

[2] Ethanol is a biofuel produced by converting corn or other plant material into alcohol.

[3] We constrain the emission reductions under CAT and the LCFS to be equal to those under the RFS. The emission reductions under SUBs are actually roughly 30 percent lower than these.

[4] According the theory of collective action in Olson (1965), policies with relatively concentrated benefits and diffuse

the counties gain more than \$1,250 per capita, while one county gains \$6,600 per capita; but, no county loses more than \$100 per capita. In contrast, the 95th percentile county under CAT gains only \$70 per capita, with no county gaining more than \$1,015 per capita. Furthermore, the gains are more concentrated in the sense that the winning-counties are less populated, while small losses are spread over heavily populated counties. Nationally, the average *person* loses \$30 per capita under the SUBs, but the average *county* gains \$180 per capita. Under the RFS, the average person loses \$34, while the average county gains \$160. Similar characteristics exist with the LCFS. This contrasts considerably with CAT, where the average person loses only \$11 per year, but the average county gains less than \$3 per capita.

To test whether our simulation results translate into political incentives, we correlate our estimates of county-level gains and losses with Congressional voting on H.R. 2454, better known as the Waxman-Markey cap & trade bill. One provision in Waxman-Markey was a new accounting of ethanol carbon emissions that would substantially weaken the RFS. Therefore, House members likely viewed the two policies as substitutes. We find that, holding a district's per capita CAT gains and House member's party affiliation constant, the greater the district's RFS gains, the *less* likely the House member voted for Waxman-Markey. In addition there is some evidence of the opposite effect, *i.e.* that holding a district's per capita gains under the RFS and the House member's party affiliation constant, the greater the district's CAT gains, the *more* likely the House member voted for Waxman-Markey. The effects are substantial. The probability that a House member votes for Waxman-Markey falls by 40 percentage points when a district's gains from the RFS increase from the first to the fourth quartile. Similar effects exist when correlating voting behavior with subsidies. The results remain significant even after controlling for measures of House member's political ideology, state and district-level carbon emissions from sources other than transportation, and current corn production.

We also investigate one of the major mechanisms through which the district-level gains and losses influence voting behavior. In particular, we correlate campaign contributions from organizations that either supported or opposed WM with our district estimates of the gains and losses from the RFS and CAT. We find that the greater a district's gain from the RFS, the more money the district's House Member received from organizations opposing Waxman-Markey. Over a two-year period around the Waxman-Markey vote, a Member whose district falls in the upper quartile of RFS gains and the bottom quartile in terms of CAT gains receives roughly \$33,000 more from organizations opposing Waxman-Markey compared to a member whose district is in the bottom

costs (*i.e.,* a right-skewed distribution of benefits) are more likely to lead to coalition formation and lobbying and are more likely to be adopted.

quartile of RFS gains and the upper quartile of CAT gains. This represents over a fourfold increase from the average member. When we correlate voting behavior with contributions, we find large reductions in the likelihood of voting for Waxman-Markey with opposition contributions and large increases with contributions from supporting organizations.

The results with respect to campaign contributions are further supported when we consider how the policies differ with respect to their incidence across consumers and different types of producers. Consumer surplus losses are largest under CAT at approximately $65 billion per year. However, this ignores the $59 billion of potential revenue if the permits were auctioned and the revenue returned to consumers. Under the RFS and LCFS, consumer surplus falls by $27 and $29 billion per year, respectively. Consumer surplus remains unchanged under subsidies.

Producer surplus increases under *all* policies (even ignoring any free allocation of permits under CAT), but the increases vary considerably both across policies and across types of ethanol producers.[5] The $2.5 billion increase in producer surplus under CAT comes from changing the marginal fuel from gasoline to ethanol. By doing so, the price increase more than offsets the increase in costs associated with fuel production under CAT. In the public discourse surrounding Waxman-Markey and other cap & trade bills at the national and state levels, firms argued that free permits were required to "make them whole" in the presence of rising costs; this argument ignores the change in equilibrium prices arising from increases in costs, that can in principle, more than offset the aggregate increase in costs.

These arguments underscore one of the other major differences between cap & trade and its alternatives. Under the cap & trade programs that have been either proposed or implemented, including WM, allocation of free permits in the transportation sector have gone to gasoline refiners, since they are able to point to higher costs under the legislation. Ethanol producers cannot make such arguments. Therefore, while we simulate that producers gain under all policies, which *types* of producers gain varies dramatically across policies

Under subsidies, the RFS and the LCFS, producer surplus increases by approximately $20 billion per year. Therefore, the alternatives to cap & trade not only alter the distribution of net gains and losses, but they also redirect gains to ethanol producers at the expense of consumers.

Our results add to a large literature analyzing the relationship between policy and the gains of stakeholders. Both Seltzer (1995) and Kroszner and Strahan (1999) model Congressional voting behavior as function of both ideology and the interests of legislator's constituents. Both papers

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[5]By assumption, gasoline producers receive no surplus in our main model. We relax this assumption in Appendix C.8.

find strong evidence that both stakeholder gains and ideology correlate with voting behavior. Also related are papers that model the outcomes of policy changes. For example, Wright (1974) and Fleck (2008) correlate state-level expenditures in the New Deal with Senator influence and economic variables. They find that the power of the states' Senators explains gains even when conditioning on the states' need. Knittel (2006) models the adoption of state-level electricity regulation during the beginning of the 20th century and finds that interest group strength explains adoption. More recently, Cragg and Kahn (2009) correlate voting behavior on anti-carbon legislation with political ideology and per capita emissions and finds that higher emissions are correlated with a lower probability of voting for carbon-reducing legislation. Similarly, we find that stakeholder gains are correlated with voting. In addition, there is a substantial literature showing that there are other potential channels (*e.g.,* employee voting) through which stakeholders can affect voting and campaign contributions (see Stratmann (1992, 1995); Bombardini and Trebbi (2011)).

More fundamentally, our analysis relates to research on the private-interest theory of regulation. This theory characterizes the regulatory process as one in which well-organized groups capture rents at the expense of more dispersed groups (see Stigler (1971), Peltzman (1976), Becker (1983), and Kroszner and Strahan (1999)). This theory has been effective in explaining regulations (e.g., regulatory barriers to entry) that are difficult to rationalize with the public-interest theory of regulation in which government interventions correct market failures and maximize social welfare (see Joskow and Noll (1981)). Kroszner and Strahan (1999) provide evidence that the private-interest theory also helps explain the removal of regulations in the banking sector. However, in each of these cases, the test of the private-interest theory rests on correlating whether or not a regulation is adopted or removed with *proxies* of interest group gains and losses.

In contrast, our analysis compares Congressional voting behavior with simulated interest group gains and losses from two *alternative* regulations with the same public-interest goals: reducing greenhouse gas (GHG) emissions. This provides a much more direct test of the private-interest theory since we control for the level of environmental benefit of the two regulations. Our analysis shows strong support for the private-interest theory. We find that the regulation with more concentrated private benefits is maintained over the competing regulation with higher social benefits but with less concentrated private benefits. Moreover, we show evidence that the well-organized groups are able to use their influence (i.e., campaign contributions) in a manner consistent with the private-interest theory.

The remainder of the paper is organized as follows. Section 2 summarizes the current set of transportation-related GHG policies. Sections 3 & 4 describe our theoretical framework, data and simulation methodology. Sections 5 & 6 present our main results. Section 7 describes a number of

robustness checks and Section 8 concludes.

2 Policy background

A variety of policies exist that either directly or indirectly promote biofuels at both the federal and state levels. The most relevant direct subsidy is the Volumetric Ethanol Excise Tax Credit (VEETC). Under this policy, now expired, fuel blenders received a 45 cent tax credit per gallon of ethanol sold.[6] The VEETC was established in 2004 as a 51 cent tax credit under the JOBS Creation Act and extended in 2008 via the Farm Bill, dropping the rate to 45 cents once annual sales of ethanol exceed 7.5 billion gallons. Prior to the VEETC ethanol received an implicit subsidy (relative to gasoline) as it was exempt from the federal fuel-excise tax beginning in 1978. The 2008 Farm Bill establishes a subsidy for producers of cellulosic ethanol of $1.01 per gallon tax credit minus the applicable VEETC collected by the blender of the cellulosic ethanol. In addition, producers with less than 60 million gallons of production capacity are entitled to a Small Ethanol Producer Tax Credit of $0.10 per gallon.

We note that these figures actually understate the subsidy level because they are on a per-gallon basis, not on a per-energy basis. One gallon of ethanol has roughly 66 percent of the energy content of a gallon of gasoline; implying, it requires 1.52 gallons of ethanol to displace one gallon of gasoline. Therefore, on a per gallon of gasoline equivalent (gge) basis, corn-based ethanol receives a 68 cent per gge subsidy; 84 cents for a small producer. Cellulosic ethanol receives a $1.53 per gge subsidy.

The other major federal ethanol policy is the Renewable Fuel Standard (RFS). The first RFS was adopted as part of the Energy Policy Act of 2005. The 2005 RFS required 7.5 billion gallons of ethanol by 2012.[7] The Energy Independence and Security Act (EISA) of 2007 expanded the RFS considerably, known as RFS-2. Not only does the new RFS increase the minimum ethanol requirements, it also differentiates ethanol by its feedstock and lifecycle greenhouse gas content; biomass-based diesel is also included. Four categories are created. Each of the four categories qualifies as renewable fuel, defined as ethanol and bio-diesel with lifecycle emissions at least 20 percent below those of gasoline. However, the 20 percent requirement only holds for renewable fuel facilities that commenced construction after December 19, 2007. Existing facilities are grand-fathered, therefore, the actual greenhouse gas savings from these facilities are unknown. The first

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[6]Although the VEETC was allowed to expire on December 31, 2011, a variety of ethanol subsidies still exist including the federal cellulosic subsidy and various state subsidies. Therefore, we simulate a policy like the VEETC to understand the impact of these policies.

[7]Current gasoline consumption is approximately 138 billion gallons per year. Because of the lower energy content of ethanol, 7.5 billion gallons displaces roughly 5 billion gallons of gasoline.

category is corn-based ethanol. The second category is "Advanced Biofuel," defined as renewable fuel with lifecycle emissions at least 50 percent below those of gasoline. "Biomass-based" diesel is bio-diesel with emissions at least 50 below petroleum-based diesel. Finally, cellulosic biofuel is a renewable fuel with lifecycle emissions at least 60 percent below gasoline or petroleum-based diesel. When fully implemented in 2022, the new RFS calls for 36 billion gallons of biofuel, with 21 billion gallons coming from advanced biofuels, where advanced biofuels have a lower GHG content than corn-based ethanol.

In contrast to the RFS and subsidy policies, a national cap & trade system would price the carbon emitted by all transportation fuels. The 2009 House of Representatives bill, H.R. 2454 or the "Waxman-Markey" bill would have established a broad national cap & trade system. The bill would have set legally binding limits on greenhouse gases with the goal of reducing emissions 17% below 2005 levels by 2020.[8] In addition, the bill contained specific provisions aimed at addressing leakage and deforestation and supporting research and development for low carbon technologies. H.R. 2454 would also have severely reduced the benefits to a large number of ethanol producers under the existing RFS by including indirect land use effects in the lifecycle emissions of ethanol. While the magnitudes of the EPA-assigned indirect land use effects for each of the ethanols are unknown, the figures used for recent Californian legislation imply that many corn-based ethanol producers would no longer qualify as having emissions that are 20 percent below gasoline.

Waxman-Markey's effect on the RFS-2 and agriculture was clearly in the consciousness of lawmakers. House Agriculture Committee Chairman Collin Peterson (D - MN) felt that Waxman-Markey would undermine the RFS.[9] Just prior to the house vote, Peterson and the bill's co-sponsor Henry Waxman (D - CA) agreed on an amendment to Waxman-Markey that would prohibit the EPA from imposing indirect land use change adjustments to the RFS-2 for 5 years. After that period, the Secretaries of Agriculture and Energy along with the EPA must agree on the indirect land use change calculations.[10]

This amendment was sufficient to ensure Peterson's vote for Waxman-Markey, but other Representatives still felt that the support for biofuels under the RFS was still not sufficiently protected. On the night of the floor vote, Frank Lucas (R - OK) expressed appreciation to Peterson for his "goodfaith efforts with Chairman Waxman to try to correct the worst features of this bill" by

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[8]Also known as the "American Clean Energy and Security Act of 2009."

[9]Peterson said that he would work to "defeat any climate change legislation on the floor of the House of Representatives until his 'Renewable Fuel Standard Improvement Act,' becomes law" (http://grist.org/article/2009-05-18-peterson-nuke-waxman1/). He further stated "What I'm upset about is not so much what's going on today, but the interaction of this [i.e., the GHG footprint of biofuel] with the climate change bill." (http://grist.org/article/2009-05-15-pols-rage-epa/).

[10]http://www.greencarcongress.com/2009/06/peterson-20090626.html.

delaying the indirect land use change adjustments for 5 years but worried that "6 years from now, it comes at us like a brick bat," Lucas (2009). Similarly, Stephanie Herseth Sandlin (D - SD) was reassured by the implementation delay but was concerned that the "flawed definition of renewable biomass in the Renewable Fuels Standard (RFS)" was not corrected in the bill, Sandlin (2009).

On June 26, 2009, the bill passed the U.S. House of Representatives with Peterson's amendment by a margin of 219 for to 212 against. In July of 2009, H.R. 2454 was placed on the Senate calendar, though a vote never occurred. On July 22, 2010 Senate Majority Leader Harry Reid (D - NV) was cited as abandoning the original bill in favor of a scaled-down version without emissions caps, Chaddock and Parti (2010). The bill never came to a vote in the Senate.

In addition to federal policies, a number of state-level policies exist. Many states have additional subsidies for biofuels, as well as minimum blend levels of ethanol in gasoline.[11] A more recent policy is the Low Carbon Fuel Standard, adopted in California in 2009 requiring the state to reduce the average carbon intensity of transportation fuels 10 percent by 2020. The California LCFS has also been influential at the Federal level. Early versions of the Waxman-Markey Energy Bill would have created a national LCFS similar to California's system.

3   Theoretical framework

This section builds a common theoretical framework for analyzing the four policies studied in the paper: SUBs, RFSs, LCFSs, and CAT. Let $q_1, q_2 \ldots, q_{n-1}$ be quantities of ethanol fuels, *e.g.,* corn or cellulosic ethanol, and q_n be gasoline where $mc_i(q_i)$ is the marginal cost of producing the ith fuel (with $mc_i' \geq 0$) and β_i is its carbon emissions rate. Throughout we assume that all fuels are measured using energy equivalent units and that fuels are perfect substitutes after controlling for energy content.[12] Let p be the common price of all the substitute fuels, and let $D(p)$ be the market demand for fuel. For ease of exposition, as in Holland, Hughes, and Knittel (2009), we model a single, representative, price-taking firm which produces all types of fuels. These market results hold for heterogeneous firms under trading, which is allowed for by all currently proposed policies.[13]

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[11]For example, Iowa awards a retail tax credit of 6.5 cents per gallon for ethanol sales above a minimum percentage. Minnesota requires all gasoline sold contain at least 10% ethanol (E10). Many states have similar policies. For a full listing, the reader is referred to http://www.afdc.energy.gov/afdc/laws/state.

[12]Recent studies by Anderson (2010) and Salvo and Huse (2011) provide evidence that consumers may not treat high-level ethanol blends (e.g. E85 or E100) and gasoline as perfect substitutes. There is little evidence that consumers perceive low-level ethanol blends as substantially different from gasoline.

[13]Under the market-based policies (the RFS, LCFS, and CAT) a single, representative, price-taking firm would not sell permits to itself. However, modeling a single firm is still useful since the prices of the permits are determined by the shadow values of the constraints.

For welfare calculations, we follow the usual assumptions that consumer and producer surplus can be calculated from the demand and supply curves. Except for the externality from greenhouse gas emissions, we assume that there are no additional distortions.[14] In particular, for transfers from the general funds (only required for the ethanol subsidies), we assume that funds can be raised without additional costs; we also ignore any potential benefits from using permit revenues to reduce other, distortionary, taxes.[15]

3.1 Ethanol subsidies

Suppose ethanol fuel i receives an ethanol subsidy s_i. In an unregulated competitive market, the firm will produce until the marginal cost of each fuel equals the fuel price. However, the ethanol fuels are subsidized, and, as is well known, a subsidized firm produces until marginal cost less the subsidy equals the market clearing price. This implies:

$$p = mc_i(q_i) - s_i \tag{1}$$

for each ethanol fuel. For gasoline, the firm produces until marginal cost equals price. These n equations determine supply from each of the n fuels at a given price. The equilibrium price is determined by market clearing:

$$D(p) = \sum_{i=1}^{n} q_i. \tag{2}$$

Solving for the equilibrium price and quantities involves solving a system of $n + 1$ equations. The equilibrium for a baseline without subsidies can be solved similarly by setting $s_i = 0$ for all fuels.

3.2 Renewable fuel standard

A renewable fuel standard (RFS) sets a minimum quantity (or proportion) of "renewable fuel" that must be produced in a given year, but does not explicitly consider the carbon emissions of the fuels. However, the current Federal RFS sets different standards for three types of renewable fuels (cellulosic, advanced, and total) in a manner that roughly reflects carbon emissions. Appendix Table 1 shows the current standards for 2010, 2015, and 2022. The three categories are additive, *i.e.,* cellulosic fuel is counted toward the advanced requirement and advanced fuel is counted toward the total requirement. The Federal RFS classifies ethanol produced from agricultural waste and

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[14]Holland (2009) shows that the relative efficiency of policies may change in the presence of additional market distortions such as incomplete regulation or market power.

[15]See Goulder (1995) for a discussion of the double-dividend.

energy crops, which are expected to have the lowest lifecycle GHG emissions, as cellulosic. Ethanol produced from food waste (municipal solid waste) is classified as advanced, and total renewable fuel captures other renewable fuels, *e.g.,* corn ethanol, which have higher emissions than advanced or cellulosic fuels.

To implement the policy, the EPA translates the volumetric targets into proportional targets (which we call *RFS ratios*) by projecting gasoline demand for the upcoming year. Each RFS ratio is then the volumetric renewable target divided by the projected gasoline demand.[16] Let σ_{RFSj} be the jth RFS ratio with $j \in \{$cell, adv, tot$\}$. For each gallon of gasoline produced, the representative firm would be required to produce σ_{RFSj} gallons of gasoline equivalent (gges) of the jth type of ethanol. Note that whether or not the regulation meets the volumetric ethanol target will depend on the accuracy of the EPA's forecast of gasoline production.[17]

To allow ethanol production by the least cost firms, Renewable Identification Numbers (RINs) are created for each gge of renewable fuel.[18] These RINs are then freely traded and are used to demonstrate compliance with the RFS. The RINs (and their market prices) are differentiated by the three types of ethanol. Let p_{RINj} be the price of the jth type of RIN. Since an ethanol producer can sell a RIN with every gge of ethanol produced, the RINs act as a subsidy to ethanol production. Thus in the equilibrium:

$$p = mc_i(q_i) - p_{RINj}, \tag{3}$$

where ethanol i is of type j and p_{RINj} is the price of a RIN of type j. The RINs also are an implicit tax on the production of gasoline since production of each gge of gasoline increases the renewable obligation of each type of ethanol. Thus, in equilibrium, the optimality condition for gasoline is:

$$p = mc_n(q_n) + p_{RINcell}\sigma_{cell} + p_{RINadv}(\sigma_{adv} - \sigma_{cell}) + p_{RINtot}(\sigma_{tot} - \sigma_{adv}). \tag{4}$$

This equation is derived and explained in Appendix A.1. Intuitively, producing additional gasoline increases ethanol procurement obligations. An additional gallon of gasoline requires σ_{cell} additional gges of cellulosic ethanol or cellulosic RINs which costs $p_{RINcell}\sigma_{cell}$. The additional gallon of gasoline also requires additional advanced ethanol and total ethanol, but since the categories are additive the additional costs from the advanced requirement is $p_{RINadv}(\sigma_{adv} - \sigma_{cell})$ and from the total requirement is $p_{RINtot}(\sigma_{tot} - \sigma_{adv})$.

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[16]See Federal Register Vol. 75, No. 58; Friday, March 26, 2010; Rules and Regulations.

[17]In the simulations, we endogenously update the ratios so that the volumetric targets are met.

[18]In practice, the RINS are for gallons of ethanol and energy volumes are adjusted later. For ease of exposition, we simply focus on gges.

The n equations above define the quantities of each fuel for given fuel and RIN prices. The equilibrium fuel and RIN prices are determined by market clearing for fuel as in Equation 2 and for each type of ethanol, *e.g.*, $\sigma_{RFStotal}q_n = q_1 + \cdots + q_{n-1}$. Note that the market clearing conditions for the other two ethanol types need not hold with equality due to the additive nature of the constraints. For example, if cellulosic ethanol is cheap to produce on the margin relative to advanced ethanol, then the cellulosic constraint might not hold with equality. In this case, the RIN prices would be equal for these two types of ethanol. Note that since the constraints are additive, the RIN prices must be such that $p_{RINcell} \geq p_{RINadv} \geq p_{RINtot}$.

3.3 Low carbon fuel standard

Under an LCFS, the average emissions intensity, defined as emissions divided by total energy output, may not exceed the standard σ_{LCFS} Holland, Hughes, and Knittel (2009).[19,20] This constraint is given by:

$$\frac{\beta_1 q_1 + \beta_2 q_2 + \cdots + \beta_n q_n}{q_1 + q_2 + \cdots + q_n} \leq \sigma_{LCFS}. \tag{5}$$

Firms adjust total fuel output and the relative quantities of fuel produced to comply with the regulation. The first-order condition for profit maximization for fuel i is:

$$p = mc_i(q_i) + \lambda_{LCFS}(\beta_i - \sigma_{LCFS}), \tag{6}$$

where λ_{LCFS} is the shadow value of the constraint in Equation 5 (or equivalently, the price of carbon under a LCFS). Notice that if the emission intensity β_i is greater than the standard, the last term in Equation 6 is positive. This implies that fuel i faces an implicit tax equal to $\lambda_{LCFS}(\beta_i - \sigma_{LCFS})$. On the other hand, if the fuel's emission intensity is below the standard, fuel i faces an implicit subsidy equal to $\lambda_{LCFS}(\beta_i - \sigma_{LCFS})$. Note that, under very general conditions, it is impossible to design a LCFS which results in the efficient allocation of energy production and emissions since each fuel with positive carbon emissions should be taxed (not subsidized) Holland, Hughes, and Knittel (2009).

To solve for the equilibrium, the system of equations includes the n first-order conditions in Equation 6, demand equal to supply in the fuel market, and market clearing in LCFS credits (Equation 5).

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[19]A LCFS has been adopted by California and is currently under development by various federal and state policy-makers.

[20]In our simulations, σ_{LCFS} is set to produce the same reduction in emissions as the RFS and CAT systems.

3.4 Carbon trading

Consider a cap (σ_{CAT}) on the total emissions of carbon.[21] Since the total emissions summed over all fuels produced must not exceed the cap, the constraint is:

$$\beta_1 q_1 + \beta_2 q_2 + \cdots + \beta_n q_n \leq \sigma_{CAT}, \tag{7}$$

which simply states that the sum of emissions associated with each fuel type cannot exceed the carbon cap. The first-order conditions of the firm's profit maximization problem are:

$$p = mc_i(q_i) + \lambda_{CAT}(\beta_i), \tag{8}$$

where λ_{CAT} is the shadow price of the carbon constraint (or equivalently, the price of a carbon permit). Note that the carbon cap implicitly taxes production of each carbon-emitting fuel in proportion to its carbon emissions. By taxing dirtier fuels more, carbon trading achieves a target level of carbon emissions at least cost, *i.e.,* is cost effective.

To solve for the equilibrium, the system of equations includes the n first-order conditions in Equation 8, demand equal to supply in the fuel market, and market clearing in carbon permits (Equation 7).

4 Modeling assumptions

To compare the effects of these four policies, we use detailed data on projected U.S. ethanol supply to simulate the long-run market equilibria. This section outlines the modeling assumptions and methods. See Appendix B for more details.

We use ethanol supply curves for corn ethanol and for six different cellulosic ethanol feedstocks: agricultural residues, orchard and vineyard residues, forest biomass, herbaceous energy crops, municipal solid waste, and municipal solid waste from food.[22] We construct county-level supply curves using estimates of biomass feedstock availability and aggregate county production to the national level for our policy simulations. For a given price of ethanol, the model selects optimal biorefinery locations to minimize costs of feedstock collection, ethanol production, and ethanol distribution. Reoptimizing the model for a range of ethanol prices provides an estimate of the long-run supply for each of the seven different types of ethanol.

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[21]In our simulations, the cap (σ_{CAT}) is set to produce the same *total* emissions as the RFS.

[22]Appendix C.9 investigates the sensitivity of our results to ethanol costs that are higher or lower than expected.

The supply side of the model is completed by aggregating the supply from each type of ethanol with supply of conventional gasoline. We assume that the long-run gasoline supply is perfectly elastic at $2.75 in our baseline.[23] The market supply depends on the policy since each policy may differentially affect the producer price of each of the types of fuel.

The producer prices under CAT and the LCFS depend directly on the carbon emissions of the fuels. We use lifecycle carbon emissions for each of the fuels including estimates of indirect land use effects where appropriate. In light of the great uncertainty and controversy over lifecycle emissions, we explore the robustness of our results to a variety of assumptions about lifecycle emissions. These two policies which explicitly target carbon emissions will generally result in less corn ethanol (which has relatively high carbon emissions) and more ethanol from advanced feedstocks (which has lower carbon emissions).

The demand side of the model assumes that ethanol and gasoline are perfect substitutes after adjusting for their differential energy content. We model fuel demand with a constant elasticity which we set at 0.5 in our baseline case. The level of demand is calibrated to the U.S. EIA estimate of annual fuel consumption in 2022 of 140 billion gge and our baseline gasoline price of $2.75.

For each of the policies, we calculate the vector of consumer and producer prices which equates supply and demand. For business as usual (BAU), our baseline, the equilibrium price of $2.75 is determined by the long-run supply of gasoline. We next simulate the RFS, which requires us to use a series of loops to calculate the equilibrium fuel price and RIN prices for each of the three types of ethanol such that total ethanol production hits the cumulative 2022 targets: 36 billion gallons of total ethanol of which 21 billion gallons is advanced of which 16 billion gallons is cellulosic (23.67 billion gges, 13.81 billion gges, and 10.52 billion gges respectively).

To compare the policies equally, we calibrate the CAT and LCFS so that each policy attains the same level of carbon emissions as the RFS. For CAT, we simply set the cap at this level and calculate the equilibrium price vector which now includes a carbon price. For the LCFS, the equilibrium price vector also includes a carbon price, and we adjust the carbon intensity required by the LCFS so that in equilibrium the LCFS leads to the same carbon emissions as the RFS and CAT.

Finally, we calculate the SUBs policies which model subsidies like the VEETC. The SUBs policy includes a smaller subsidy of $0.45 per gallon for corn ethanol and a larger subsidy of $1.01 per gallon for more advanced types of ethanol ($0.68 per gge and $1.54 per gge respectively).

At the national level, we calculate and compare the surplus gains and cost of carbon under each of the policies. Additionally, we construct estimates of producer surplus at the county-level

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[23]Appendix C.8 shows that our results are not overly sensitive to this assumption.

using our disaggregate supply curves and the equilibrium prices under each policy. We calculate the change in per capita producer surplus under each policy at the Congressional district-level by summing surplus changes and population across counties within that district. The district-level per capita producer surplus change is then the aggregated surplus change divided by the aggregated population.[24] Consumer surplus and carbon market revenue changes are allocated per capita to the districts.

5   Simulation results

We discuss a variety of equilibrium outcomes from our simulations. We begin by comparing equilibrium fuel prices, quantities, and carbon emissions. Then, we estimate the relative efficiencies of the policies. Our measure is the average social cost per unit of GHG abated, which we refer to as "average abatement costs," reflecting the impact on consumer and producer surplus and the social costs associated with changing the fuel mix. We compare these costs to recent estimates for the social cost of carbon.

5.1   Energy prices, quantities, and emissions

Table 1 below presents energy prices, energy production and emissions under BAU and the RFS, LCFS, CAT, and subsidy (SUBs) policies. In the preferred specification we assume a BAU fuel price of \$2.75 per gasoline gallon equivalent. Under the RFS, fuel prices increase to approximately \$2.94 per gge and total fuel consumption decrease by approximately 5 billion gge per year to 135.31 billion gge. We find the RFS leads to a 10.2% reduction in GHG emissions, relative to BAU. The lower emissions under the RFS are a result of lower total fuel consumption and greater share of lower carbon cellulosic ethanol required by the advanced and cellulosic RFS rules.

In our simulations the LCFS and CAT are designed to produce the same reduction in carbon emissions as the RFS. The two policies differ in the mechanisms by which these reductions are achieved. Under the LCFS, fuel prices increase to \$2.96 per gallon, total fuel consumption is approximately 134.99 billion gge per year of which approximately 20.07 billion gge are ethanol. Under CAT, fuel prices are higher at \$3.23 per gallon, resulting in lower total fuel consumption of approximately 129.09 billion gge per year. As a result, less ethanol is required to achieve the desired 10.2% emissions reduction. We come back to this in Section 5.2.

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[24]The county-level ethanol production data allow us to calculate the land-use changes under each policy. The alternatives to CAT result in substantially larger shifts in agricultural activity. See Holland et al. (2011) for details on these calculations.

Finally, we also simulate the equilibrium under the current set of subsidies. Under direct subsidies, fuel prices are unchanged.[25] Ethanol production increases from approximately 5.16 billion gge per year to 23.38 billion gge per year. Carbon emissions fall by approximately 6.9% relative to BAU.

Table 1 also summarizes ethanol production by three broad categories and by policy. SUBs and the RFS result in the largest shifts in corn ethanol production, increasing from 0.96 billion gge per year in the BAU scenario to approximately 9.25 and 9.86 billion gge per year, respectively. This occurs since these two policies target ethanol production not carbon emissions, and corn ethanol has the highest carbon emissions of all the ethanol fuels. Since the LCFS explicitly targets carbon intensities, corn ethanol production is lower under the LCFS at approximately 5.58 billion gge per year with a larger share of ethanol production coming from waste and cellulosic feedstocks. Since CAT explicitly targets carbon levels, CAT results in no increase in corn ethanol production but increases in the low-carbon ethanols utilizing waste feedstocks.

5.2 Costs and relative efficiencies

Table 1 summarizes abatement costs under each policy calculated as the sum of changes in consumer and producer surplus net of any carbon market revenue or subsidy payments. An intuitive metric for comparison is the average abatement cost calculated as abatement cost divided by the total reduction in emissions. The average abatement cost for a 10.2% reduction in emissions under CAT is approximately $19.52 per metric ton of carbon dioxide equivalent ($MTCO_2e$). The marginal cost, or price of an emissions permit, at this level is approximately $40.83 per $MTCO_2e$ as shown in the bottom panel of Table 1. We note that while consumer surplus falls under CAT by roughly $65 billion, this calculation ignores the roughly $59 of potential revenue that could be cycled back to consumers if permits were auctioned. We find that total producer surplus increases even in the absence of free permit allocation. The intuition behind this result stems from shifting the price-setting marginal firm from the lower cost gasoline producers to higher cost ethanol firms.

Abatement costs under the alternative policies are much higher; however, producers benefit more from these policies, while consumers are harmed relative to a CAT program that recycles revenues from permits back to consumers. Under the RFS, average abatement costs are $57.90 per $MTCO_2e$. Producer surplus increases by $17.12 billion per year. Average abatement costs under the LCFS are $48.58 per $MTCO_2e$.[26] Finally, the average abatement costs under the subsidy

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[25]This is a consequence of the perfectly elastic supply curve for gasoline.

[26]We note that this figure is below many of the results in Holland, Hughes, and Knittel (2009) reflecting the long run nature of our ethanol supply curves.

programs are the highest at \$82.30 per $MTCO_2e$ despite the fact that abatement is roughly 30 percent lower. Consumers are unharmed by a SUBs since fuel prices do not change. Producer surplus increases by nearly \$18.89 billion. Total government outlays exceed \$28 billion.

The large variation in average abatement costs brings up the possibility that, for given levels of marginal damage estimates, some of the policies may reduce welfare. A number of estimates of the externalities associated with GHGs exist. Tol (2008) provides a meta-study of 211 estimates of the "social cost of carbon" (SCC). He reports the points of the distribution of estimates after fitting the results to a parametric distribution. Across the three assumed distributions, for studies written after 2001, the median SCC ranges from \$17 to \$62 per $MTCO_2e$, while the mean ranges from \$61 to \$88 per $MTCO_2e$ (in 1995 dollars). More recently, the Interagency Working Group on Social Cost of Carbon, United States Government (2010) estimates the SCC for a variety of assumptions about the discount rate, relationship between emissions and temperatures, and models of economic activity. Appendix Table 2 summarizes their results (in 2007 dollars). Because our analysis represents conditions in 2022, we focus on the 2020 estimates. For all but the most pessimistic set of assumptions, the RFS and LFCS reduce welfare relative to business-as-usual; the current sets of subsidies reduce welfare even 95th percentile of estimates using a 3 percent discount rate. In contrast, CAT increases welfare for all of the reported results with discount rates below 5 percent.

6   The political economy of climate change policy

The obvious question that leads from our results is, given how much more efficient CAT is relative to the other policies, why have policy makers chosen the VEETC and Renewable Fuel Standard over CAT? We investigate the distributional impacts of the different policies as a potential answer.[27] We do this in a number of ways. We first calculate net private surplus changes for each county and analyze the distributions of these across the different policies.[28] A highly right-skewed distribution indicates that benefits are relatively concentrated and costs are diffuse. These characteristics of gains serve to increase coalition formation and lobbying and make policies more successful politically, Olson (1965).[29] We then aggregate these to the Congressional district level and correlate these changes with Congressional voting behavior on H.R. 2454, better known as the Waxman-

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[27]Other possible reasons include the higher fuel prices which would result under CAT; the perception that CAT is a "tax"; ideological opposition to efficient regulations; and opposition to environmental regulations in general and climate policy in particular.

[28]See Section 4 for a discussion of the aggregation methodology.

[29]See Bombardini (2008) for more recent work on the relationship between heterogeneous gains and lobbying.

Markey Climate Bill (WM). To investigate one potential mechanism through which private surplus changes affect Congressional behavior, we correlate our measures of private surplus changes with political contributions from organizations either supporting or opposing WM. Finally, we take our estimates from the House vote and predict the outcome of WM had it gone to vote in the Senate.

Figure 1 graphically illustrates the geographic variation in net changes in per capita surplus changes for each policy. Under CAT, the number of counties that benefit from the policy is small as are the benefits. However, the losses are also small, predominantly coming from the consumer surplus losses associated with higher fuel prices.[30] To see this, Table 2 reports different points in the distribution of county-level and Congressional district-level gains and losses for each of the policies. Note that because these are not weighted by county populations, the county mean values will not coincide with our aggregate loss calculations above. Congressional districts on the other hand, are created with roughly equal populations, and therefore coincide more closely with the aggregate measures.[31]

Beginning with the county-level statistics for CAT in Panel A, the largest mean annual county per capita loss is $20.33, while no county gains more than $1,015 per capita. The median county loses $14.87, while the county mean is a gain of $2.98. Furthermore, 24 percent of the counties have a net-positive gain from the policy.

The results from the other policies contrast greatly with the CAT results. The average county gains considerably across these policies. These average gains range from $160 per capita under the RFS to over $209 per capita under the LCFS. The distribution of gains and losses are quite skewed as well, as the median county loses in all cases but the LCFS where, the median county gains substantially less than the mean. No county loses more than $100 under the SUBs, but one county gains over $6,600 per capita. Under the RFS, the average county gains $160, while 43 percent of counties gain something. The right tail of the distribution under the RFS is also long. Ten percent of counties gain over $530 per capita, per year, while 5 percent gain over $1,100.[32] Figure 1 shows that the gains from these other policies are concentrated in the Midwest, with additional gains in forest areas and areas that might grow crops such as switchgrass on marginal lands.[33] The positive mean, despite the negative weighted-mean, and right skew of these distributions suggest that the gains from these policies are concentrated, but the costs are diffuse. This may lead to

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[30]In determining the consumer surplus loss under CAT, we assume that carbon market revenue is returned to consumers in a lump sum fashion.

[31]Unfortunately, we cannot calculate the distribution of gains within a county.

[32]The distribution of gains under each policy are also shown graphically in Appendix Figures A.7 and A.8.

[33]Appendix C.10 provides additional intuition into the sources of gains by investigating the role of underlying agricultural endowments.

political dynamics that lend themselves to passing such policies despite their overall inefficiency, Olson (1965).

The trends in the district-level data in panel B are quite similar to those discussed above. The median district loses under every policy, though the magnitude of the loss is greater under the alternatives to CAT. While the district-level distribution is somewhat less skewed the RFS, LCFS and SUBs still exhibit a long right tail relative to CAT. Five percent of districts gain around $100 or more per capita under the RFS, LCFS, or SUBs, compared with less than $8 under CAT. Furthermore, gains in the highest gaining district are an order of magnitude larger compared with CAT suggesting that the gains under these policies are still quite concentrated when measured at the district level.

6.1 Determinants of voting in the House

To motivate our empirical work, Table 3 reports a number of points in the distribution of our private surplus changes and contributions across Democrats and Republicans and their votes on WM.[34] The top two panels report district-level per capita annual gains and losses from CAT and the RFS, respectively. The third panel shows relative gains, defined as the difference between per capita gains under the RFS and under CAT. The simple cross-tabs suggest that Democrats who voted against WM tended to be in districts where the private surplus changes were larger under the RFS. The gains from the RFS are larger for Republicans that voted against, but we note statistical power is an issue because only eight Republicans voted for WM.

Contributions also show variation across votes, within a party. We discuss the data on contribution in detail below, but the third panel suggests that Democrats that voted against WM received, on average, nearly $13,000 more from organizations opposing WM, while Republicans voting against received nearly $6,000 more. The tail of the Democrats' distribution is also much longer with the 75th and 90th percentiles over $23,000 and $28,000 larger, respectively, for Democrats that voted against. The tail of this distribution is less clear for Republicans. The contributions from organizations supporting WM do exhibit differences across Republicans that voted for and against, however. Those Republicans voting for WM received, on average, over $64,000 more dollars in supporting contributions. The Republican at the 90th percentile among those that voted for WM received

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[34]The p-values for the median, 75th and 90th percentiles are computed using qreg in Stata and are the p-values associated with the dummy variable for whether the Congressman voted for WM. Because we have never seen this reported, we verified that this dummy replicates the actual differences in these points in the distributions across the two samples, but have not verified the standard error.

more than $425,000 more than the Republican at the 90th percentile that voted against WM.[35]

We next investigate whether our measures of gains and losses have explanatory power for Congressional voting behavior and political contributions. Our cleanest voting "experiment" is for cap & trade legislation. An LCFS has never come up for a House vote, and the bill that extended the VEETC was a hodgepodge of disparate legislation. Indeed, the name was "Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010." Similarly the bill that established the most recent RFS contained numerous energy-related measures. Therefore, we focus on correlating our gain and loss measures with votes on Waxman-Markey (WM)—H.R. 2454, "The American Clean Energy and Security Act of 2009"—which focused almost exclusively on a CAT program to reduce GHG emissions. As we described in Section 2, many Congressional Members likely viewed WM and the RFS as substitutes. We center our analysis on these two policies.

Table 4 shows the marginal impacts of a probit model of whether a House Member voted for WM.[36] Model 1 includes an indicator for whether the Member is a Democrat and our estimated per capita district-level gain from CAT in natural logarithms.[37] We report the marginal effects at the means of the continuous variables. The Democrat indicator is positive and large suggesting the probability a Democrat voted for WM is nearly 78 percentage points higher.[38] Without controlling for gains from the RFS, the coefficient associated with per capita gains from CAT is negative. If Congressional members viewed WM and RFS as substitutes, insofar as the gains from CAT and the RFS are correlated, the CAT gain variable is confounding two countervailing effects.

Model 2 includes both the gains from CAT and the gains from the RFS. Once we account for both, greater gains from CAT are correlated with voting for WM, though the coefficient is not precisely estimated.[39] In contrast, greater gains from the RFS are correlated with a lower likelihood of voting for WM; this correlation is statistically significant. Model 3 allows for level shifts in voting behavior due to unobserved factors that vary at the state-level by including state fixed-effects. The point estimates are consistent with Model 2, though the results are somewhat noisier as a result of having to omit states where all of the House members either voted for or against WM. Models 4 and 5 investigate the correlation between the relative gains under CAT versus the RFS. Larger

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[35] The 90th percentile may be driven by outliers since only eight Republicans voted against.

[36] Results from a linear probability model are qualitatively similar.

[37] Because many of the districts experience losses, we shift the district-level gains under each policy by a common factor of $100 per capita so that the natural logarithm is defined. Since we do not separately value welfare gains due to reduced carbon emissions, one may interpret this shift as a benefit of $100 per capita from reduced climate change damages.

[38] Appendix C.7 demonstrates that our results do not depend on including measures of political ideology.

[39] A regression of the net gains from CAT on the net gains from the RFS yields a slope of 0.09 and an R-squared of 0.61. Identification of the two coefficients is obviously coming from deviations in the linear fit.

CAT gains, relative to the RFS, are correlated with an increased likelihood of voting for WM even accounting for state fixed-effects.[40,41]

The effects from the RFS and CAT are also politically significant. Using Model 2, if a district moves from the 25th percentile to 75th percentile in terms of RFS gains, the probability its member votes for WM falls by 13 percentage points. Moving from the minimum to the maximum in RFS gains, the likelihood of voting for WM falls by 62 percentage points. Using Model 4, if a district moves from the 25th percentile in terms of the relative gains from the RFS to CAT, to the 75th percentile, the probability its member votes for WM increases by 60 percentage points.

We next investigate the linearity assumption. Table 5 splits districts into quartiles in terms of their gains and losses. The results suggest that the relationship may be non-linear. Model 1 again includes only the gains from CAT. Model 2 includes the quartiles from the RFS and Model 3 adds state fixed-effects. When we include the RFS quartiles, the CAT quartiles are positive, though only the coefficient on the third quartile is statistically significant. The RFS quartiles, in contrast, suggest the negative correlation in the linear model is being driven by larger winners from the RFS with the parameter estimate increasing in magnitude for the higher quartiles.[42] The estimated effects are substantial. Holding a district's gains under CAT constant, a House member's likelihood of voting for Waxman-Markey falls by 18 percentage points if the district is in the second quartile of gains from the RFS relative to if they were in the bottom quartile. However the probability falls by over 39 percentage points moving from the first to the fourth quartile.[43]

Of course, the transportation sector was not the only sector to be regulated under WM. The effect of WM on for example, electricity generation, may also have influenced voting behavior. Furthermore political ideology, either party affiliation or ideology more broadly defined, may help explain Representative's votes. Indeed, Cragg and Kahn (2009) find that district-level per capita GHG emissions is strongly correlated with Congressional voting on GHG-reducing legislations more

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[40]Since WM did not explicitly repeal the RFS, the test is not perfectly clean. Appendix A.2 shows that we cannot analyze an impure test in our model since reasonable cap and trade programs (e.g., a cap and trade with a $25 carbon price or a cap and trade which achieved the same emissions reductions as the RFS) would not induce additional ethanol beyond that induced by the RFS. In this case, the surplus gains to ethanol producers would be identical under the RFS and under the mixed model (e.g., RFS plus CAT) and the district level surplus changes would be perfectly correlated. Thus our model cannot identify effects of a mixed CAT and RFS separately from the effects of the RFS.

[41]Appendix C.6 analyzes a cleaner test of WM without Peterson's amendment. Since Peterson claimed to have the support of the entire agriculture committee, we can analyze voting on WM without the Peterson amendment if we assume all votes would have been the same except for 17 Democrats on the Agriculture committee who would have voted "Nay" instead of "Aye." The results in Appendix C.6 are unchanged for this analysis.

[42]Appendix C.11 provides additional evidence of the increasing marginal effect of gains.

[43]The quartiles across CAT and RFS are obviously correlated, however 8 percent of the districts in the upper RFS quartile are in the bottom two CAT quartiles. Appendix Figure 2 illustrates the source of identification.

broadly. To investigate the influence of these factors, Table 6 presents estimates of the base model controlling for those variables included in Cragg and Kahn (2009)—various measures of district carbon emissions and the political ideology of the district's Representative. Model 1 adds indicator variables for whether the Member is a Democrat and whether the district is in a top-10 coal producing state.[44] Model 2 replaces the Democrat indicator variable with DW-nominate, a measure of political ideology based on a comparison of roll-call votes of House members.[45] A higher score indicates a more conservative voting record. Model 2 also adds district-level per capita carbon dioxide emissions and average power plant carbon emissions rate. Model 3 adds corn production and population density, and Model 4 adds state-fixed effects.[46]

The results in Table 6 are remarkably similar to the base model. Increasing RFS gains conditional on CAT gains are associated with a lower likelihood of the Member voting for WM all else equal, though the estimated coefficients by quartile are generally smaller in magnitude. The emissions per capita and ideology controls have the appropriate signs and are in general statistically significant. In Model 1, the probability that a Democratic Member voted for WM is 75 percentage points higher. The probability that a Member in a top-10 coal producing state voted for WM is approximately 7 percentage points lower, though this parameter is imprecisely estimated. In Model 2, the coefficient on DW-nominate indicates that Representatives with more conservative voting records were less likely to vote for WM as were Members from districts with higher per capita emissions. Controlling for district-level gains and per capita carbon emissions, neither the coefficients on electricity plant emissions nor corn production are statistically significant. Representatives from more densely populated districts appear more likely to vote in favor of WM, all else equal. The parameters of interest do not change substantially with the addition of state fixed-effects.

We next investigate one of the mechanisms of these correlations—political contributions. We collected data on donations to Representatives from MapLight.org (2011). MapLight reports contributions for individual donors giving $200 or more to one candidate collected from Federal Election Commission filings. Donors are categorized into political interest groups according to the industry or occupation of the donor. For major pieces of legislation, MapLight.org researchers classify political interest groups as being in support of or opposed to a bill using Congressional hearing testimony, news databases and trade association web sites to assign interests.[47] We assume that donors from a

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[44]Similar results are obtained for top-5 coal producing states or controlling for coal consumption.

[45]DW-nominate is the voteview.org measure of political ideology based on all roll-call votes, not simply votes on environmental issues.

[46]We also experimented with employment shares in agriculture, refining and the automobile industry as proxies for the potential influence of these interest groups in Congressional districts. There results, which are quite similar to our main results, appear in the online appendices to the paper.

[47]A list of opposing and supporting organizations, as well as the documentation of this categorization by Map-

given interest group share this group's position on H.R. 2454. Because political donation patterns follow election cycles, we focus on donations during a two-year period from January 1, 2009 to December 31, 2010.[48] One may worry that this period is too broad to capture donations specific to H.R. 2454. As a robustness check, we limit our data to a 60-day window around the House vote. These results are qualitatively similar to those presented below.

Table 7 shows the results of a linear regression of contributions from organizations opposing and supporting WM on party affiliations, our CAT and RFS quartiles and in columns 2 and 4, state fixed-effects. We measure contributions in logs.[49] The first two columns focus on contributions from opposing donors. Greater district-level gains from CAT are correlated with less contribution dollars from donors opposing WM. Moving from the 1st to the 4th quartile is associated with a 1.97 reduction in the log of contributions. In contrast, higher RFS gains are correlated with more money from opposition donors. A move from the 1st to the 4th quartile is associated with a 4.74 increase in the log of opposition contributions. These results are qualitatively similar with state fixed effects. There is less evidence that contributions from donors *supporting* WM are correlated with our simulated gains and losses.

Next, we include the contribution variables in the voting model to see whether the correlations between voting and gains/losses are working through contributions or through gain/losses more generally.[50] Column 1 of Table 8, which includes only the contributions data, shows that greater contributions from donors supporting WM are correlated with an increase in the probability of voting for WM and that greater contributions from donors opposing WM are correlated with a decrease in the probability of voting for WM. When we include both the contribution variables and our gain/losses variables we find that the RFS quartile indicators still have explanatory power and are still politically significant. This is true even when we include fixed state effects in Model 3. Taking the Model 2 point estimates, a one standard deviation increase in the log of contributions supporting WM is associated with an 3 percentage point increase in the likelihood of voting for WM, while a one standard deviation increase in the log of contributions opposing WM is associated with a 3 percentage point decrease in the likelihood of voting for WM. Model 4 adds carbon emissions controls, corn production and population density. Model 5 adds state fixed-effects. The point estimates for contributions in support of and opposed to WM decrease in magnitude slightly

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light.org is available at: http://maplight.org/us-congress/bill/111-hr-2454/371786/total-contributions.table

[48]Recall the House vote on H.R. 2454 occurred on June 26, 2009.

[49]We add one to allow us to account for observations with zero contributions.

[50]As noted in the introduction, substantial literature shows that there are other potential channels (*e.g.,* employee voting) through which stakeholders can affect voting in addition to contributions (see Stratmann (1992, 1995); Bombardini and Trebbi (2011)).

but remain statistically significant, but so do the RFS quartile dummies. The RFS, Quartile 4 coefficients in Models 4 and 5 are no longer statistically significant, though the point estimates remain large and negative. These specifications clearly ask a lot of the data given the small number of observations. Overall, it appears as though the gains and losses from the policies affect voting through more than just the contribution channel.

6.2 Predicting voting in the Senate

We next use our estimates from the House vote to predict how the Senate would have voted. This requires a number of assumptions. Because the relationship between gains and voting may change considerably between the House and the Senate, we focus on the specifications that include the gains and losses quartiles and indicators for Democrat and "Top 10 Coal State" (Model 1 in Table 6). By doing so, we categorize Senators into 64 bins. We aggregate up the gains and losses to the state level and then reconstruct these variables.

We present the results in two ways. First, we calculate the fitted probability of voting for WM and assume each Senator votes for WM if their predicted value is greater than 0.5 to predict positive votes. Second, we simulate 1,000 different votes using the fitted values. In particular, we take the fitted value of the latent variable and bootstrap the error term, which by definition has a normal distribution with mean zero and standard deviation of one. For each bootstrap, we calculate the number of votes and plot the distribution of votes across all bootstraps.

Using only the fitted probability and the 0.5 rule, we end up with 53 votes. Interestingly, this is enough votes to pass WM, if it were to go to a vote. However, during this time period many bills that would have had a majority did not make it to vote because of filibustering. The 0.5 voting rule suggests that WM would not have had enough votes to break a filibuster.

Figure 2 plots the distribution of voting probabilities. This distribution is as we would expect given the large coefficient associated with party affiliation, and all 53 of the Senators with voting probabilities greater than 0.5 are Democrats. We do, however, find that five Democrats have probabilities less than 0.5. These are all in high corn and coal states—Illinois (Dick Durbin and Roland Burris—Barack Obama's former seat), Indiana (Evan Bayh), and North Dakota (Kent Conrad and Byron Dorgan). The Senators have fitted probabilities of 0.45 coming from being in a state in the 4th quartile of RFS and CAT gains and in a coal mining state.

On the other side of the 0.5 cut-off are 5 Senators with fitted probabilities of 0.62. These are all Democrats—two from Arkansas, one from Iowa, one from Maine and one from South Dakota.

These states are all in the 4th quartiles of RFS and CAT gains, but not in coal mining states. In addition, there are 4 Democratic Senators from Montana and New Mexico with fitted probabilities of 0.67. Both states are in the 2nd quartile of RFS gains and the 1st quartile of CAT gains but are top-10 coal states. As Figure 2 illustrates, there is little hope that WM could have passed filibuster and our simulations bear this out. While it is conceivable for the five Democrats to change their votes, the next highest fitted probability is 0.23. Indeed, we find that the maximum number of votes WM receives across our 1,000 draws is 59; this occurred one time. Figure 3 plots the distribution of these draws. Interestingly, on average WM garners 50 votes in the Senate. The reason why this is below our estimated number is that while the change in voting probabilities are symmetric, because we are adding a normal draw to the fitted $X\beta$, the change in votes is not symmetric. Basically, it is easier to get Senators to switch their votes from Aye to Nay than it is to switch from Nay to Aye. To see this, we point to the nine Senators with fitted probabilities of 0.62 and 0.67, but there are only five Senators close to this on the other side of the 0.5 cut-off (each with a probability of 0.45).

7 Robustness

Appendix C investigates the robustness of our results to changes in the preferred scenario parameters. Specifically we vary: the baseline fuel price; the emissions intensities of corn and cellulosic ethanol; and the elasticity of fuel demand. Finally, we relax our assumptions that corn prices are not substantially affected by shifts in ethanol production and that gasoline supply is perfectly elastic. We briefly summarize the results of these robustness checks here. Appendix C also presents a cleaner test of voting behavior based on the Peterson amendment, robustness to excluding political ideology variables, sensitivity tests for our ethanol supply curves, reduced form relationships for underlying agricultural endowments and other industry interests as well as evidence of increasing returns to relative gains. The reader is referred to the Appendix for a more detailed discussion.

The main results are all quite robust to these alternate parameters scenarios. The cost advantage of CAT over the alternative policies is very robust. Across all scenarios, average abatement costs are at least 2 times as large as CAT and can be nearly 7 times greater. Average abatement costs under the LCFS and RFS are consistently around 2.5 to 4 times greater than CAT. Average abatement costs under subsidies are 3 to 7 times larger than CAT.

Producer surplus gains, and gains to corn ethanol producers in particular, can be quite concentrated as shown in Table 2 and Figure 1. We find that across our scenarios, the relative gains to

ethanol producers under the RFS compared with CAT are fairly constant. A possible exception to this trend is the case of high baseline fuel prices. Higher prices result in higher levels of ethanol production absent policy intervention. In our high baseline fuel price ($3.25 per gallon) scenario, surplus gains to corn ethanol producers fall from approximately $3.2 billion per year to approximately $2 billion, relative to our $2.75 baseline fuel price scenario. Gains to corn ethanol producers increase slightly under CAT. We note that fuel prices at the time of the final vote on H.R. 2454 were approximately $2.60 per gallon, and *below* our preferred baseline fuel price of $2.75.[51]

To test the robustness of our political economy results, we run Model 1 of Table 6 under ten alternative parameter scenarios. (See Appendix C for details.) The results are remarkably consistent across all scenarios: *i.e.,* neither the point estimates nor standard errors change substantially. In particular: the RFS quartile coefficients are all negative and statistically significant; the CAT quartile coefficients are all positive although some are not statistically different from zero; and the Democrat and coal-state indicators are of the expected sign and significant.

8 Conclusion

We analyze equilibrium outcomes for carbon cap & trade and three alternative policies aimed at promoting low carbon transportation fuels. To do this we numerically simulate the market for transportation fuel for the U.S. in 2022. Our simulations exploit feedstock-specific ethanol supply curves developed from detailed agricultural feedstock data and engineering ethanol production models.

We find that the 2022 Federal RFS reduces carbon emissions by approximately 10.2% relative to BAU levels. Our analysis shows that the alternatives to CAT are quite costly. Average abatement costs range from $49 per $MTCO_2e$ for the LCFS to $82 per $MTCO_2e$ for subsidies, compared with only $20 per $MTCO_2e$ under CAT. These results are robust to a variety of assumptions about the modeling parameters including: business as usual fuel prices, the elasticity of fuel demand and the emissions characteristics of the various fuel pathways.

Overall, producer surplus increases under each of the policies, with the largest changes occurring under direct subsidies at approximately $19 billion per year. Consumer surplus decreases under the RFS, LCFS and CAT systems relative to BAU. The change in consumer surplus is largest under the CAT system at approximately $65 billion per year. However, auctioning of permits would

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[51]Recent research by Anderson, Kellogg, and Sallee (2010) suggests that current fuel prices are a reasonable proxy for consumers' expectations about future fuel prices. It seems reasonable to extend this result to the constituents of Congressional districts.

create nearly $59 billion in carbon market revenue which could be distributed to consumers. Under subsidies, consumer surplus in unchanged.

Given the higher costs of alternatives to CAT, we investigate one possible explanation for the popularity of ethanol subsidies and the RFS. Specifically, we generate county-level estimates for the producer and consumer surplus changes under each policy. These estimates suggest an unequal distribution of the gains and loses. Under the alternative to CAT, the median county experiences a small gain or loss. However, gains in some counties can be greater than $6,600 per capita. Under the RFS, five percent of counties gain more the $1,100 per capita and no county loses more than $95 per capita. In contrast, under CAT fewer counties experience gains as result of the policy and these gains are smaller in magnitude than under the alternatives policies. The 95th percentile surplus change under CAT is $73 per capita per year and no county gains more than $1,015 per capita.

We test whether these results translate into political incentives by correlating surplus changes at the Congressional district level with voting behavior on the Waxman-Markey H.R. 2454 cap & trade bill. We argue that under this bill, the RFS and CAT are likely viewed as substitutes. Conditional on a Representative's party affiliation and the district's predicted gains under the RFS, gains under CAT are positively correlated with voting for Waxman-Markey. Similarly, greater RFS gains are negatively correlated with a vote for Waxman-Markey.

We provide evidence that political contributions are one mechanism by which these political incentives are translated into voting behavior. Greater district level gains are associated with fewer donations by groups opposed to H.R. 2454. Higher RFS gains are associated with more contributions from groups opposed to WM. Contributions from groups who support WM are associated with an increased probability of a yes vote. Contributions from groups opposed to the bill are associated with a decreased probability of a yes vote.

Taken together, these results strongly support the private-interest theory of regulation. We find that regulation with more concentrated private benefits, the RFS, is maintained over a CAT system which would offer larger social benefits but with less concentrated private benefits. The pattern of campaign contributions around the vote on H.R. 2454 is consistent with political interest groups effectively influencing carbon regulation in a manner consistent with private interest theory.

References

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, and A. Slayton. 2002. "Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover." Tech. Rep. NREL/TP-510-32438, National Renewable Energy Laboratory.

Anderson, Soren T. 2010. "The Demand for Ethanol as a Gasoline Substitute." Working Paper 16371, National Bureau of Economic Research. URL http://www.nber.org/papers/w16371.

Anderson, Soren T., Ryan Kellogg, and James M. Sallee. 2010. "What do Consumers Believe About Future Gas Prices?" *Unpublished* .

Becker, Gary S. 1983. "A Theory of Competition among Pressure Groups for Political Influence." *The Quarterly Journal of Economics* 98 (3):371–400.

Biomass Research and Development Board. 2009. "Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research." Tech. rep.

Bombardini, Matilde. 2008. "Firm heterogeneity and lobby participation." *Journal of International Economics* 75 (2):329 – 348.

Bombardini, Matilde and Francesco Trebbi. 2011. "Votes or money? Theory and evidence from the US Congress." *Journal of Public Economics* 95 (78):587 – 611.

Butzen, S. and T. Hobbs. 2002. "Corn processing III. Wet milling." *Crop Insights* 12:1–6.

California Air Resources Board. 2009. "Proposed Regulation to Implement the Low Carbon Fuel Standard: Volume I." Tech. rep.

Chaddock, Gail R. and Tarin Parti. 2010. "Harry Reid: Senate will abandon cap-and-trade energy reform." Christian Science Monitor, July 22, 2010.

Cragg, Michael I. and Matthew E. Kahn. 2009. "Carbon Geography: The Political Economy of Congressional Support for Legislation Intended to Mitigate Greenhouse Gas Production." Working Paper 14963, National Bureau of Economic Research. URL http://www.nber.org/papers/w14963.

Fargione, Joseph, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne. 2009. "Land Clearing and the Biofuel Carbon Debt." *Science* 326 (5952):527–528.

Fleck, Robert K. 2008. "Voter Influence and Big Policy Change: The Positive Political Economy of the New Deal." *Journal of Political Economy* 116 (1):1–37.

Gallagher, P. W., H. Brubaker, and H. Shapouri. 2005. "Plant size: capital cost relationships in the dry mill ethanol industry." *Biomass and Bioenergy* 28 (6):565–571.

Gallagher, P. W. and H. Shapouri. 2005. "USDA's 2002 Ethanol Cost-of-Production Survey." .

Gardner, Bruce. 2007. "Fuel Ethanol Subsidies and Farm Price Support." *Journal of Agricultural and Food Industrial Organization* 5 (4):1–20.

Goulder, Larry H. 1995. "Environmental Taxation and the Double Dividend: A Reader's Guide." *International Tax and Public Finance* 2 (3):157–183.

Graham, R. L., R. Nelson, J. Sheehan, R. D. Perlack, and L. L. Wright. 2007. "Current and Potential U.S. Corn Stover Supplies." *Agronomy Journal* 99 (1):1.

Hamelinck, Carlo N., Geertje van Hooijdonk, and Andre P. C. Faaij. 2005. "Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle- and long-term." *Biomass and Bioenergy* 28 (4):384–410. 0961-9534 doi: DOI: 10.1016/j.biombioe.2004.09.002.

Holland, Stephen P. 2009. "Taxes and Trading versus Intensity Standards: Second-Best Environmental Policies with Incomplete Regulation (Leakage) or Market Power." Working Paper 15262, National Bureau of Economic Research.

Holland, Stephen P., Jonathan E. Hughes, and Christopher R. Knittel. 2009. "Greenhouse Gas Reductions under Low Carbon Fuel Standards?" *American Economic Journal: Economic Policy* 1 (1):106–46.

Holland, Stephen P., Jonathan E. Hughes, Christopher R. Knittel, and Nathan C. Parker. 2011. "Some Inconvenient Truths About Climate Change Policy: The Distributional Impacts of Transportation Policies." Working Paper WP-220, Energy Institute at Haas.

Hu, Patricia, Timothy Reuscher, Richard Schmoyer, and Shih-Miao Chin. 2007. "Transferring 2001 National Household Travel Survey." Tech. rep., Oak Ridge National Laboratory.

Idaho National Laboratory. 2010. "Uniform-Format Solid Feedstock Supply System: A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass." Tech. rep.

Interagency Working Group on Social Cost of Carbon, United States Government. 2010. "Appendix 15A:Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866." Tech. rep., Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, Department of the Treasury.

Joskow, Paul L. and Roger G. Noll. 1981. "Regulation in Theory and Practice: An Overview." In *Studies in Public Regulation*, NBER Chapters. National Bureau of Economic Research, Inc, 1–78.

Knittel, Christopher R. 2006. "The Adoption of State Electricity Regulation: The Role of Interest Groups." *Journal of Industrial Economics* 54 (2):201–222.

Kroszner, Randall S. and Philip E. Strahan. 1999. "What Drives Deregulation? Economics and Politics of The Relaxation Of Bank Branching Restrictions." *Quarterly Journal of Economics* 114 (4):1437–1467.

Lucas, Frank. 2009. *Congressional Record*, June 26, 2009. 155 (98):H7627-H7628.

MapLight.org. 2011. "H.R. 2454 - American Clean Energy and Security Act of 2009." URL http://maplight.org/us-congress/bill/111-hr-2454/371786/contributions-by-vote. Accessed, March 11, 2010.

McAloon, A., F. Taylor, W. Yee, K. Ibsen, and R. Wooley. 2000. "Determining the cost of producing ethanol from corn starch and lignocellulosic feedstocks." Tech. Rep. NREL/TP-580-28893, National Renewable Energy Laboratory.

National Agricultural Statistics Service. 2009. "2007 Census of Agriculture."

Nelson, Richard. 2010. "National Biomass Resource Assessment and Supply Analysis."

Office of the Chief Economist, World Agricultural Outlook Board, United States Department of Agriculture. 2010. "USDA Agricultural Projections to 2019." Tech. Rep. OCE-2010-1.

Oil Price Information Service. 2007. "Petroleum Terminal Encyclopedia."

Olson, Mancur. 1965. *The Logic of Collective Action: Public Goods and the Theory of Groups.* Harvard University Press, 1971 ed.

Peltzman, Sam. 1976. "Toward a More General Theory of Regulation." *Journal of Law & Economics* 19 (2):211–40.

Renewable Fuels Association. 2009. "Biorefinery Locations."

Salvo, Alberto and Cristian Huse. 2011. "Is Arbitrage Tying the Price of Ethanol to that of Gasoline? Evidence from the Uptake of Flexible-Fuel Technology." *Energy Journal* 32 (3):119–148.

Sandlin, Stephanie Herseth. 2009. *Congressional Record*, June 26, 2009. 155 (98):H7662.

Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions From Land-Use Change." *Science* 319 (5900):1238–1240.

Seltzer, Andrew J. 1995. "The Political Economy of the Fair Labor Standards Act of 1938." *Journal of Political Economy* 103 (6):1302–42.

Simmons, P., N. Goldstein, S. Kaufman, N. Themelis, and J. Thompson Jr. 2006. "The State of Garbage in America." *BioCycle* 47 (3):26–43.

Small, Kenneth and Clifford Winston. 1999. "The Demand for Transportation: Models and Applications." In *Essays in Transportation Economics and Policy*, edited by Jose Gomez-Ibanez, William B. Tye, and Clifford Winston. Brookings Institute.

Stigler, George J. 1971. "The Theory of Economic Regulation." *Bell Journal of Economics* 2 (1):3–21.

Stratmann, Thomas. 1992. "Are Contributors Rational? Untangling Strategies of Political Action Committees." *Journal of Political Economy* 100 (3):pp. 647–664.

———. 1995. "Campaign Contributions and Congressional Voting: Does the Timing of Contributions Matter?" *The Review of Economics and Statistics* 77 (1):pp. 127–136.

Tol, Richard S. J. 2008. "The Social Cost of Carbon: Trends, Outliers and Catastrophes." *Economics* 2 (2008-25).

U.S. Energy Information Administration. 2010. "Annual Energy Outlook." URL http://www.eia.doe.gov/oiaf/aeo/.

U.S. Environmental Protection Agency. 2007. "2006 MSW Characterization Report."

Wooley, R., M. Ruth, J. Sheehan, K. Ibsen, H. Majdeski, and A. Galvez. 1999. "Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis current and futuristic scenarios." Tech. rep., National Renewable Energy Laboratory.

Wright, Gavin. 1974. "The Political Economy of New Deal Spending: An Econometric Analysis." *The Review of Economics and Statistics* 56 (1):30–38.

Wullschleger, E. B., E. B. Davis, M. E. Borsuk, C. A. Gunderson, and L. R. Lynd. 2010. "Biomass Production in Switchgrass across the United States: Database Description and Determinants of Yield." *Agronomy Journal* 102:1158–1168.

Figures

Figure 1: County-level surplus changes ($\Delta PS + \Delta CS$) under a CAT, a LCFS, the 2022 RFS and subsidies.
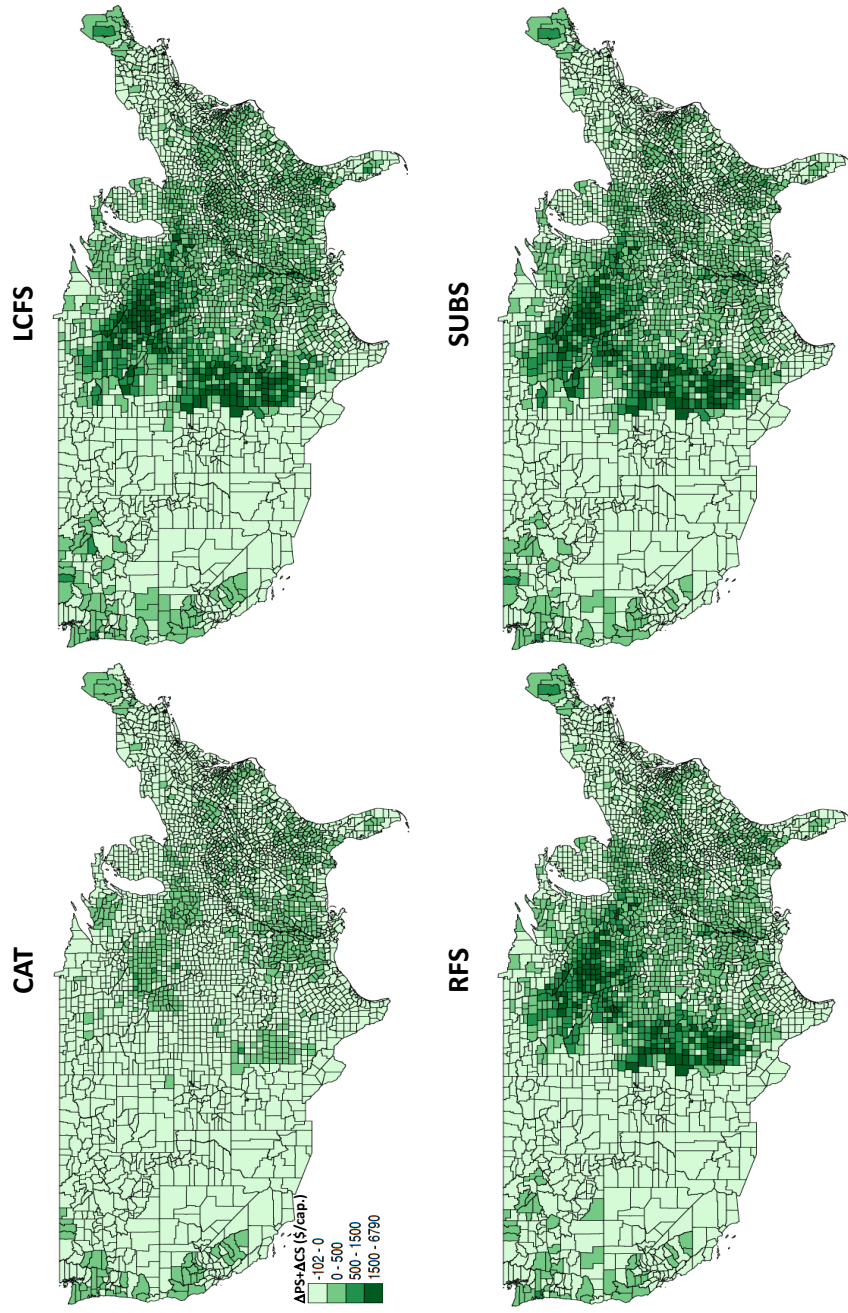
Figure 2: Distribution of the Senate-vote probabilities.
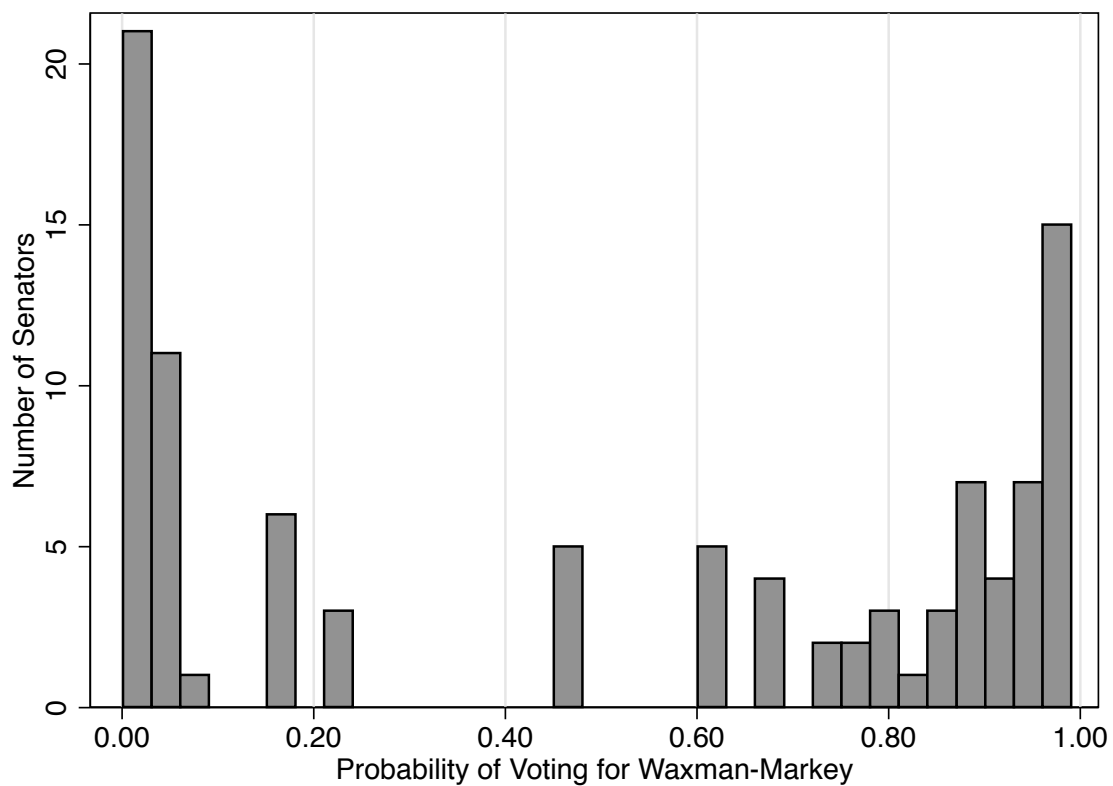
Figure 3: Histogram of simulated Senate-vote outcomes.
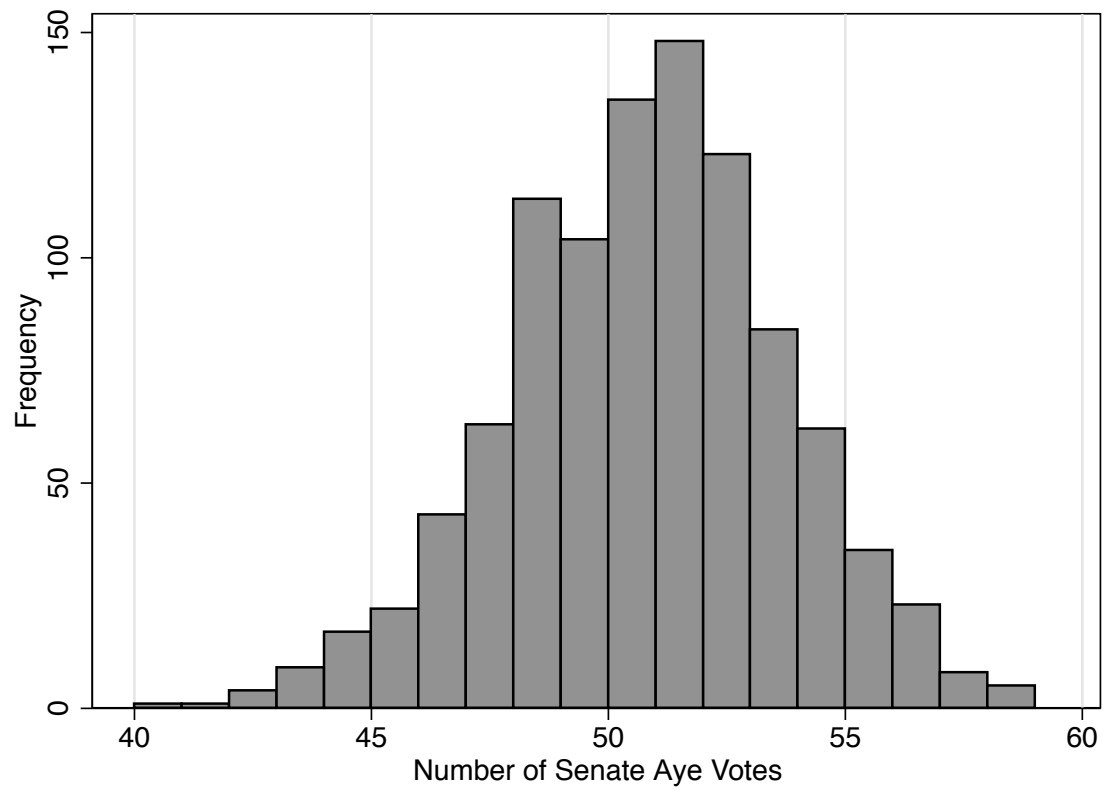
Tables

Table 1: Equilibrium outcomes under alternate policies.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)	$2.75	$2.94	$2.96	$3.23	$2.75
Fuel Quantity (bn. gge)	140	135.31	134.99	129.09	140
Gasoline Quantity (bn. gge)	134.84	111.64	114.92	120.11	116.62
Ethanol Quantity (bn. gge)	5.16	23.67	20.07	8.98	23.38
Corn Ethanol	0.96	9.86	5.58	0.96	9.25
Herb. Energy Crops	0.09	4.43	4.62	0.59	4.57
Waste Feedstocks	4.11	9.37	9.87	7.43	9.57
Emissions (MMTCO$_2$e)	1619	-10.2%	-10.2%	-10.2%	-6.9%
ΔCS ($ bn.)		-$26.69	-$28.59	-$65.07	$0.00
ΔPS ($ bn.)		$17.12	$20.56	$2.49	$18.89
ΔPS Corn Ethanol ($ bn.)		$3.19	$0.91	$0.09	$2.50
Carbon Market Revenue ($ bn.)				$59.35	
Subsidy Payments ($ bn.)					$28.05
Carbon Permit Price ($/MTCO2e)			$189.70	$40.83	
Abatement Cost ($ bn.)		-$9.57	-$8.03	-$3.23	-$9.16
Avg. Abatement Cost ($/MTCO$_2$e)		$57.90	$48.58	$19.52	$82.30

Table 2: The distribution of county- and district-level gains and losses across the different policies.

Panel A: County-level distributions

	CAT	LCFS	RFS	SUBS
Mean	$2.98	$209.42	$159.85	$186.83
Percentage>0	24%	49%	43%	46%
Minimum	-$20.33	-$101.60	-$94.85	-$99.67
25th Percentile	-$20.33	-$68.07	-$71.93	-$72.03
Median	-$14.87	$11.26	-$16.30	-$5.12
75th Percentile	$0.14	$209.70	$133.19	$166.53
90th Percentile	$34.98	$688.43	$537.34	$625.59
95th Percentile	$73.21	$1,363.58	$1,109.67	$1,252.99
Maximum	$1,015.28	$6,786.71	$6,596.38	$6,618.38

Panel B: District-level distributions

	CAT	LCFS	RFS	SUBS
Mean	-$11.49	-$29.10	-$34.33	-$32.97
Percentage>0	9%	18%	14%	15%
Minimum	-$20.33	-$101.60	-$94.85	-$99.67
25th Percentile	-$17.22	-$82.03	-$80.30	-$82.86
Median	-$15.04	-$68.79	-$70.09	-$71.49
75th Percentile	-$11.05	-$25.87	-$39.29	-$36.28
90th Percentile	-$1.72	$50.86	$24.27	$33.09
95th Percentile	$7.69	$134.07	$97.45	$111.81
Maximum	$110.44	$1,080.16	$1,101.95	$1,129.85

Table 3: Points of the distribution for key co-variates across party and voting on Waxman-Markey, H.R. 2454.

Variable	Statistic	Democrats				Republicans			
		Voted For (211)	Voted Against (43)	+Against	P-value of Difference	Voted For (8)	Voted Against (171)	+Against	P-value of Difference
Gains from CAT ($/per capita)	Mean	-13.40	-8.58	4.82	0.003	-16.95	-9.56	7.39	0.200
	Median	-15.85	-11.46	4.39	0.000	-17.07	-14.08	2.99	0.129
	75th	-12.99	-1.65	11.34	0.000	-14.63	-9.69	4.94	0.238
	90th	-7.42	5.50	12.92	0.067	-14.43	-0.44	13.99	0.359
Gains from RFS ($/per capita)	Mean	-51.73	-20.02	31.71	0.039	-78.81	-13.63	65.18	0.239
	Median	-76.65	-37.81	38.84	0.000	-81.87	-56.67	25.20	0.165
	75th	-60.61	11.71	72.32	0.000	-74.05	-28.23	45.82	0.230
	90th	-13.53	60.27	73.80	0.115	-68.25	60.22	128.47	0.289
Gains from RFS - Gains from CAT ($/per capita)	Mean	-38.33	-11.44	26.89	0.057	-61.86	-4.07	57.79	0.252
	Median	-60.56	-27.30	33.26	0.000	-59.68	-44.52	17.72	0.284
	75th	-47.04	4.97	52.01	0.000	-59.41	-20.88	36.72	0.246
	90th	-9.98	44.04	54.02	0.135	-49.37	70.74	120.11	0.276
Political Contributions Against ($1,000s)	Mean	3.46	16.14	12.68	0.000	10.25	16.03	5.78	0.559
	Median	0.50	12.00	11.50	0.000	1.00	7.55	6.55	0.195
	75th	3.35	26.60	23.25	0.000	9.50	18.85	9.35	0.284
	90th	9.00	36.95	27.95	0.000	64.85	36.45	-28.40	0.077
Political Contributions For ($1,000s)	Mean	90.69	90.25	-0.44	0.971	143.65	79.48	-64.17	0.071
	Median	70.51	74.84	4.33	0.690	137.25	58.03	-79.22	0.000
	75th	112.65	104.95	-7.70	0.731	143.35	90.40	-52.95	0.051
	90th	156.41	182.55	26.14	0.397	581.86	156.76	-425.10	0.000

Notes: This table lists points in the distribution across Democrats and Republicans that voted for and against H.R. 2454. 211 Democrats voted for the policy, while 43 voted against. 8 Republicans voted for the policy, while 169 voted against. The standard errors are calculated via Stata's req and qreg commands and are the standard errors associated with the indicator variable for whether the member voted for the policy. Gains from CAT is average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. Gains from RFS is average per capita benefits across the district from the current federal RFS program in 2022. Gains from RFS minus gains from CAT is the difference in per capita gains across policies. Political Contributions Against is the amount of political contributions received by the House member from organizations opposing H.R. 2454, measured in $1000s. Political Contributions For is the amount of political contributions received by the House member from organizations supporting H.R. 2454, measured in $1000s.

Table 4: Probit model correlating voting behavior for Waxman-Markey with estimated gains and losses: Linear terms.

	Model 1	Model 2	Model 3	Model 4	Model 5
Democrat	0.777***	0.749***	0.720***	0.752***	0.720***
	(0.028)	(0.019)	(0.019)	(0.019)	(0.019)
ln(Per Capita Benefits from CAT)	-0.530***	0.319	0.154		
	(0.137)	(0.222)	(0.249)		
ln(Per Capita Benefits from RFS)		-0.114***	-0.110***		
		(0.026)	(0.031)		
ln(Benefits from CAT) - ln(Benefits from RFS)				0.094***	0.105***
				(0.016)	(0.021)
State Fixed Effects	No	No	Yes	No	Yes
Observations	431	431	394	431	394
Chi-Square Statistic	315.11	334.66	340.56	333.64	340.52
P-Value	0.000	0.000	0.000	0.000	0.000
Log-Likelihood	-141.13	-131.36	-102.64	-131.87	-102.66
Pseudo-R2	0.53	0.56	0.62	0.56	0.62

Notes: The dependent variable equals one if the House member voted for H.R. 2454. The reported coefficients are the average of marginal coefficients taken at each observations level of the righthand side variables. For indicator variables, the coefficient represents the average change in the probability of voting yes from changing the indicator from zero to one. Democrat is an indicator equal to one if the House member is a Democrat. Per Capita Benefits from Cap & Trade is average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. Per Capita Benefits from RFS is average per capita benefits across the district from the current federal RFS program in 2022. We simulate that this leads to a 10 percent reduction in GHG emissions. Natural logarithms are calculated by adding \$100 per capita to gains under each policy. ***, **, and * denotes statistical significance at the 1, 5, and 10 percent levels, respectively. Standard errors are in parentheses.

Table 5: Probit model correlating voting behavior for Waxman-Markey with estimated gains and losses: Quartile indicators.

	Model 1	Model 2	Model 3
Democrat	0.774***	0.755***	0.724***
	(0.029)	(0.031)	(0.037)
Per Capita Benefits from Cap & Trade, Quartile 2	-0.0230	0.0510	0.095**
	(0.042)	(0.042)	(0.047)
Per Capita Benefits from Cap & Trade, Quartile 3	-0.0270	0.111**	0.124**
	(0.043)	(0.045)	(0.056)
Per Capita Benefits from Cap & Trade, Quartile 4	-0.191***	0.0710	0.0730
	(0.050)	(0.057)	(0.066)
Per Capita Benefits from RFS, Quartile 2		-0.182***	-0.165***
		(0.050)	(0.053)
Per Capita Benefits from RFS, Quartile 3		-0.254***	-0.264***
		(0.060)	(0.067)
Per Capita Benefits from RFS, Quartile 4		-0.393***	-0.358***
		(0.069)	(0.080)
State Fixed Effects	No	No	Yes
Observations	431	431	394
Chi-Square Statistic	322	351	355
P-Value	0.000	0.000	0.000
Log-Likelihood	-137.60	-123.15	-95.37
Pseudo-R2	0.54	0.59	0.65

Notes: The dependent variable equals one if the House member voted for H.R. 2454. The reported coefficients are the average of marginal coefficients taken at each observations level of the righthand side variables. For indicator variables, the coefficient represents the average change in the probability of voting yes from changing the indicator from zero to one. Democrat is an indicator equal to one if the House member is a Democrat. The Per Capita Benefits from Cap & Trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. Per Capita Benefits from RFS quartile indicators are the quartiles of the average per capita benefits across the district from the current federal RFS program in 2022. We simulate that this leads to a 10 percent reduction in GHG emissions. ***, **, and * denotes statistical significance at the 1, 5, and 10 percent levels, respectively. Standard errors are in parentheses.

Table 6: Correlating voting behavior for Waxman-Markey with estimated gains and losses, other GHG-related variables, and political ideology: Quartile model.

	Model 1	**Model 2**	**Model 3**	**Model 4**
Democrat	0.752***		0.711***	0.702***
	(0.031)		(0.035)	(0.041)
Per Capita Benefits from Cap & Trade, Quartile 2	0.043	0.007	0.013	0.043
	(0.042)	(0.039)	(0.046)	(0.054)
Per Capita Benefits from Cap & Trade, Quartile 3	0.106**	0.033	0.045	0.053
	(0.045)	(0.043)	(0.048)	(0.059)
Per Capita Benefits from Cap & Trade, Quartile 4	0.065	0.002	-0.006	0.006
	(0.057)	(0.054)	(0.063)	(0.073)
Per Capita Benefits from RFS, Quartile 2	-0.174***	-0.123***	-0.133***	-0.141***
	(0.049)	(0.044)	(0.047)	(0.051)
Per Capita Benefits from RFS, Quartile 3	-0.234***	-0.120**	-0.133**	-0.156**
	(0.061)	(0.054)	(0.064)	(0.072)
Per Capita Benefits from RFS, Quartile 4	-0.383***	-0.150**	-0.156*	-0.168*
	(0.070)	(0.076)	(0.091)	(0.100)
Top 10 Coal Producing State	-0.068*	-0.032	-0.062*	
	(0.036)	(0.030)	(0.035)	
DW-Nominate		-0.426***		
		(0.014)		
ln(Per Capita CO2 Emissions)		-0.097***	-0.094***	-0.087***
		(0.023)	(0.027)	(0.033)
ln(Average Power Plant CO2 Rate)		0.035	0.029	0.024
		(0.028)	(0.027)	(0.040)
ln(Corn Production)			-0.001	-0.002
			(0.003)	(0.004)
ln(Population Density)			0.029**	0.027*
			(0.013)	(0.016)
State Fixed Effects	No	No	No	Yes
Observations	431	424	431	394
Chi-Square Statistic	354.90	408.00	383.17	372.28
P-Value	0.000	0.000	0.000	0.000
Log-Likelihood	-121.24	-89.77	-107.10	-86.78
Pseudo-R2/R2	0.59	0.69	0.64	0.68

Notes: The dependent variable equals one if the House member voted for H.R. 2454. The reported coefficients are the average of marginal coefficients taken at each observations level of the righthand side variables. For indicator variables, the coefficient represents the average change in the probability of voting yes from changing the indicator from zero to one. The Per Capita Benefits from Cap & Trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. Per Capita Benefits from RFS quartile indicators are the quartiles of the average per capita benefits across the district from the current federal RFS program in 2022. We simulate that this leads to a 10 percent reduction in GHG emissions. DW-nominate is the voteview.org measure of political ideology for the House member. Per capita CO_2 emissions is the Purdue University Vulcan estimate of district's annual per capita CO_2 emissions. Average power plant CO_2 rate is the EIA measure of the average CO_2 emission rate of power plants within the district. Corn production is the district's total corn production in 2007. Congressional district average population density is calculated using county populations and areas from the 2000 U.S. Census. ***, **, and * denotes statistical significance at the 1, 5, and 10 percent levels, respectively. Standard errors are in parentheses.

Table 7: Correlating campaign contributions by groups in support of or opposed to Waxman-Markey with estimated gains and losses: Quartile model.

	ln(Contributions Opposing WM)	ln(Contributions Opposing WM)	ln(Contributions Supporting WM)	ln(Contributions Supporting WM)
Democrat	-2.180***	-1.746***	0.372***	0.399***
	(0.347)	(0.360)	(0.122)	(0.125)
Per Capita Benefits from Cap & Trade, Quartile 2	-1.508***	-1.914***	0.213	0.321
	(0.525)	(0.611)	(0.185)	(0.213)
Per Capita Benefits from Cap & Trade, Quartile 3	-1.679***	-1.960***	0.134	0.330
	(0.627)	(0.720)	(0.221)	(0.251)
Per Capita Benefits from Cap & Trade, Quartile 4	-1.966**	-2.488***	-0.055	0.082
	(0.764)	(0.882)	(0.269)	(0.307)
Per Capita Benefits from RFS, Quartile 2	1.574***	1.568***	0.016	-0.129
	(0.552)	(0.585)	(0.195)	(0.204)
Per Capita Benefits from RFS, Quartile 3	2.819***	3.081***	0.061	-0.131
	(0.638)	(0.718)	(0.225)	(0.250)
Per Capita Benefits from RFS, Quartile 4	4.741***	5.004***	0.3690	0.276
	(0.773)	(0.898)	(0.272)	(0.313)
State Fixed Effects	No	Yes	No	Yes
Observations	430	430	430	430
R2	0.23	0.37	0.03	0.23

Notes: All models are estimated via OLS. The dependent variable in the first two columns is the amount of political contributions received by the House member from organizations opposing H.R. 2454, measured in $1000s. The dependent variable in the columns three and four is the amount of political contributions received by the House member from organizations supporting H.R. 2454, measured in $1000s. Democrat is an indicator equal to one if the House member is a Democrat. The Per Capita Benefits from Cap & Trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. We simulate that this leads to a 10 percent reduction in GHG emissions. Per Capita Benefits from RFS quartile indicators are the quartiles of the average per capita benefits across the district from the current federal RFS program in 2022. ***, **, and * denotes statistical significance at the 1, 5, and 10 percent levels, respectively. Standard errors are in parentheses.

Table 8: Correlating voting behavior for Waxman-Markey with estimated gains and losses, other GHG-related variables, and contributions: Quartile model.

	Model 1	Model 2	Model 3	Model 4	Model 5
Democrat	0.689***	0.670***	0.640***	0.650***	0.631***
	(0.042)	(0.043)	(0.051)	(0.043)	(0.053)
Per Capita Benefits from Cap & Trade, Quartile 2		0.024	0.056	0.005	0.034
		(0.041)	(0.047)	(0.046)	(0.054)
Per Capita Benefits from Cap & Trade, Quartile 3		0.081*	0.094*	0.042	0.057
		(0.044)	(0.054)	(0.048)	(0.058)
Per Capita Benefits from Cap & Trade, Quartile 4		0.027	0.047	-0.011	0.014
		(0.057)	(0.066)	(0.063)	(0.073)
Per Capita Benefits from RFS, Quartile 2		-0.154***	-0.142***	-0.130***	-0.130***
		(0.047)	(0.051)	(0.046)	(0.050)
Per Capita Benefits from RFS, Quartile 3		-0.185***	-0.201***	-0.121**	-0.142**
		(0.056)	(0.064)	(0.061)	(0.069)
Per Capita Benefits from RFS, Quartile 4		-0.256***	-0.246***	-0.131	-0.143
		(0.077)	(0.086)	(0.086)	(0.096)
ln(Contributions Supporting Waxman-Markey)	0.034**	0.036***	0.033**	0.035***	0.030*
	(0.014)	(0.014)	(0.016)	(0.013)	(0.016)
ln(Contributions Split on Waxman-Markey)	0.005	0.001	-0.002	0.001	-0.002
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
ln(Contributions Opposing Waxman-Markey)	-0.031***	-0.023***	-0.021***	-0.017***	-0.017***
	(0.005)	(0.004)	(0.005)	(0.004)	(0.005)
Top 10 Coal Producing State				-0.045	
				(0.034)	
ln(Per Capita CO2 Emissions)				-0.077***	-0.072**
				(0.026)	(0.034)
ln(Average Power Plant CO2 Rate)				0.035	0.045
				(0.027)	(0.054)
ln(Corn Production)				-0.001	-0.002
				(0.003)	(0.004)
ln(Population Density)				0.018	0.013
				(0.013)	(0.016)
State Fixed Effects	No	No	Yes	No	Yes
Observations	427	427	391	427	391
Chi-Square Statistic	349.32	375.89	373.20	395.24	382.56
P-Value	0.000	0.000	0.000	0.000	0.000
Log-Likelihood	-121.26	-107.97	-84.27	-98.30	-79.59
Pseudo-R2/R2	0.59	0.64	0.69	0.67	0.71

Notes: The dependent variable equals one if the House member voted for H.R. 2454. The reported coefficients are the average of marginal coefficients taken at each observations level of the righthand side variables. For indicator variables, the coefficient represents the average change in the probability of voting yes from changing the indicator from zero to one. The Per Capita Benefits from Cap & Trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. Per Capita Benefits from RFS quartile indicators are the quartiles of the average per capita benefits across the district from the current federal RFS program in 2022. We simulate that this leads to a 10 percent reduction in GHG emissions. DW-nominate is the voteview.org measure of political ideology for the House member. Political Contributions Opposing is the amount of political contributions received by the House member from organizations opposing H.R. 2454, measured in $1000s. Political Contributions Supporting is the amount of political contributions received by the House member from organizations supporting H.R. 2454, measured in $1000s. Per capita CO_2 emissions is the Purdue University Vulcan estimate of district's annual per capita CO_2 emissions. Average power plant CO_2 rate is the EIA measure of the average CO_2 emission rate of power plants within the district. Corn production is the district's total corn production in 2007. Congressional district average population density is calculated using county populations and areas from the 2000 U.S. Census. ***, **, and * denotes statistical significance at the 1, 5, and 10 percent levels, respectively. The coefficient for Per Capita Benefits from RFS, Quartile 4 in Model 4 is significant at the 10 percent level, but the marginal effect p-values are slightly greater than 0.10.

Appendices for
"Some Inconvenient Truths About Climate Change Policy: The Distributional Impacts of Transportation Policies"

A Modeling the Renewable Fuel Standard

This appendix models the RFS with three ethanol types which are cumulative. The appendix then discusses analyzing the RFS together with a cap and trade policy.

A.1 Renewable Fuel Standard with three fuel types

The current Federal RFS sets different standards for three types of renewable fuels (cellulosic, advanced, and total). The three categories are additive, *i.e.,* cellulosic fuel is counted toward the advanced requirement and advanced fuel is counted toward the total requirement. To implement the policy, the EPA translates the volumetric targets into proportional targets (which we call *RFS ratios*) by projecting gasoline demand for the upcoming year. Each RFS ratio is then the volumetric renewable target divided by the projected gasoline demand.

To model the RFS with three additive fuel types, consider a representative firm which produces all three types of ethanol as well as gasoline. Let q_1, q_2, and q_3 be the quantities of the three types of ethanol with q_3 being cellulosic ethanol, q_2 being advanced (but not cellulosic) ethanol, and q_1 being neither cellulosic nor advanced. Let q_G be the gasoline quantity.

Let σ_{RFSj} be the jth RFS ratio with $j \in \{\text{cell, adv, tot}\}$. For each gallon of gasoline produced, the representative firm would be required to produce σ_{RFSj} gallons of gasoline equivalent (gges) of the jth type of ethanol.

To allow ethanol production by the least cost firms, Renewable Identification Numbers (RINs) are created for each gge of renewable fuel. The RINs (and their market prices) are differentiated by the three types of ethanol. Let p_{RINj} be the price of the jth type of RIN. These RINs are then freely traded and are used to demonstrate compliance with the RFS. Let RIN_j be the number of RINs the representative firm buys in the market. If RIN_j is negative then the firm is selling RINs.

The representative firm chooses production and RIN purchases to maximize profits

$$p(q_1 + q_2 + q_3 + q_G) - c_1(q_1) - c_2(q_2) - c_3(q_3) - c_G(q_G) - \sum_{j\in\{cell,adv,tot\}} RIN_j p_{RINj}.$$

subject to the additive RFS constraints for the three different fuel types:

$$RIN_{tot} + RIN_{adv} + RIN_{cell} + q_1 + q_2 + q_3 \geq \sigma_{tot}q_G$$

$$RIN_{adv} + RIN_{cell} + q_2 + q_3 \geq \sigma_{adv}q_G$$

$$RIN_{cell} + q_3 \geq \sigma_{cell}q_G.$$

The RFS constraints can be satisfied either by producing ethanol or purchasing RINs. Note that RIN purchases reduce the objective function, but relax the RFS constraints. Conversely, RIN sales increase the objective function but tighten the RFS constraints.

Let λ_j be the Lagrange multiplier of the jth constraint. The firm's FOCs for fuel production and RIN purchases are

$$p = mc_1(q_1) - \lambda_{tot}$$

$$p = mc_2(q_2) - (\lambda_{tot} + \lambda_{adv})$$

$$p = mc_3(q_3) - (\lambda_{tot} + \lambda_{adv} + \lambda_{cell})$$

$$p = mc_G(q_G) + \lambda_{tot}\sigma_{tot} + \lambda_{adv}\sigma_{adv} + \lambda_{cell}\sigma_{cell}$$

$$p_{RINcell} = \lambda_{tot} + \lambda_{adv} + \lambda_{cell}$$

$$p_{RINadv} = \lambda_{tot} + \lambda_{adv}$$

$$p_{RINtot} = \lambda_{tot}.$$

These first-order conditions can be rewritten for ethanol as

$$p = mc_i(q_i) - p_{RINj}$$

and for gasoline as

$$p = mc_G(q_G) + p_{RINtot}\sigma_{tot} + (p_{RINadv} - p_{RINtot})\sigma_{adv} + (p_{RINcell} - p_{RINadv})\sigma_{cell}$$

which can be rewritten as

$$p = mc_G(q_G) + p_{RINcell}\sigma_{cell} + p_{RINadv}(\sigma_{adv} - \sigma_{cell}) + p_{RINtot}(\sigma_{tot} - \sigma_{adv}).$$

The intuition of these optimality conditions is easily explained. Since an ethanol producer can

sell a RIN with every gge of ethanol produced, the RINs act as a subsidy to ethanol production and thus simply decrease the marginal cost of production. The optimality condition for gasoline is more complicated. Part of the cost of producing more gasoline is that it increases the RIN procurement obligations. In particular, producing an additional gge of gasoline requires σ_{cell} additional gallons of cellulosic ethanol or cellulosic RINs which costs $p_{RINcell}\sigma_{cell}$. But that additional gallon of gasoline also requires σ_{adv} additional gallons of advanced ethanol or RINs. Since the cellulosic ethanol counts as advanced ethanol, the cost of the additional gallon of gasoline for satisfying the advanced ethanol requirement is $p_{RINadv}(\sigma_{adv} - \sigma_{cell})$. Similarly, the cost of the additional gallon of gasoline for satisfying the total requirement is $p_{RINtot}(\sigma_{tot} - \sigma_{adv})$ since all the advanced ethanol counts toward the total ethanol requirement.

A.2   Renewable Fuel Standard plus CAT

Section 2 explains that many representatives likely viewed WM and the RFS as substitutes. Since WM did not explicitly repeal the RFS, the policies are not actually substitutes. In this appendix, we discuss analyzing the CAT and RFS together.

First, note that the policy we analyze and compare to the RFS is a CAT that achieves the same emissions reductions as the RFS. If we analyze these two policies together (CAT + RFS) the result is identical to the RFS results alone. To see this, think of the two policies as constraints: the CAT requires emissions to be no greater than some level and the RFS requires ethanol production to be greater than certain levels. The combined policy CAT + RFS would require production to satisfy both sets of constraints. But clearly the RFS alone satisfies the RFS constraints and the CAT constraint since the CAT emissions are determined by the RFS. Since RFS and CAT + RFS yield the exact same equilibrium, there is no variation to identify their separate effects.

Second, while we cannot analyze voting behavior under CAT+RFS, we can investigate equilibrium outcomes. Specifically, we can analyze a \$25 per ton CO_2 price in combination with the other policies. The idea is that this is a reasonable price for an economy wide cap and trade program. The results of this analysis are presented in Appendix Table 3. The CAT column is simply the \$25 CO_2 price and the RFS, LCFS, and SUBS columns have the policies plus the \$25 CO_2 price. The table shows that the combined policy (\$25 CO_2 + RFS) in column 2 reduces emissions by 14.6% which more than the \$25 CO_2 alone (6.6% from the CAT column) or than the RFS alone (10.2% from Table 1 in the paper). However comparing the results in the second column of Appendix Table 3 (\$25 CO_2 + RFS) and the second column of Table 1 (RFS) shows that ethanol production is almost identical in these two scenarios. Since both scenarios yield almost the same ethanol

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production, the reduced emissions come entirely from the reduction in gasoline production. This means that the entire difference comes through consumer surplus changes, carbon revenue, and gasoline producer surplus changes (here zero). Since we allocate consumer surplus, carbon revenue and gasoline producer per capita, the gains under the RFS and the combined policy ($25 CO_2 + RFS) will be perfectly correlated. Appendix Figure 4 shows a scatterplot of these two gains. Again our model yields no variation to separately identify these two effects.

To be more precise, assume the RFS and ($25 CO_2 + RFS) yield exactly the same ethanol production. The per capita surplus to county i from the RFS is $Surp_{RFS,i} = EthSur_{RFS,i} + CS_{RFS}$. Note that since the consumer surplus, CS_{RFS}, is the same per capita, the only variation across counties comes from the ethanol surplus $EthSur_{RFS,i}$. Similarly, the per capita surplus to county i from the ($25 CO_2 + RFS) policy is $Surp_{25+RFS,i} = EthSur_{25+RFS,i} + CS_{25+RFS} + TaxRev_{25+RFS}$. Now if ethanol production is exactly the same across the two policies, then the producer prices to ethanol and the production costs are identical across the two scenarios so surplus is the same across the two scenarios: $EthSur_{RFS,i} = EthSur_{25+RFS,i}$. Thus $Surp_{RFS,i} = Surp_{25+RFS,i} + K$ where $K \equiv CS_{RFS} - CS_{25+RFS} - TaxRev_{25+RFS} > 0$. The scatterplot in Appendix Figure 4 is consistent with this result.

B   Modeling assumptions

Using data on biofuel supply and emissions intensity, we simulate fuel production, emissions, and land use in the U.S. under ethanol subsidies, RFS, LCFS, CAT, and SUBs systems. The simulation model captures the key characteristics of the market for transportation fuels in a simple framework that enables us to iteratively solve for market outcomes under each policy. In the sections that follow we describe our simulation model, key assumptions, and data.

B.1   Simulation methodology and data

We limit our analysis to a transportation fuel market consisting of gasoline and ethanol fuels. Because ethanol, and to a lesser extent gasoline, are likely to have very different emissions characteristics based on the feedstocks and technologies used in fuel production, we define a unique fuel as the combination of feedstock and production technology leading to a finished transportation fuel. For example, gasoline, ethanol produced by fermentation of corn, and ethanol produced from

lignocellulosic forest biomass are considered distinct fuels.[1] It is worth noting that while our biofuel supply data focus on the U.S., other nations such as Brazil are likely to be important suppliers of biofuels in the future. Because we lack reliable data on these regions, we focus our analysis on domestic production.

We assume that on an energy basis these fuels are perfect substitutes and can be represented by a single demand equation for transportation fuel. This approach can be thought of as combining gasoline and ethanol fuels into a single blended fuel where the volume fraction of ethanol depends on the relative aggregate supply of each fuel. This simplification seems reasonable since modern gasoline vehicles can operate on blends containing up to, perhaps, 20% ethanol by volume and fuel economy, once adjusted for energy content, does not vary substantially for gasoline and ethanol fuels.[2]

B.2 Fuel demand

Baseline consumption of 140 billion gge per year is taken from the U.S. Department of Energy estimate for motor fuel consumption in 2022 U.S. Energy Information Administration (2010). This estimate includes the effect of policies such as the new Corporate Average Fuel Economy standards on future fuel consumption. We use a BAU retail price of $2.75 per gallon.[3] Because future fuel prices are uncertain, we rerun our simulations using high and low price scenarios with retail prices of $2.25 per gallon and $3.25 per gallon. To put these numbers in perspective, the mean retail U.S. average price for gasoline in 2005 dollars from 2005 - 2009 was approximately $2.45 per gallon with 25th and 75th percentiles of approximately $2.20 and $2.85 per gallon. Compared with recent prices, our base case BAU price is relatively high. However, this value is conservative in the sense that it favors higher BAU ethanol production and smaller changes in ethanol production and land use due to the adoption of carbon policy.

For our main analysis we assume that demand has constant elasticity, *i.e.*, $D(p) = Ap^{-\epsilon}$, where the elasticity ϵ is 0.5 and A is determined by the baseline consumption of 140 billion gge at a price of $2.75. In our sensitivity analysis, we solve for different As at fuel prices of $2.25 per gallon

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[1]Similarly, gasoline produced from light sweet crude and gasoline produced from tar sands would be considered distinct fuels. However, since the focus of this paper is on biofuel production, we limit our analysis to gasoline produced from conventional oil resources.

[2]One limitation of this approach is that it ignores any utility consumers have for fuels that have environmental benefits, i.e. "warm glow."

[3]We convert ethanol wholesale prices to retail prices by adding $0.63 per gge to the wholesale price. This figure, meant to capture fuel taxes and distribution costs, is taken from the average difference between retail and wholesale gasoline prices from 2000 to 2009.

and \$3.25 per gallon. This long-run elasticity of 0.5 is consistent with recent estimates from the literature, for example Small and Winston (1999). The long-run demand elasticity is meant to capture both the short-run (*e.g.*, driving less) and long-run (*e.g.*, purchasing a more fuel efficient vehicle) behavior of consumers in response to changes in the price of fuel. We test the sensitivity of our results to the demand elasticity assumption below.

B.3 Gasoline supply

We assume that gasoline supply is perfectly elastic in the long run. Gasoline supply is primarily limited by refinery capacity in the short-run. Since each policy studied here serves to reduce gasoline consumption, it is unlikely that capacity constraints will be important in the long run. Violations of this assumption would come from an upward sloping long run average cost curve. This could occur, for example, if the refinery locations vary in their quality in terms of either access to inputs or demand.

The assumption of perfectly elastic supply at \$2.75 per gallon (retail) means that gasoline is always the marginal fuel and the fuel price is always determined by the effects of the policies on the cost of gasoline production. Furthermore, the assumption of perfectly elastic supply implies that gasoline production is determined by the demand for transportation fuel and the total level of ethanol production as discussed previously.

Finally, we assume that real state and federal fuel excise taxes in 2022 are unchanged from today's levels and that no additional taxes are levied on transportation fuel. The net U.S. average state and federal gasoline tax is approximately \$0.48 per gallon. Taking the average difference between retail and wholesale prices of \$0.63 described above, implies distribution and retail costs (and, possibly, mark ups) of approximately \$0.15 per gallon. This approach assumes that gasoline and ethanol are treated the same on a energy equivalent basis. However, this assumption implies changes in the structure of fuel taxes to take the energy content of fuels into account.

B.4 Ethanol supply curves

We construct ethanol supply curves using cost estimates for biomass feedstocks, conversion, and ethanol distribution. We consider grain and lignocellulosic ethanol produced from: corn (grain); agricultural residues, such as rice straw and corn stover; orchard and vineyard waste; forest biomass, including waste and farmed trees; herbaceous energy crops, such as switchgrass; and municipal solid

waste.[4] Feedstock costs are based on county-level geographic information system (GIS) data on agricultural production in the United States. Conversion costs are based on engineering models for ethanol production facilities. Transportation costs are based on GIS data for existing truck, rail, and marine facilities.

These data are combined with a simplified model for the biofuel refining industry in a mixed integer linear optimization program. The industry is modeled as a set of competitive firms with perfect information. Firms choose plant location and plant size (output) to maximize profit conditional on the price of fuel, biomass resources, and transportation costs. The model explicitly accounts for the trade-off between economies of scale in the conversion of biomass to fuels and the feedstock collection costs. Supply curves are constructed by varying the price of fuel and calculating the profit maximizing level of biofuel production. Different prices correspond to different levels of plant production as well as different industry configurations in terms of the number, size and location of production facilities. Therefore, the supply curves represent estimates of long-run biofuel supply. The resulting supply curves are shown in Appendix Figure 1.

Biomass resource estimates are constructed as follows. National corn production and price projections Office of the Chief Economist, World Agricultural Outlook Board, United States Department of Agriculture (2010) are disaggregated to county level by assuming future production matches the historical geographic distribution of production National Agricultural Statistics Service (2009). Total corn ethanol production is constrained at 15 billion gallons per year in compliance with the RFS.

Herbaceous energy crop resource (switchgrass) estimates are take from Wullschleger et al. (2010). We assume that herbaceous energy crop production is limited to marginal land, defined as cropland that was idle or in pasture (not pastureland) in the 2007 Census of Agriculture National Agricultural Statistics Service (2009). In this case, our results can be interpreted as a lower bound on the projected land use changes. In reality, high energy prices may cause farmers to switch production of herbaceous energy crops to land previously used for other types of agriculture.

Sustainably removable quantities of agricultural residues − corn stover, wheat straw, orchard and vineyard prunings − are estimated based on historical yields, land areas, and production practices with binding constraints on wind erosion, water erosion and organic matter in the soil Graham et al. (2007); Nelson (2010). The cost of harvesting, storing and transporting agricultural residues comes from a feedstock logistics model developed by Idaho National Laboratory Idaho National Laboratory (2010).

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[4]Given that ethanol and gasoline are substitutes for low level ethanol blends, we focus on ethanol production pathways. Future work may explore implications of carbon policy on diesel and biodiesel supply.

Forest residue resource assessments are taken from Biomass Research and Development Board (2009). Production of biomass from farmed trees is modeled using pulpwood supply curves obtained from the U.S. Forest Service.[5] Finally, the municipal solid waste resource is estimated by projecting the organic fraction of municipal solid waste using state-level per capita waste production statistics Simmons et al. (2006) and the composition of wastes currently landfilled U.S. Environmental Protection Agency (2007). A fraction of the gross waste landfill is assumed to be available for fuels production. The cost of sorting waste biomass for use in an ethanol production facility is assumed to be $30/ton.

We model grain and cellulosic ethanol production technologies. The engineering economic models represent future technology costs in the year 2017. Given that new ethanol plants operating in 2022 will include a mix of facilities built both immediately prior to 2022 and a number of years before, 2017 seems a reasonable approximation for plant vintage.

For grain ethanol, both wet and dry-mill corn ethanol technology are considered. Production costs are taken from Gallagher, Brubaker, and Shapouri (2005); Gallagher and Shapouri (2005); Butzen and Hobbs (2002). All dry mill facilities are modeled with natural gas for process heat and dry distillers grains as a co-product. We assume conversion efficiencies of 2.8 gallons per bushel for dry mill facilities and 2.5 gallons per bushel for wet mill facilities. Existing ethanol plants are modeled with zero capital cost. The locations and capacities of existing plants are fixed Renewable Fuels Association (2009). Due to the relative cost of the technologies, all new facilities use dry mill technology.

The conversion of cellulosic feedstocks to ethanol uses a dilute acid enzymatic hydrolysis and fermentation technology. Cost and performance are taken from Wooley et al. (1999); Hamelinck, Hooijdonk, and Faaij (2005); Aden et al. (2002); McAloon et al. (2000). The technology cost and performance reflect *nth* of a kind facilities and represent significant advances from the current state of the industry. Conversion efficiencies are dependent on composition of the feedstock and range from 70 gallons per dry ton to 90 gallons per dry ton. For all technologies, capital cost are converted to levelized costs of conversion using a 20-year economic life and a 12.3% annual discount rate.

Finally, finished ethanol fuel is distributed to existing gasoline distribution terminals Oil Price Information Service (2007) in proportion to the fraction of national vehicle miles traveled (VMT) within each terminal service area Hu et al. (2007). Distribution costs are based on the highway distance between ethanol plants and gasoline distribution terminals.

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[5]Obtained via personal communication with Ken Skog at the USFS.

B.5 GHG emissions intensities

The distinguishing feature of biofuels, compared to other fuels, is the fact that growing plants remove carbon dioxide from the atmosphere. The combustion of fuel produced from biomass feedstocks releases this carbon back into the atmosphere, where in principle, a roughly equivalent quantity is absorbed by the next generation of biomass. Therefore, overall carbon emissions can be limited within this cycle. In practice however, the cultivation, collection, conversion, and distribution of biomass feedstock and ethanol fuel create additional carbon emissions. Unfortunately, for many developing technologies, production scale facilities do not currently exist. As a result, engineers rely on techniques of life-cycle analysis to estimate the average emissions characteristics of different ethanol pathways.

Life-cycle analysis assigns emissions factors to the various stages of ethanol production such as feedstock collection, conversion, and fuel combustion. Differences in emissions for fuel pathways arise from variation in ethanol yield and energy input requirements for alternate feedstocks and production processes. In addition to direct process emissions, the cultivation of biomass feedstocks may result in carbon emissions due to indirect land use changes. The emissions intensities used here are intended to capture both direct and indirect emissions.

Recent work Searchinger et al. (2008); California Air Resources Board (2009); Fargione et al. (2009) suggests that switching land to energy crop production emits large quantities of sequestered carbon. The argument is that increased biofuel consumption can lead to new land being put into production either directly, by growing energy crops, or indirectly by displacing other agricultural activity. Carbon sequestered in the soil and in existing vegetation is released into the atmosphere when the new land is cleared and tilled. While considerable uncertainties exist, one recent study estimated that accounting for these effects increases the emissions associated with corn and cellulosic ethanol production by 30 g/MJ and 18 g/MJ, respectively California Air Resources Board (2009). Effects of this magnitude represent increases of approximately 44% and 98% of model estimates for corn and cellulosic ethanol emissions excluding land use changes.[6]

Unfortunately, there is no single study or research group that provides estimates of life-cycle GHG emissions for all the fuels considered here and, as noted, for studies that overlap, there is substantial variation in the parameter values. Appendix Table 4 summarizes the life-cycle GHG estimates for various subsets of the ethanol fuels in this paper. The results are presented as normalized emissions intensities where the intensity of each ethanol fuel is divided by the emission

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[6]In the case of corn ethanol, indirect land use effects of this magnitude would result in CO_2e emissions exceeding those of conventional gasoline.

intensity of gasoline. This leads to a more intuitive interpretation. For example, a normalized intensity of 0.90 means that GHG emissions are 90% of GHG emissions of conventional gasoline.

Due to the considerable variability in these estimates, we adopt baseline values that fall conservatively in the range of those presented in Appendix Table 4. We construct a series of scenarios to gauge the sensitivity of our results to changes in these parameters. The base case emissions intensities and scenario parameters are presented in Appendix Table 5.

B.6 County-level surplus calculations

To understand the distributional impacts of transportation carbon policies across the U.S., we first estimate changes in consumer and producer surplus under each policy at the county level. To do this we calculate the change in producer surplus relative to BAU for corn ethanol, the seven cellulosic fuels, and gasoline for each county using the equilibrium producer fuel prices from our national model and our county-level ethanol supply curves. Because we lack detailed data on fuel consumption or driving at the county level, we assign changes in consumer surplus to counties based on population.[7] County-level surplus changes are then calculated as the difference in producer and consumer surplus changes under each policy. Because counties may be of substantially different size, we report changes per capita.

Our analysis of Congressional voting behavior requires aggregating the county-level surplus data to Congressional Districts. We assign counties to Congressional districts based on the 110th Congress.

Despite the concentration of agricultural activity in the U.S. Midwest, there is substantial variation in county-level gains and loses across policies. Appendix Figure 2 compares county-level gains under the RFS and CAT. Deviations for the dotted line identify the RFS and CAT gains parameters in Tables 4 through 8.

B.7 Numerical simulation algorithm

Given the theoretical framework described above, the equilibrium under each of the four policies could be solved analytically for continuous functional forms. However, our detailed ethanol supply curves are discontinuous, which necessitates a numerical simulation. The code for the calculations is available on the web. Here we briefly describe the algorithm.

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[7]Weights were derived based on population from the 2000 U.S. Census.

In the baseline case with no carbon policy, the fuel price is simply determined by the marginal cost of gasoline. Fuel demand is then found from the demand curve, and supply of each type of ethanol is determined by the ethanol supply curves. Gasoline production is simply the residual after subtracting total ethanol production from the quantity demanded.

For the case with ethanol subsidies, the calculation is quite similar except now supply of each type of ethanol is determined by Equation 1. As above, the price is determined by the marginal cost of gasoline.

The RFS simulation is somewhat more complicated since the fuel price is now determined by the optimality condition for gasoline in Equation 4 which in turn depends on the RIN prices. The equilibrium is calculated with a series of nested loops. Assuming the RFS ratios are exogenous, the algorithm begins with an arbitrary vector of RIN prices.[8] The supply of each type of ethanol can be calculated from Equation 3. Since the fuel price is determined by Equation 4, the fuel demand is determined and again gasoline fills the residual demand. However, given these prices, the cellulosic RIN price may not satisfy the RFS ratio for cellulosic ethanol. By raising the cellulosic RIN price if there is too little cellulosic ethanol and lowering it if there is too much cellulosic ethanol, the cellulosic RIN price can be adjusted so that the RFS ratio for cellulosic ethanol is exactly satisfied.[9] However, now the RFS ratio for advanced ethanol may not hold. By using a nested loop, the RIN prices can be adjusted so that both the cellulosic and advanced RFS ratios hold. Adding another nested loop ensures that all three RFS ratios hold.[10]

For the LCFS, for a given λ_{LCFS}, the fuel price is determined by Equation 6 for gasoline. With this price and λ_{LCFS}, the quantities of each ethanol and of gasoline can be calculated. However, the LCFS constraint in Equation 5 may not be satisfied. By looping over λ_{LCFS}, the LCFS equilibrium can be calculated.

Finally for carbon trading, the fuel price is determined for a given λ_{CAT} by Equation 8 for gasoline. The supply of each type of ethanol can then be determined by Equation 8 for each type of ethanol. As above, the carbon price can be increased if carbon emissions exceed the cap or can be decreased otherwise until Equation 7 holds with equality. This yields the carbon trading equilibrium.

To make the policies comparable, the LCFS standard and carbon cap are set so that they each

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[8] The code actually uses the equivalent shadow values as presented in Appendix A.1.

[9] Actually, the algorithm starts with upper and lower bounds for the price and then calculates new upper and lower bounds by evaluating the midpoint of the interval. Note that changing the cellulosic RIN price requires that all the equilibrium values be recalculated.

[10] We add three additional loops to ensure that the RFS ratios indeed hit the volumetric targets.

yield the same emissions reductions as the RFS.

C Robustness

In this section, we investigate the robustness of our results to changes in the preferred simulation parameters. In the following scenarios we vary; the baseline fuel price; the emissions intensities of corn and cellulosic ethanol; and the elasticity of fuel demand. We relax our assumptions that corn prices are not substantially affected by shifts in ethanol production and that gasoline supply is perfectly elastic. In addition, we present a cleaner test of voting behavior based on the Peterson amendment, robustness to excluding political ideology variables, sensitivity tests for our ethanol supply curves, reduced form relationships for underlying agricultural endowments and other industry interests as well as evidence of increasing returns to relative gains.

C.1 Gasoline price scenarios

The fuel price scenarios in Appendix Table 6 highlight the effect of our BAU fuel price assumption on equilibrium prices, average abatement costs, consumer and producer surplus changes. Because ethanol and gasoline are substitutes, we expect higher baseline levels of ethanol production during periods of high fuel prices. Therefore at higher BAU prices, the RFS results in lower changes in ethanol production and lower predicted emissions reductions. As a result, consumer and producer surplus changes as well as average abatement costs are lower with higher BAU fuel prices. Because the LCFS and CAT systems are designed to achieve the same reduction in emissions as the RFS, changes under these policies also decrease with higher baseline fuel prices.

Average abatement costs continue to vary substantially across policies. At \$2.25 per gallon, abatement costs under the RFS are more than three times those under CAT, while abatement costs under the LCFS are more than two times greater. Increasing the baseline fuel price to \$3.25 reduces average abatement costs for all of the policies, though the relative levels remain fairly constant. Abatement costs under the RFS and LCFS continue to be over two and a half times those of CAT.

Producer surplus gains to ethanol producers decreases with higher baseline fuel prices under the RFS, LCFS and CAT systems. However, the differences between gains under CAT and the alternatives remains large. Under subsidies, producer surplus gains increase with higher BAU fuel prices. Approximately half of this gain (\$3.79) goes to corn ethanol producers.

Because the difference in producer surplus gains between the RFS and CAT systems decreases with high baseline fuel prices, we re-estimate our empirical model with data from the high fuel price scenario. With high baseline fuel prices, gains to producers under the RFS fall from approximately $17 billion per year to approximately $12.5 billion per year. However, county-level gains under the alternatives to CAT are still large and concentrated. Appendix Table 7 shows points on the distribution of gains and loses under each of the policies. Under the RFS and subsidies, the top 5% of counties gain more than $953 and $2,076 per capita, respectively. No county loses more than $105 per capita. Under CAT, the top 5% of counties gain more than $146 per capita. No county gains more than $789. Correlations between gains, loses, voting behavior, and contributions are very similar to results using our preferred simulation parameters.

C.2 GHG emissions intensities scenarios

In our baseline simulation, we used emissions intensities for the different ethanol feedstocks that fall conservatively in the range of those presented in Appendix Table 4 and conduct a series of scenarios to gauge the sensitivity of our results to changes in these parameters. The base case emissions intensities and scenario parameters are presented in Appendix Table 5. The "High Indirect Land Use" scenario is meant to capture the case where emissions due to indirect land use changes are higher than initially estimated. "Waste Zero Emissions" captures the case where ethanol produced from waste biomass is assigned zero emissions.[11] Finally, the "Existing Corn" scenario represents the case where future corn ethanol technologies fail to realize fewer emissions than current technology.

Appendix Table 8 presents simulation results under the base case and the three emissions intensity scenarios. Fuel prices and production are unchanged under the RFS and subsidies as these policies do not take into account the carbon emissions characteristics of fuels. Similarly, producer and consumer surplus changes under the RFS and subsidies are unaffected by changes in emissions parameters. Under the LCFS and CAT systems, energy prices and consumer surplus loses decrease, and producer surplus gains increase, under the high indirect land use scenario. Producer surplus gains to ethanol producers are largest under the scenario where waste biomass is assigned an emissions intensity of zero.

Abatement costs also move in expected ways. Under the "High Indirect Land Use" and "Existing Corn" scenarios average abatement costs increase for the RFS and SUBs policies. This is because

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[11]Though in reality these feedstock may generate emissions, due to the uncertainty in estimating emissions policy makers may be inclined to give these fuels a "free pass."

the higher emissions intensities of fuels in these scenarios decreases the total emissions reduction under policies that don't take carbon production into account. The mechanism varies by policy, however. In the scenarios where emissions intensities increase, under the RFS and SUBs the change in private surplus from the regulations is unaltered, but abatement is reduced, leading to an increase in average abatement costs. Under the LCFS and CAT, there are two competing effects. For one, the required abatement under these policies is reduced since this is set by abatement under the RFS. Second, because the emission intensities of some fuels has increased, it is more costly to meet a given level of abatement. We find the first effect dominates, leading to an decrease in abatement costs. Under the "Waste Zero Emissions" scenario, the availability of "zero carbon" fuels results in lower average abatement costs in all scenarios. In all cases the relative abatement cost differences across policies remains large.

C.3 Fuel demand price elasticity scenarios

Appendix Table 9 presents simulation results for a range of price elasticities of gasoline demand. Our base case simulations use a price elasticity of -0.50. In addition, we simulate less elastic and more elastic demand with elasticities of -0.30 and -0.70, respectively. The land use estimates are very robust to changes in the demand elasticity. There are no changes in equilibrium outcomes under subsidies as fuel prices under the policy are unchanged. Under CAT, fuel price increases are smaller with more elastic demand. Fuel price changes under the RFS and LCFS are essentially unchanged across the scenarios. Under CAT, consumer surplus loses decrease substantially when demand is assumed to be more elastic. Surplus to gains to ethanol producers vary slightly depending on the assumed demand elasticity, though the large differences across policies remain. In particular, the large gains to corn ethanol producers under the RFS compared with CAT are essentially unchanged.

C.4 Corn price and gasoline supply elasticity scenarios

Corn represents a substantial fraction of the cost of producing corn ethanol, in our simulations approximately $2.00 per gasoline gallon equivalent. We set corn prices under the 2022 RFS to $3.64 per bushel, consistent with production of 10 billion gge per year of corn ethanol Office of the Chief Economist, World Agricultural Outlook Board, United States Department of Agriculture (2010). At these levels, corn used in ethanol production represents a substantial share of U.S. corn production. However, substantially less corn ethanol is produced under BAU and CAT. In these cases, we may expect lower prices reflecting a decreased demand for corn. To gauge the sensitivity of our results to endogenous changes in corn prices, we adjust our corn ethanol supply curve using

a elasticity of corn prices with respect to corn consumption for ethanol production of 0.12 (Gardner (2007)). Supply curves for corn ethanol with and without corn price effects are shown in Appendix Figure 3. The upper supply curve is our base case. The lower supply curve shows the adjustment to marginal costs from decreased corn prices at lower production levels. The horizontal line in Appendix Figure 3 shows the marginal cost of production plus the carbon charge under CAT. The intersection of the horizontal line with the supply curves gives the levels of ethanol production in each case. Because corn supply is relatively elastic, small shifts in prices result in large changes in corn ethanol production.

Appendix Table 10 shows the simulation results for each policy in the base case and accounting for corn price effects. Equilibrium outcomes are quite similar to the base case. Energy price increases are essentially unchanged under the RFS, LCFS and CAT policies when changes in corn prices are taken into account. Producer surplus gains for corn ethanol producers are slightly larger under all policies with endogenous corn prices. As a result, average abatement costs decrease modestly. However, the overall cost difference across policies remains large.

Our main simulation results assume gasoline supply is perfectly elastic. We relax this assumption here by running our simulation model assuming gasoline supply elasticities of 1 and 2. Appendix Table 11 shows equilibrium outcomes from this simulation. We see that consumer surplus is larger when gasoline supply is not perfectly elastic and producer surplus changes for ethanol producers remain large and positive. Average abatement costs remain substantially larger for the alternatives to CAT. We evaluate our assumption of perfectly elastic gasoline supply as related to estimated gains and voting behavior in section C.8 below.

C.5 Political economy

We investigate the robustness of our political economy results to changes in our simulation parameters. We focus on the specification used to predict the Senate vote, *i.e.* the model which includes gains and losses quartiles and indicators for Democrat and "Top 10 Coal State." For each column, we vary our simulation parameters according to the scenarios described above, re-run our simulations, and construct the Congressional district-level estimates for gains and losses under each policy in the same manner as before. Appendix Table 12 demonstrates that the correlations between surplus changes and voting behavior are remarkably robust to changes in our simulation parameters. The RFS quartiles estimate in particular have similar sign, magnitude and significance as those presented in Table 6.

C.6 Peterson amendment

As explained in Section 2, many representatives likely viewed WM and the RFS as substitutes. Thus predicting the votes on WM requires both the CAT and RFS surplus. However, WM did not explicitly repeal the RFS and hence the test is not perfectly clean.

To analyze a "cleaner" counterfactual, we utilize the controversy surrounding a change in rules requiring the measurement of indirect land use effects. This change was viewed as a significant threat to the RFS. As explained in Section 2, this controversy was resolved by an amendment proposed by Representative Peterson which delayed implementation of the measurement of indirect land use changes.

Unfortunately, we do not observe a vote on WM without the Peterson amendment. However, Peterson claimed that he had the support of the entire Agriculture Committee, which he chaired.[12] If we assume that all the Agriculture Committee Democrats would have voted against WM in the absence of Peterson's amendment, 17 votes would have switched and WM would not have passed. Nonetheless, we can still analyze this cleaner test noting that the votes are now measured with error.

The results are shown in Appendix Table 13 which replicates Table 5 but with the dependent variable changed for 17 Democrats. The results are even stronger than those in Table 5. Each of the coefficients is significant with the anticipated sign even when controlling for state fixed effects. Thus this "cleaner" test is more precisely predicted by our measures of estimated gains although the dependent variable is imprecisely measured.

C.7 Sensitivity to political variables

A highly significant variable in all the regressions of voting behavior is the political orientation of the member of Congress. This is not surprising. However, in terms of determining the causal impact of district level (net) benefits derived from regulation on voting behavior, it may not be a valid control variable as it may be driven by net benefits; i.e. districts will vote for candidates that are more likely to vote in their interests and also choose between party affiliation accordingly.[13]

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[12] "Peterson's bill that reins in the EPA has the backing of his committee's top Republican, Representative Frank Lucas of Oklahoma, all 29 Democrats on the committee, and by Monday, probably most of the Republicans. As of Friday his bill had support from a few other House Democrats, with 42 co-sponsors joining Peterson and Lucas in opposing the EPA. House Republicans are expected to vote as a block against the climate bill, anyway." (http://grist.org/article/2009-05-18-peterson-nuke-waxman1/)

[13] We thank an anonymous referee for pointing this out.

To show that our results are not dependent upon this control, we first exclude the political orientation variable and re-estimate the models in Table 5. Appendix Table 14 shows that excluding party affiliation does not qualitatively alter our results. Conditional on CAT gains, in models 2 and 3, higher RFS gains are associated with a lower likelihood of voting for WM. This is true even when state fixed effects are included. The magnitudes of these effects are similar, though somewhat larger than the effects in Table 5. Note that the DW nominate variable is already excluded from several specifications in the text and that our results in these cases are consistent with models which include this measure of political ideology.

Second, we explore whether benefits under each policy may be correlated with a Representative's party affiliation by regressing our Democratic Party dummy on the quartiles of gains under CAT and the RFS. Appendix Table 15 shows marginal effects from probit specifications similar to those shown above for voting behavior. We see in model 1 that districts with higher gains under CAT are less likely to be represented by a Democrat than districts in the first quartile. Adding in RFS gains, the effect shifts mainly to districts with larger RFS gains. These effects may reflect urban areas being associated with lower agricultural production and as a result lower gains under these policies.

C.8 Elastic gasoline supply

Our main analysis assumes that long run gasoline supply is perfectly elastic. This assumption seems quite reasonable since gasoline supply is primarily limited by refinery capacity in the short-run and each policy studied here serves to reduce gasoline consumption.

To investigate the sensitivity of our results to our assumption of perfectly elastic long-run gasoline supply we incorporate upward sloping gasoline supply into our model. This requires us to calculate the equilibrium fuel price since the fuel price is no longer pinned down by the marginal cost of supplying gasoline. This price is calculated by a series of loops which adjust the price until supply equals demand.

Although we expect the long-run gasoline supply elasticity to be quite large, Appendix Table 16 presents our main simulation results assuming a constant supply elasticity of 2. We see that fuel prices and emissions reductions are somewhat lower relative to our preferred model with perfectly elastic supply. However, the overall magnitudes and relative ordering of average abatement costs is comparable to Table 1.

To see whether upward sloping gasoline supply affects our results correlating voting on HR 2454 with district level gains and losses, we re-estimate model 1 from Table 6 using producer

and consumer surplus changes derived from our simulation with upward sloping gasoline supply. Appendix Table 17 shows the main results from our preferred simulation in column 1 and results assuming gasoline supply elasticities of 1 and 2 in columns 2-7. In columns 2 and 3 we allocate changes in gasoline producer surplus to Congressional districts based on population. In columns 4 and 6 we allocate gasoline producer surplus changes based on a Congressional district's share of refining capacity. We include these loses separately to more flexibly estimate the effect on voting. Because refining capacity doesn't vary across scenarios, we can include only the interaction with either RFS or CAT producer surplus changes. Whether we include loses under RFS or CAT doesn't affect the other parameter estimates. Finally, columns 5 and 7 replace the linear term for gasoline producer surplus changes with a dummy variable that is equal to one when a district's share of producer surplus loses exceed $500 million. In each of these checks, the estimated parameters are quite similar to our preferred model.

C.9 Sensitivity to ethanol supply assumptions

Since the ethanol supply curves are based on a complicated optimization model, it is useful to check that our results are not overly sensitive to the precise assumptions of the ethanol supply curves. We would like to compare our model's predictions with actual production levels. Unfortunately, cellulosic ethanol technology is currently under development and no large scale production facilities yet exist.

To demonstrate that our results are not overly sensitive to the particular supply modeling assumptions, we perform a sensitivity analysis where we alternately increase or decrease the cost of producing corn and cellulosic ethanol by +/- 20 percent. Appendix Table 18 repeats our analysis of voting on H.R. 2454 where we independently vary the costs of producing corn and cellulosic ethanol. The first column reproduces the results from Model 1 in Table 6 of the paper using our preferred supply curves. The middle columns vary cellulosic and corn ethanol costs. The final column, assumes actual costs of cellulosic ethanol are 20 percent below what our supply curves predict and costs for corn ethanol are 20 percent higher. In all cases, the results support our finding that Representatives from districts whose gains under the RFS are larger, conditional on CAT gains, are less likely to have voted from Waxman-Markey. With the exception of the scenario with 20 percent higher cellulosic ethanol costs, the estimates for the quartiles of RFS gains are all statistically significant. The magnitudes are similar to those using our preferred supply curves.

We also verified that the equilibrium outcomes shown in Table 1 are similar in each of the scenarios above. Appendix Table 19 below summarizes these results for the case with higher than

expected corn and lower than expected cellulosic ethanol costs. Again, these results are qualitatively similar to those using our preferred supply curves. The main difference comes from lower carbon emissions in the BAU scenario due to higher initial levels of cellulosic ethanol production (without policy) when costs are lower. This difference aside, energy prices, abatement costs and the relative differences across policies are similar to those reported in Table 1.

As a final check of our supply curves, we compare our predictions for county-level corn production with actual historical production. We focus on corn production rather than ethanol production because the latter is unobserved. If we regress county-level corn production in 2007 as measured by the USDA (the most recent year for which data are available) on the levels predicted by our supply curve at a fuel price comparable to 2007, the coefficient on predicted production is 0.97 and the r-squared of the regression is 0.72. This suggests that our corn supply curve captures both the size and spatial distribution of corn production reasonably well.

C.10 "Reduced form" probits from underlying endowments and sensitivity to additional controls

To increase the transparency of the main results, we report "reduced form" regressions of the underlying agricultural endowments (namely crop yields) directly on voting behavior. For agricultural suitability, we use estimates of yields for energy crops (HEC) and corn in tons per acre. Appendix Table 20 shows probit estimates of voting on H.R. 2454 where our measures of district level gains and loses are replaced with yields. For HEC, these yields are estimated. For corn, yields are based on average historical production. The first set of results assumes a linear relationship between yields and voting. Consistent with our main results, we see that corn yields are negatively associated with the likelihood of voting for WM. The middle column uses quartiles of crop yields and the final column adds state fixed effects. For corn, the first quartile contains only districts that grow no corn, i.e. yields are zero. Representatives from districts with positive corn yields are again less likely to vote in favor of WM, though the effect does not appear to increase with larger yields. There is little evidence of a relationship between HEC yields and voting. Overall, these results support our main findings that corn growing regions that benefit under the current RFS corn ethanol mandate are less likely to support the alternative CAT system created by WM.

We investigate the possibility that other interests apart from the agricultural sector we model may explain voting on WM. The robustness checks in Table 8 explore coal production and CO_2 emissions rates as additional control variables. Here we investigate automobile, agriculture and refinery industry interests, as well as population density. We use employment shares, calculated

as industry employment divided by total employment as proxies for auto, agricultural and refining interests. We measure employment share at the county level and use the average across counties for our district-level measure. The results of several specifications using these controls are shown in Appendix Table 21. The first column reproduces our main results from column 1 of Table 6. The middle column adds employment shares and the final column adds average population density, a proxy for the degree of urbanity of an area. We see that employment shares do not seem to explain voting on WM conditional on the other controls. The likelihood of supporting WM does appear higher in more densely populated areas. More importantly, in all cases our main results are robust to including these additional controls.

C.11   Evidence of increasing marginal effects

The finding of concentrated benefits and disperse costs is consistent with government failure. Finding evidence of increasing returns to net benefits helps fill in the mechanism by which the benefits affect voting. We explore this by including higher order terms to models 4 and 5 of Table 4. Appendix Table 22 shows the results of specifications that include the log of the ratio of RFS to CAT gains, as in Table 4, as well as squared and cubic terms. The columns marked model 4, include only the gain and party affiliation variables. The columns labeled as model 5 add state fixed effects. The top rows show the raw estimates from the probit estimation. The bottom row presents the average marginal effect for relative gains. Across these specifications, the average marginal effects of relative gains are similar to those reported in Table 4.

To get a sense of how the marginal effects of relative gains on voting vary over the sample when higher order terms are included, we calculate and plot the marginal effect as a function of ln(Benefits from CAT) - ln(Benefits from RFS). We focus on the model 4 specifications with quadratic and cubic gains terms, shown in Appendix Figures 5 and 6 Results adding state fixed effects, model 5, are quite similar.

Focusing on the quadratic model in Appendix Figure 5, the estimated probability of voting for WM is decreasing in relative gains below -1, though this decrease is not statistically significant. The probability of voting for WM is increasing in relative gains for values larger than -1 and is statistically significant. More importantly, the positive slope indicates the effect grows at an increasing rate consistent with increasing returns to relative gains.

Evidence from the cubic model in Appendix Figure 6 is somewhat less clear. The probability of voting for WM is decreasing in relative gains below approximately -0.5, though again is not statistically significant. The probability of voting for WM is increasing in relative gains for values

between -0.5 and 2.5. The rate at which relative gains affect voting behavior initially grows, then decreases for values larger than approximately 0.75.

We are cautious to place too much weight on this evidence given the relatively small number of observations at the extremes of small and large relative gains (as apparent in the relatively large confidence intervals in these regions). That said, the intermediate ranges where the marginal effects are more precisely estimated do appear to support increasing returns to relative gains.

C.12   Illustration of gains under the policies

Table 2 shows the summary statistics of the distribution of gains under the four policies and indicates that the gains are highly right skewed. Moreover we argue that the gains under the RFS are much more right skewed than the gains under CAT. This relative skewness can be illustrated with kernel densities.

Appendix Figures 7 and 8 illustrate kernel density estimates of the distribution of gains under the four policies. In Appendix Figure 7, we truncate the distribution at gains of $500 to improve the presentation of the overall distributions. For CAT, loses among those counties negatively affected are smaller relative to the other policies. However, gains are also smaller. The distributions of gains and loses under the RFS, LCFS and SUBS are quite similar, each with a long right tail. To better see this, Appendix Figure 8 focuses on the right tail by plotting the distribution for gains between $100 and $1000 per capita. For each alternative to CAT, the density of counties with positive gains is larger including cases where gains approach $1000 per capita. This illustrates that the distribution of gains under the RFS is much more highly right skewed than under the CAT gains.

Appendix Figures

Appendix Figure 1: Ethanol supply curves for corn based and cellulosic ethanol.
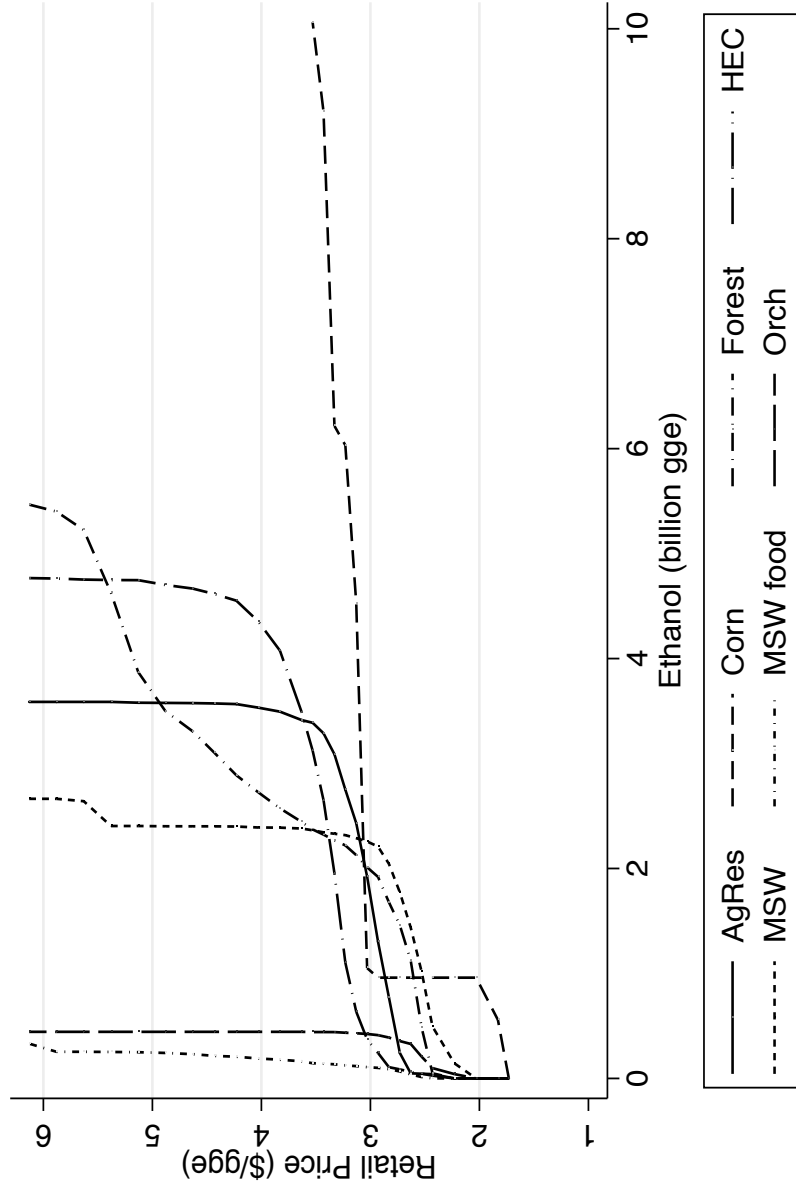
Appendix Figure 2: Comparison of net district-level gains from CAT and from the RFS.
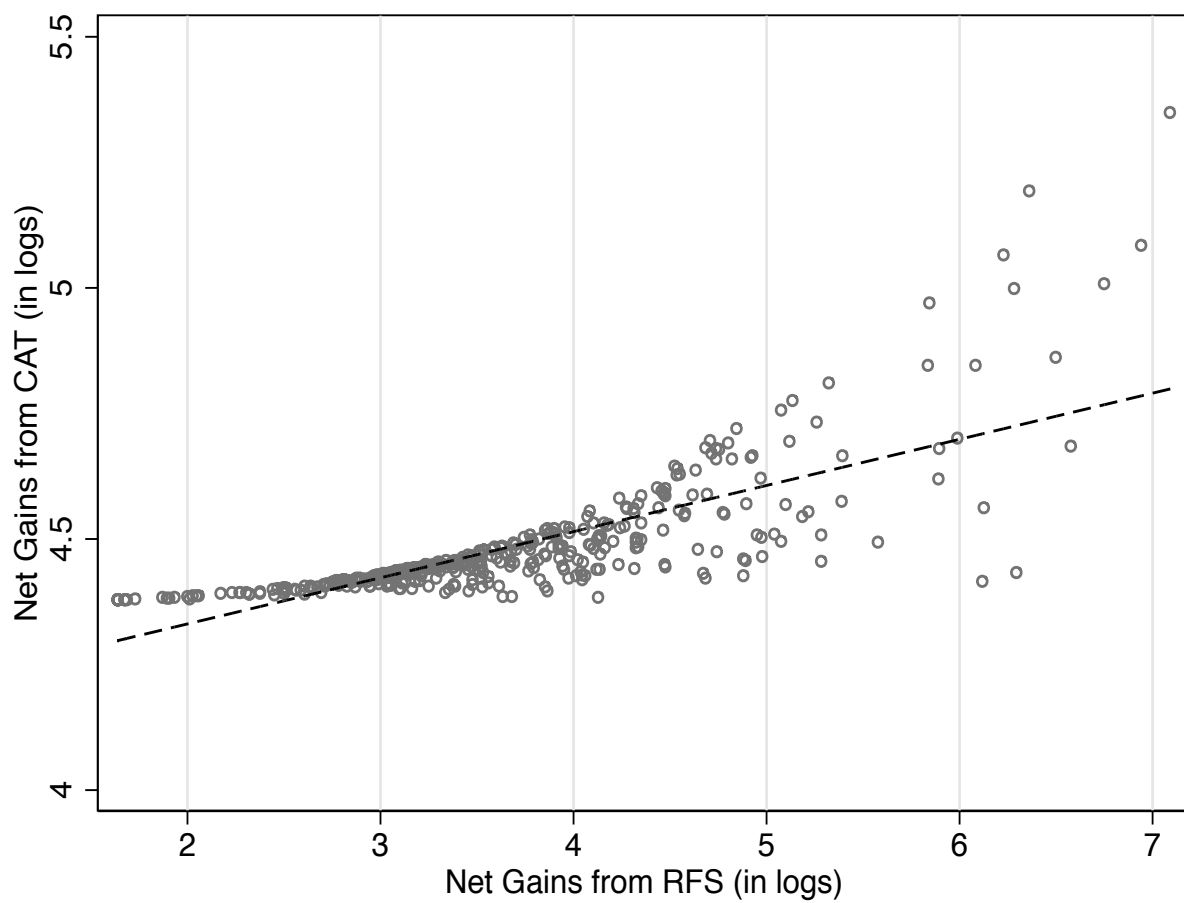
Appendix Figure 3: Corn ethanol supply curves with and without corn price effects.
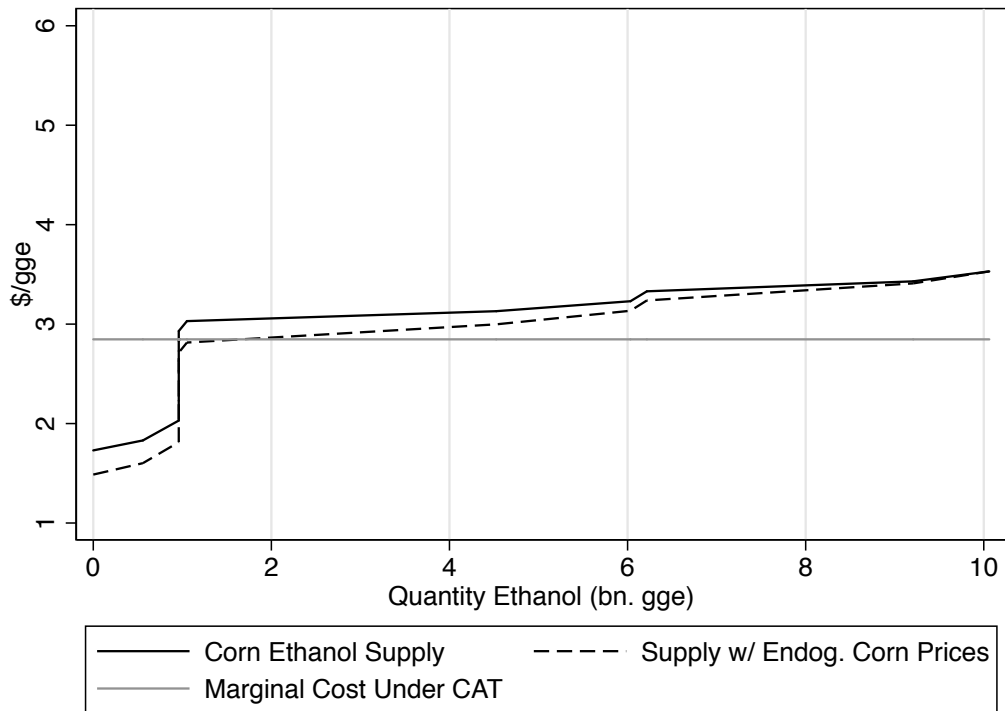
Appendix Figure 4: Scatter plot of RFS gains versus RFS + \$25 CO_2 price gains.
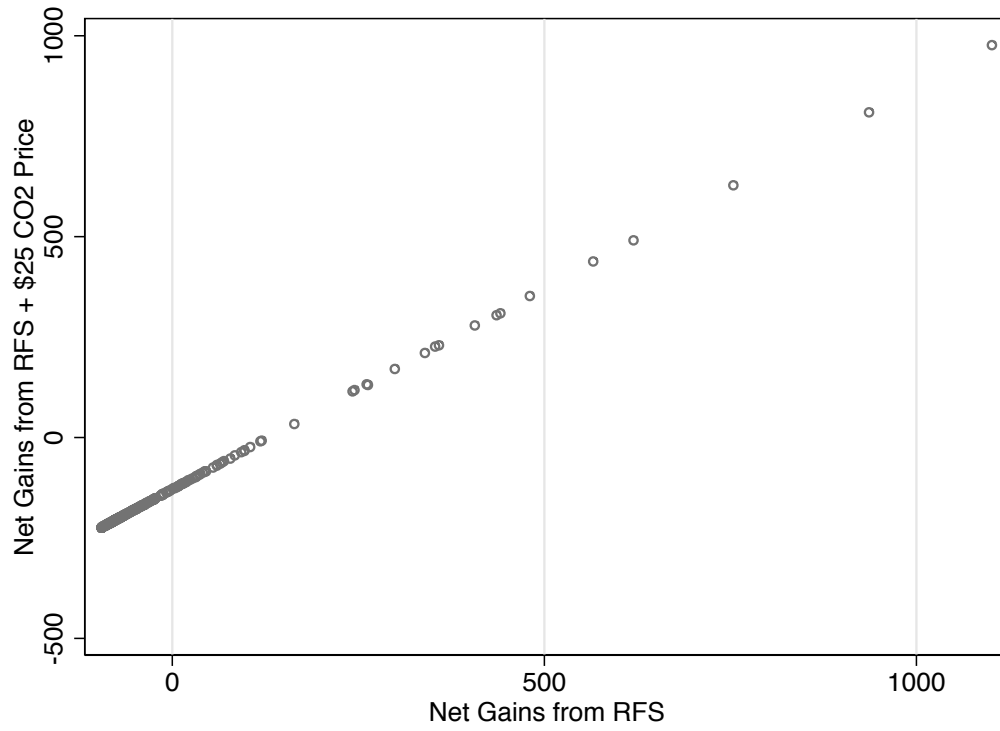
Appendix Figure 5: Increasing marginal effects of voting for WM in relative gains: Quadratic
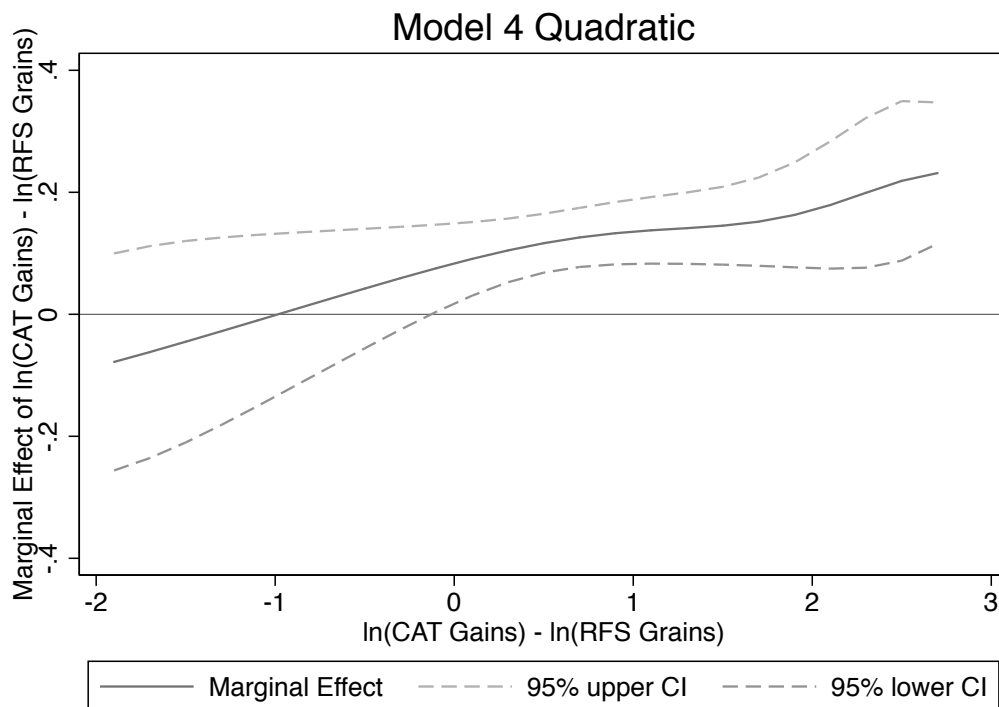
Appendix Figure 6: Increasing marginal effects of voting for WM in relative gains: Cubic
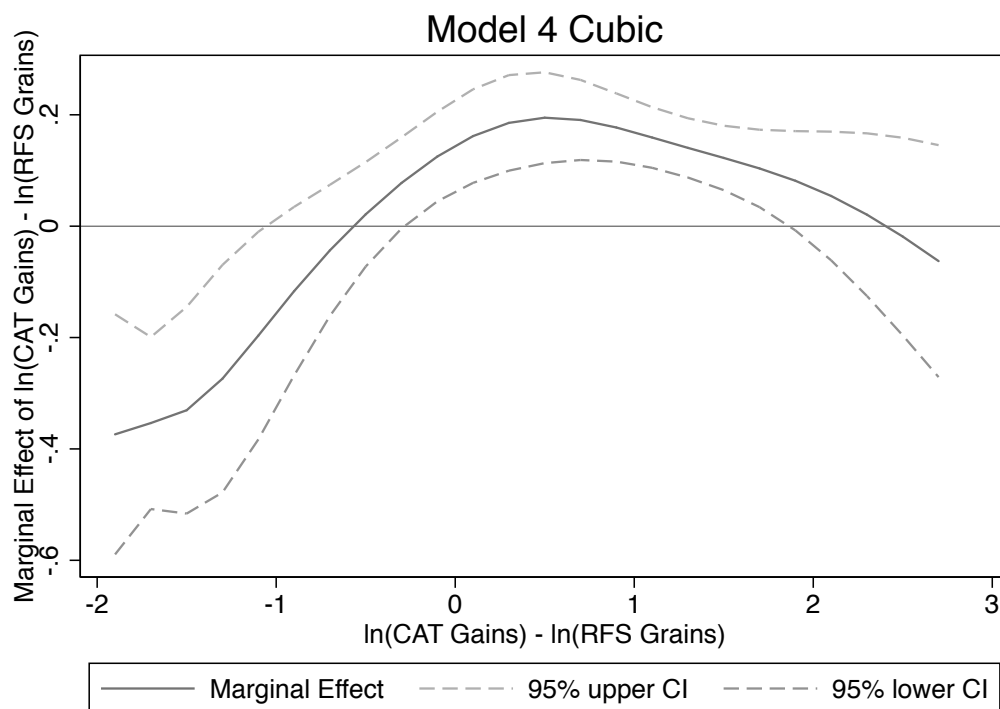
Appendix Figure 7: Kernel density of gains under the four policies for gains less than $500

Distributions of County-Level Gains
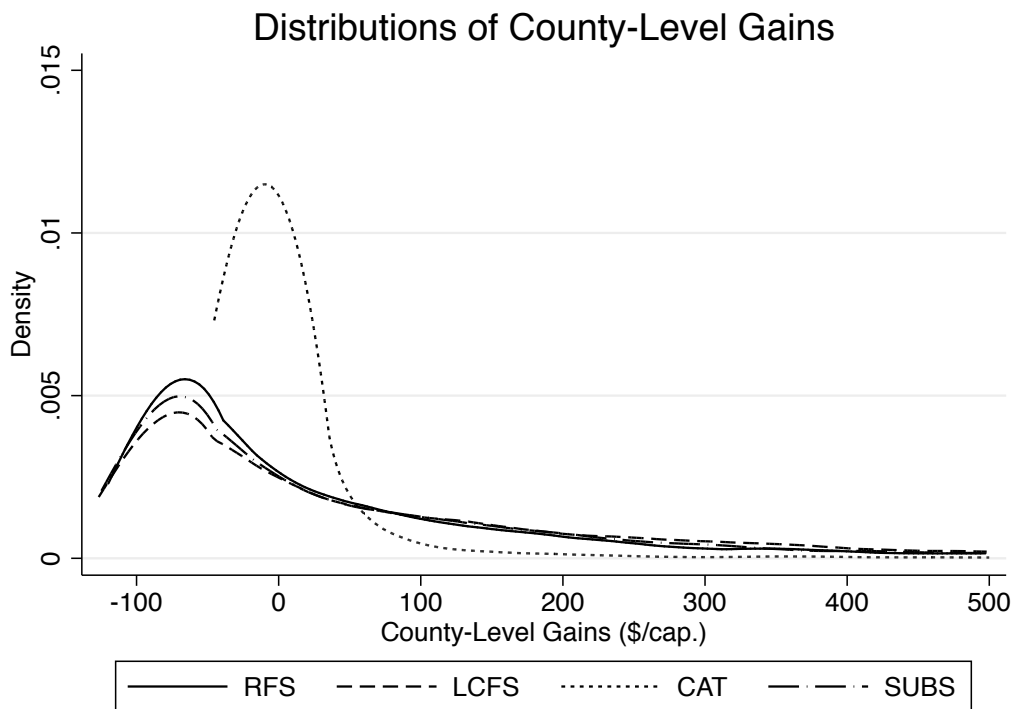
Appendix Figure 8: Kernel density of gains under the four policies for gains greater than $100
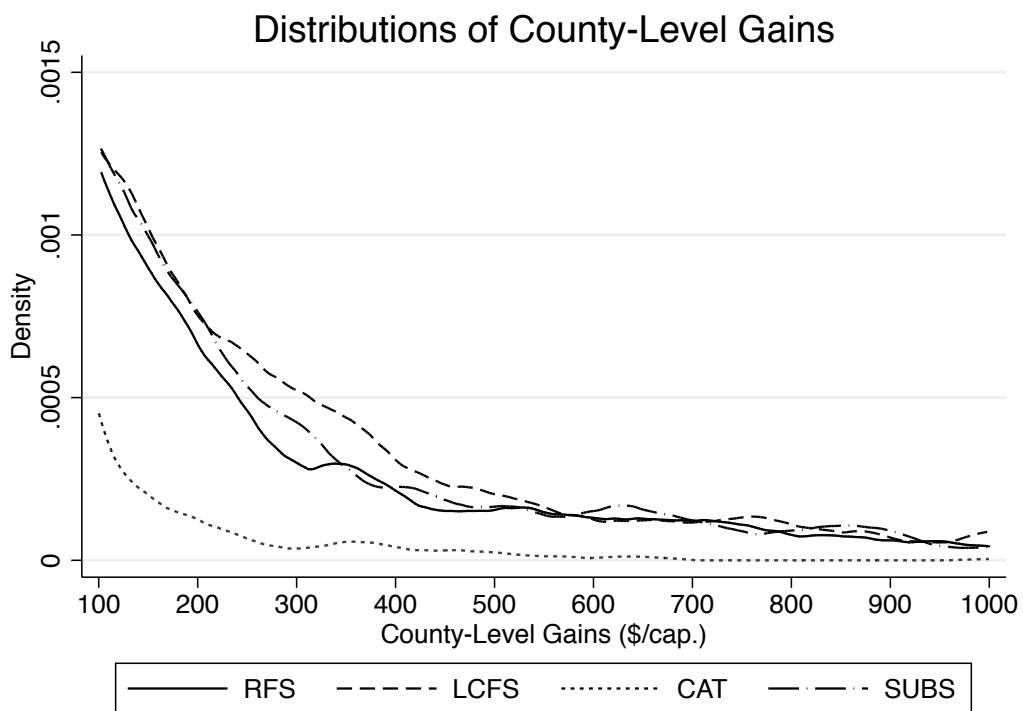
Appendix Tables

Appendix Table 1: Federal Renewable Fuel Standard for 2010, 2015 and 2022.

	2010	2015	2022
Cellulosic (bn. gal./year)	0.1	5.5	16
Advanced (bn. gal./year)	1	3	21
Total Renewable Fuel (bn. gal./year)	12	20.5	36

Appendix Table 2: Externality estimates from the Interagency Working Group on Social Cost of Carbon (2010).

	Discount Rate			
	5%	3%	2.5%	3%
Year	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.8	90.9
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Appendix Table 3: Equilibrium outcomes under alternate policies with a $25 CO_2 price

	BAU	RFS+WM	LCFS+WM	WM	SUBS+WM
Fuel Price ($/gge)	$2.75	$3.22	$3.24	$3.05	$3.05
Fuel Quantity (bn. gge)	140	129.37	129.06	133.01	133.01
Gasoline Quantity (bn. gge)	134.84	105.7	108.97	125.36	108.78
Ethanol Quantity (bn. gge)	5.16	23.67	20.09	7.65	24.23
Corn Ethanol	0.96	9.86	5.60	0.96	9.75
Herb. Energy Crops	0.09	4.43	4.62	0.30	4.64
Waste Feedstocks	4.11	9.38	9.87	6.39	9.84
Emissions (MMTCO$_2$e)	1619	-14.6%	-14.6%	-6.6%	-12.3%
ΔCS ($ bn.)		-$63.26	-$65.29	-$40.47	-$40.47
ΔPS ($ bn.)		$17.15	$20.62	$1.36	$22.78
ΔPS Corn Ethanol ($ bn.)		$3.19	$0.91	$0.06	$3.07
Carbon Market Revenue ($ bn.)		$34.60	$34.60	$37.82	$35.50
Subsidy Payments ($ bn.)					$28.91
Carbon Permit Price ($/MTCO2e)			$165.12	$25.00	
Abatement Cost ($ bn.)		-$11.53	-$10.09	-$1.29	-$11.09
Avg. Abatement Cost ($/MTCO$_2$e)		$48.89	$42.79	$12.16	$55.83

Appendix Table 4: Lifecycle GHG emission estimates for corn and cellulosic ethanol pathways.

	CARB (2009)	EPA (2010)	Zhang et al. (2010)	Kalogo et al. (2007)	Spatari et al. (2005)
Corn	0.91 to 1.04	0.79	1.04		
Herb. Energy Crops		-0.10			0.24
Waste Biomass					
Ag. Residues		-0.29	-0.09 to 0.16		0.16
Orchard and Vineyard	0.02 to 0.22				
Forest			-0.06 to 0.19		
Muni. Solid Waste			0.042	0.16 to 0.35	

Appendix Table 5: Baseline emissions intensities and emissions scenario parameters.

	Base Case	High Indirect Land use	Waste Zero Emissions	Existing Corn
Corn	0.80	1.00	0.80	0.90
Herb. Energy Crops	0.25	0.40	0.25	0.25
Waste Biomass	0.20	0.20	0.00	0.20

Notes: Emission intensities are relative to gasoline.

Appendix Table 6: Equilibrium outcomes under carbon policies for three fuel price scenarios.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)					
Low Fuel Price: $2.25	$ 2.25	$ 2.54	$ 2.57	$ 2.92	$ 2.25
Base Case: $2.75	$ 2.75	$ 2.94	$ 2.96	$ 3.23	$ 2.75
High Fuel Price: $3.25	$ 3.25	$ 3.35	$ 3.36	$ 3.49	$ 3.25
ΔCS ($ bn.)					
Low Fuel Price: $2.25		-$39.23	-$43.14	-$87.86	$0.00
Base Case: $2.75		-$26.69	-$28.59	-$65.07	$0.00
High Fuel Price: $3.25		-$14.52	-$14.63	-$33.18	$0.00
ΔPS Ethanol ($ bn.)					
Low Fuel Price: $2.25		$18.48	$27.96	$1.18	$11.11
Base Case: $2.75		$17.12	$20.56	$2.49	$18.89
High Fuel Price: $3.25		$12.53	$12.65	$2.26	$26.53
ΔPS Corn Ethanol ($ bn.)					
Low Fuel Price: $2.25		$3.67	$0.67	$0.13	$0.66
Base Case: $2.75		$3.19	$0.91	$0.09	$2.50
High Fuel Price: $3.25		$1.99	$1.71	$0.30	$6.29
Avg. Abatement Cost ($/MTCO$_2$e)					
Low Fuel Price: $2.25		$84.79	$62.08	$27.78	$79.95
Base Case: $2.75		$57.90	$48.58	$19.52	$82.30
High Fuel Price: $3.25		$25.92	$25.65	$9.85	$50.60

Appendix Table 7: Points in the distribution of net gains and losses from the different policies with baseline fuel price of $3.25 per gallon.

	CAT	LCFS	RFS	SUBS
Mean	$21.82	$150.18	$151.47	$339.58
Percentage>0	42%	52%	51%	52%
Minimum	-$10.71	-$51.97	-$51.61	-$105.13
25th Percentile	-$8.73	-$34.17	-$34.34	-$67.17
Median	-$1.97	$10.56	$9.10	$28.10
75th Percentile	$17.20	$128.07	$122.98	$276.93
90th Percentile	$61.98	$484.72	$496.12	$1,085.57
95th Percentile	$146.32	$937.57	$952.96	$2,076.31
Maximum	$788.92	$4,707.69	$5,019.16	$12,328.45

Appendix Table 8: Equilibrium outcomes under carbon policies for different emissions intensity scenarios.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)					
Base Case	$ 2.75	$ 2.94	$ 2.96	$ 3.23	$ 2.75
High Indirect Land use	$ 2.75	$ 2.94	$ 2.93	$ 3.15	$ 2.75
Waste Zero Emissions	$ 2.75	$ 2.94	$ 2.96	$ 3.23	$ 2.75
Existing Corn	$ 2.75	$ 2.94	$ 2.95	$ 3.20	$ 2.75
ΔCS ($ bn.)					
Base Case		-$26.69	-$28.59	-$65.07	$0.00
High Indirect Land use		-$26.69	-$24.30	-$53.46	$0.00
Waste Zero Emissions		-$26.69	-$28.54	-$64.82	$0.00
Existing Corn		-$26.69	-$28.11	-$60.56	$0.00
ΔPS Ethanol ($ bn.)					
Base Case		$17.12	$20.56	$2.49	$18.89
High Indirect Land use		$17.12	$18.27	$1.83	$18.89
Waste Zero Emissions		$17.12	$20.74	$3.22	$18.89
Existing Corn		$17.12	$21.43	$2.22	$18.89
ΔPS Corn Ethanol ($ bn.)					
Base Case		$3.19	$0.91	$0.09	$2.50
High Indirect Land use		$3.19	$0.00	$0.00	$2.50
Waste Zero Emissions		$3.19	$0.60	$0.09	$2.50
Existing Corn		$3.19	$0.23	$0.04	$2.50
Avg. Abatement Cost ($/MTCO$_2$e)					
Base Case		$57.90	$48.58	$19.52	$82.30
High Indirect Land use		$70.15	$44.24	$15.97	$109.49
Waste Zero Emissions		$53.84	$43.90	$19.09	$73.73
Existing Corn		$61.86	$43.14	$18.17	$90.28

Appendix Table 9: Equilibrium outcomes under carbon policies for different demand elasticity scenarios.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)					
Less Elastic: Elast. = -0.30	$ 2.75	$ 2.94	$ 2.96	$ 3.37	$ 2.75
Base Case: Elast. = -0.50	$ 2.75	$ 2.94	$ 2.96	$ 3.23	$ 2.75
More Elastic: Elast. = -0.70	$ 2.75	$ 2.95	$ 2.96	$ 3.17	$ 2.75
ΔCS ($ bn.)					
Less Elastic: Elast. = -0.30		-$26.51	-$29.04	-$84.19	$0.00
Base Case: Elast. = -0.50		-$26.69	-$28.59	-$65.07	$0.00
More Elastic: Elast. = -0.70		-$26.88	-$28.40	-$55.64	$0.00
ΔPS Ethanol ($ bn.)					
Less Elastic: Elast. = -0.30		$17.12	$21.08	$3.44	$18.89
Base Case: Elast. = -0.50		$17.12	$20.56	$2.49	$18.89
More Elastic: Elast. = -0.70		$17.12	$20.25	$2.07	$18.89
ΔPS Corn Ethanol ($ bn.)					
Less Elastic: Elast. = -0.30		$3.19	$0.95	$0.12	$2.50
Base Case: Elast. = -0.50		$3.19	$0.91	$0.09	$2.50
More Elastic: Elast. = -0.70		$3.19	$0.88	$0.08	$2.50
Avg. Abatement Cost ($/MTCO$_2$e)					
Less Elastic: Elast. = -0.30		$65.64	$55.78	$24.78	$82.30
Base Case: Elast. = -0.50		$57.90	$48.58	$19.52	$82.30
More Elastic: Elast. = -0.70		$51.90	$43.31	$16.87	$82.30

Appendix Table 10: Equilibrium outcomes under carbon policies incorporating corn price effects.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)					
Base Case	$ 2.75	$ 2.94	$ 2.96	$ 3.23	$ 2.75
Endogenous Corn Prices	$ 2.75	$ 2.94	$ 2.95	$ 3.23	$ 2.75
ΔCS ($ bn.)					
Base Case		-$26.69	-$28.59	-$65.07	$0.00
Endogenous Corn Prices		-$26.64	-$28.14	-$64.31	$0.00
ΔPS Ethanol ($ bn.)					
Base Case		$17.12	$20.56	$2.49	$18.89
Endogenous Corn Prices		$18.06	$20.76	$2.47	$19.87
ΔPS Corn Ethanol ($ bn.)					
Base Case		$3.19	$0.91	$0.09	$2.50
Endogenous Corn Prices		$4.14	$1.64	$0.11	$3.49
Avg. Abatement Cost ($/MTCO$_2$e)					
Base Case		$57.90	$48.58	$19.52	$82.30
Endogenous Corn Prices		$51.97	$44.68	$19.42	$74.16

Notes: The base case and ethanol supply reflect corn price effects.

Appendix Table 11: Equilibrium outcomes under carbon policies for different gasoline supply elasticities.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)					
Base Case	$ 2.75	$ 2.94	$ 2.96	$ 3.23	$ 2.75
Gas Supply Elast. = 2.0		$ 2.75	$ 2.77	$ 2.81	$ 3.08
Gas Supply Elast. = 1.0		$ 2.75	$ 2.66	$ 2.73	$ 2.98
ΔCS ($ bn.)					
Base Case		-$26.69	-$28.59	-$65.07	$0.00
Gas Supply Elast. = 2.0		-$2.92	-$8.30	-$45.15	$17.31
Gas Supply Elast. = 1.0		$12.74	$3.49	-$31.75	$27.53
ΔPS Ethanol ($ bn.)					
Base Case		$17.12	$20.56	$2.49	$18.89
Gas Supply Elast. = 2.0		$17.12	$19.07	$1.33	$16.25
Gas Supply Elast. = 1.0		$17.12	$14.80	$0.71	$14.83
ΔPS Corn Ethanol ($ bn.)					
Base Case		$3.19	$0.91	$0.09	$2.50
Gas Supply Elast. = 2.0		$3.19	$0.37	-$0.02	$1.58
Gas Supply Elast. = 1.0		$3.19	$0.21	-$0.07	$1.15
Avg. Abatement Cost ($/MTCO$_2$e)					
Base Case		$57.90	$48.58	$19.52	$82.30
Gas Supply Elast. = 2.0		$95.10	$62.68	$18.07	$122.50
Gas Supply Elast. = 1.0		$145.51	$71.09	$15.81	$208.04

Notes: The base case has perfectly elastic gasoline supply. The scenarios have supply elasticities of 2.0 and 1.0.

Appendix Table 12: Correlating voting behavior for Waxman–Markey with estimated gains and losses, coal production, and political ideology: Robustness to changes in simulation parameters.

	High Price	Low Price	High iLUC	Waste Pass	Old Corn	Less Elastic	More Elastic	Endog. Corn	Gas Elast.=1	Gas Elast.=2
Democrat	0.741***	0.739***	0.755***	0.754***	0.752***	0.753***	0.754***	0.755***	0.752***	0.753***
	(0.031)	(0.032)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.030)	(0.031)	(0.031)
Per Capita Benefits from Cap & Trade, Quartile 2	-0.09	0.097***	0.046	0.041	0.045	0.037	0.041	0.057	-0.004	0.038
	(0.087)	(0.037)	(0.042)	(0.044)	(0.042)	(0.045)	(0.042)	(0.043)	(0.042)	(0.042)
Per Capita Benefits from Cap & Trade, Quartile 3	0.126	0.139***	0.102**	0.144***	0.105**	0.158***	0.109**	0.117**	0.074*	0.082*
	(0.108)	(0.041)	(0.043)	(0.047)	(0.045)	(0.048)	(0.044)	(0.046)	(0.043)	(0.043)
Per Capita Benefits from Cap & Trade, Quartile 4	0.144	0.135***	0.051	0.106*	0.063	0.096	0.047	0.081	0.023	0.031
	(0.117)	(0.044)	(0.054)	(0.060)	(0.056)	(0.062)	(0.055)	(0.057)	(0.046)	(0.050)
Per Capita Benefits from RFS, Quartile 2	-0.041	-0.173***	-0.176***	-0.188***	-0.175***	-0.187***	-0.176***	-0.186***	-0.168***	-0.167***
	(0.083)	(0.047)	(0.049)	(0.052)	(0.049)	(0.052)	(0.049)	(0.051)	(0.049)	(0.049)
Per Capita Benefits from RFS, Quartile 3	-0.308**	-0.210***	-0.220***	-0.279***	-0.232***	-0.289***	-0.226***	-0.230***	-0.192***	-0.201***
	(0.134)	(0.053)	(0.060)	(0.064)	(0.061)	(0.064)	(0.060)	(0.061)	(0.056)	(0.059)
Per Capita Benefits from RFS, Quartile 4	-0.497***	-0.370***	-0.368***	-0.438***	-0.381***	-0.430***	-0.366***	-0.405***	-0.345***	-0.346***
	(0.115)	(0.052)	(0.067)	(0.068)	(0.070)	(0.072)	(0.070)	(0.067)	(0.058)	(0.065)
Top 10 Coal Producing State	-0.061*	-0.079**	-0.069*	-0.068*	-0.069*	-0.067*	-0.071**	-0.070*	-0.067*	-0.070*
	(0.035)	(0.037)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)
State Fixed Effects	No	No	No	No	No	No	No	No	No	No
Observations	431	431	431	431	431	431	431	431	431	431
Chi-Square Statistic	362.01	359.17	354.79	359.42	354.81	361.79	355.68	357.70	353.56	353.20
P-Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Log-Likelihood	-117.69	-119.10	-121.30	-118.98	-121.29	-117.79	-120.85	-119.84	-121.91	-122.09
Pseudo-R2/R2	0.61	0.60	0.59	0.60	0.59	0.61	0.60	0.60	0.59	0.59

Notes: The dependent variable equals one if the House member voted for H.R. 2454. The reported coefficients are the average of marginal coefficients taken at each observations level of the righthand side variables. For indicator variables, the coefficient represents the average change in the probability of voting yes from changing the indicator from zero to one. The Per Capita Benefits from Cap & Trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap & trade program that reduces GHG emissions by 10 percent. Per Capita Benefits from RFS quartile indicators are the quartiles of the average per capita benefits across the district from the current federal RFS program in 2022. We simulate that this leads to a 10 percent reduction in GHG emissions. ***, **, and * denotes statistical significance at the 1, 5, and 10 percent levels, respectively. Standard errors are in parentheses.

Appendix Table 13: Probit model correlating voting behavior for Waxman Markey with estimated gains and losses: Peterson amendment adjustment.

	Model 1	Model 2	Model 3
Democrat	0.716***	0.690***	0.665***
	(0.031)	(0.032)	(0.036)
Per Capita Benefits from Cap & Trade, Quartile 2	-0.0140	0.099**	0.131**
	(0.045)	(0.045)	(0.052)
Per Capita Benefits from Cap & Trade, Quartile 3	-0.0010	0.191***	0.191***
	(0.045)	(0.047)	(0.058)
Per Capita Benefits from Cap & Trade, Quartile 4	-0.213***	0.142***	0.143**
	(0.051)	(0.055)	(0.064)
Per Capita Benefits from RFS, Quartile 2		-0.250***	-0.236***
		(0.044)	(0.049)
Per Capita Benefits from RFS, Quartile 3		-0.318***	-0.320***
		(0.051)	(0.058)
Per Capita Benefits from RFS, Quartile 4		-0.497***	-0.494***
		(0.047)	(0.054)
State Fixed Effects	No	No	Yes
Observations	431	431	396
Chi-Square Statistic	284	337	335
P-Value	0.000	0.000	0.000
Log-Likelihood	-156.35	-129.84	-106.79
Pseudo-R2	0.48	0.56	0.61

Notes: The dependent variable equals one if the House member voted for H.R. 2454 *and* if the member is *not* a Democrat on the Agriculture Committee which Peterson chaired.

Appendix Table 14: Probit model correlating voting behavior for Waxman Markey with estimated gains and losses: No political party controls.

	Model 1	Model 2	Model 3
Per Capita Benefits from Cap & Trade, Quartile 2	-0.146**	-0.0180	0.1270
	(0.061)	(0.071)	(0.077)
Per Capita Benefits from Cap & Trade, Quartile 3	-0.210***	0.0560	0.1480
	(0.059)	(0.082)	(0.090)
Per Capita Benefits from Cap & Trade, Quartile 4	-0.335***	0.0740	0.165*
	(0.056)	(0.096)	(0.095)
Per Capita Benefits from RFS, Quartile 2		-0.224***	-0.208***
		(0.061)	(0.063)
Per Capita Benefits from RFS, Quartile 3		-0.353***	-0.341***
		(0.061)	(0.068)
Per Capita Benefits from RFS, Quartile 4		-0.475***	-0.453***
		(0.061)	(0.073)
State Fixed Effects	No	No	Yes
Observations	431	431	394
Chi-Square Statistic	28	57	106
P-Value	0.000	0.000	0.000
Log-Likelihood	-284.49	-270.19	-219.89
Pseudo-R2	0.05	0.10	0.19

Notes: The dependent variable equals one if the House member voted for H.R. 2454.

Appendix Table 15: Probit model correlating party affiliation with estimated gains and losses.

	Model 1	Model 2	Model 3
Per Capita Benefits from Cap & Trade, Quartile 2	-0.166***	-0.1080	0.0130
	(0.064)	(0.073)	(0.083)
Per Capita Benefits from Cap & Trade, Quartile 3	-0.251***	-0.1150	-0.0210
	(0.062)	(0.088)	(0.102)
Per Capita Benefits from Cap & Trade, Quartile 4	-0.220***	-0.0180	0.0890
	(0.063)	(0.106)	(0.114)
Per Capita Benefits from RFS, Quartile 2		-0.0990	-0.0710
		(0.076)	(0.079)
Per Capita Benefits from RFS, Quartile 3		-0.209**	-0.1550
		(0.086)	(0.097)
Per Capita Benefits from RFS, Quartile 4		-0.252**	-0.222*
		(0.099)	(0.115)
State Fixed Effects	No	No	Yes
Observations	434	434	399
Chi-Square Statistic	17	24	67
P-Value	0.001	0.001	0.009
Log-Likelihood	-285.70	-282.27	-237.63
Pseudo-R2	0.03	0.04	0.12

Notes: The dependent variable equals one if the House member is a Democrat.

Appendix Table 16: Equilibrium outcomes under alternate policies with elastic gasoline supply.

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)	$2.75	$2.77	$2.81	$3.08	$2.63
Fuel Quantity (bn. gge)	140	139.47	138.51	132.25	143.22
Gasoline Quantity (bn. gge)	134.84	115.8	121.38	124.55	123.12
Ethanol Quantity (bn. gge)	5.16	23.67	17.13	7.70	20.10
Corn Ethanol	0.96	9.86	2.74	0.96	6.18
Herb. Energy Crops	0.09	4.43	4.60	0.30	4.49
Waste Feedstocks	4.11	9.37	9.80	6.44	9.43
Emissions (MMTCO$_2$e)	1619	-7.2%	-7.2%	-7.2%	-3.9%
ΔCS ($ bn.)		-$2.92	-$8.30	-$45.15	$17.31
ΔPS ($ bn.)		-$8.11	$1.03	-$12.55	$0.49
ΔPS Corn Ethanol ($ bn.)		$3.19	$0.37	-$0.02	$1.58
Carbon Market Revenue ($ bn.)				$55.61	
Subsidy Payments ($ bn.)					$25.61
Carbon Permit Price ($/MTCO2e)			$197.78	$37.00	
Abatement Cost ($ bn.)		-$11.03	-$7.27	-$2.09	-$7.82
Avg. Abatement Cost ($/MTCO$_2$e)		$95.10	$62.68	$18.07	$122.50

Notes: Gasoline supply is assumed to have constant elasticity of 2.

Appendix Table 17: Probits with elastic gasoline supply.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Base Model	Gas Elast. = 1	Gas Elast. = 2	Gas Elast. = 1	Gas Elast. = 2	Gas Elast. = 1	Gas Elast. = 2
Democrat	0.752***	0.752***	0.753***	0.750***	0.752***	0.751***	0.753***
	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)
Per Capita Benefits from Cap & Trade, Quartile 2	0.043	-0.004	0.038	0.008	0.002	0.045	0.042
	(0.042)	(0.042)	(0.042)	(0.042)	(0.042)	(0.041)	(0.041)
Per Capita Benefits from Cap & Trade, Quartile 3	0.106**	0.074*	0.082*	0.075*	0.075*	0.079*	0.078*
	(0.045)	(0.043)	(0.043)	(0.042)	(0.042)	(0.043)	(0.042)
Per Capita Benefits from Cap & Trade, Quartile 4	0.065	0.023	0.031	0.021	0.02	0.029	0.025
	(0.057)	(0.046)	(0.050)	(0.045)	(0.046)	(0.050)	(0.050)
Per Capita Benefits from RFS, Quartile 2	-0.174***	-0.168***	-0.167***	-0.169***	-0.170***	-0.167***	-0.172***
	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)
Per Capita Benefits from RFS, Quartile 3	-0.234***	-0.192***	-0.201***	-0.191***	-0.191***	-0.200***	-0.201***
	(0.061)	(0.056)	(0.059)	(0.055)	(0.056)	(0.058)	(0.058)
Per Capita Benefits from RFS, Quartile 4	-0.383***	-0.345***	-0.346***	-0.340***	-0.338***	-0.342***	-0.341***
	(0.070)	(0.058)	(0.065)	(0.059)	(0.059)	(0.066)	(0.066)
Top 10 Coal Producing State	-0.068*	-0.067*	-0.070*	-0.061*	-0.061*	-0.063*	-0.062*
	(0.036)	(0.036)	(0.036)	(0.035)	(0.035)	(0.035)	(0.035)
Change in Gas. PS From RFS * Ref. Cap. Share				0.085**		0.142**	
				(0.042)		(0.068)	
$D_{\text{Share Change Gas. PS} > \$500 \text{ million}}$					-0.102		-0.209**
					(0.071)		(0.092)
State Fixed Effects	No	No	No	No	No	No	No
Observations	431	431	431	431	431	431	431
Chi-Square Statistic	354.90	353.56	353.20	358.30	355.96	358.20	359.59
Log-Likelihood	-121.24	-121.91	-122.09	-119.54	-120.71	-119.59	-118.90
Pseudo-R2/R2	0.59	0.59	0.59	0.60	0.60	0.60	0.60

Notes: The dependent variable equals one if the House member voted for H.R. 2454.

Appendix Table 18: Probits with ethanol costs increased and decreased by 20%

	Model 1/Tab. 6	Cell+20%	Cell-20%	Corn+20%	Corn-20%	Cell-20Corn+20
Democrat	0.752***	0.747***	0.755***	0.754***	0.751***	0.751***
	(0.031)	(0.032)	(0.031)	(0.031)	(0.031)	(0.031)
Per Capita Benefits from Cap & Trade, Quartile 2	0.043	-0.153*	0.085*	0.034	0.065	0.051
	(0.042)	(0.083)	(0.045)	(0.045)	(0.045)	(0.043)
Per Capita Benefits from Cap & Trade, Quartile 3	0.106**	-0.006	0.126***	0.150***	0.182***	0.116***
	(0.045)	(0.094)	(0.045)	(0.046)	(0.049)	(0.043)
Per Capita Benefits from Cap & Trade, Quartile 4	0.065	-0.056	0.069	0.079	0.111*	0.067
	(0.057)	(0.123)	(0.053)	(0.059)	(0.065)	(0.054)
Per Capita Benefits from RFS, Quartile 2	-0.174***	0.033	-0.218***	-0.183***	-0.201***	-0.181***
	(0.049)	(0.075)	(0.052)	(0.053)	(0.050)	(0.050)
Per Capita Benefits from RFS, Quartile 3	-0.234***	-0.143	-0.197***	-0.277***	-0.324***	-0.237***
	(0.061)	(0.106)	(0.063)	(0.062)	(0.064)	(0.058)
Per Capita Benefits from RFS, Quartile 4	-0.383***	-0.236	-0.372***	-0.409***	-0.430***	-0.391***
	(0.070)	(0.147)	(0.065)	(0.069)	(0.071)	(0.065)
Top 10 Coal Producing State	-0.068*	-0.072**	-0.088**	-0.075**	-0.065*	-0.077**
	(0.036)	(0.035)	(0.036)	(0.036)	(0.036)	(0.036)
State Fixed Effects	No	No	No	No	No	No
Observations	431	431	431	431	431	431
Chi-Square Statistic	354.90	356.75	358.00	362.19	362.09	359.94
P-Value	0.000	0.000	0.000	0.000	0.000	0.000
Log-Likelihood	-121.24	-120.31	-119.69	-117.60	-117.64	-118.72
Pseudo-R2/R2	0.59	0.60	0.60	0.61	0.61	0.60

Notes: The dependent variable equals one if the House member voted for H.R. 2454.

Appendix Table 19: Equilibrium outcomes with ethanol costs increased and decreased by 20%

	BAU	RFS	LCFS	CAT	SUBS
Fuel Price ($/gge)	$2.75	$2.98	$2.98	$3.13	$2.75
Fuel Quantity (bn. gge)	140	134.57	134.53	131.13	140
Gasoline Quantity (bn. gge)	129.46	110.9	116.84	117.77	123.5
Ethanol Quantity (bn. gge)	10.55	23.67	17.69	13.36	16.51
Corn Ethanol	0.96	8.87	0.96	0.96	0.99
Herb. Energy Crops	1.53	4.69	4.75	3.52	4.75
Waste Feedstocks	8.06	10.11	11.98	8.88	10.76
Emissions (MMTCO$_2$e)	1568.8	-8.3%	-8.3%	-8.3%	-3.5%
ΔCS ($ bn.)		-$31.07	-$31.30	-$52.09	$0.00
ΔPS ($ bn.)		$20.96	$25.75	$3.49	$21.62
ΔPS Corn Ethanol ($ bn.)		$3.24	$0.44	$0.07	$0.66
Carbon Market Revenue ($ bn.)				$46.62	
Subsidy Payments ($ bn.)					$24.51
Carbon Permit Price ($/MTCO2e)			$193.86	$32.42	
Abatement Cost ($ bn.)		-$10.11	-$5.55	-$1.98	-$2.89
Avg. Abatement Cost ($/MTCO$_2$e)		$77.26	$42.40	$15.17	$53.11

Notes: The simulation increases corn ethanol costs by 20% and decreases cellulosic ethanol costs by 20%.

Appendix Table 20: Probits with underlying agricultural endowments

	Model 1	Model 2	Model 3
Democrat	0.776***	0.751***	0.733***
	(0.029)	(0.032)	(0.036)
Average HEC Yield	0.004		
	(0.004)		
Average Corn Yield	-0.021**		
	(0.009)		
Average HEC Yield, Quartile 2		-0.0480	-0.0580
		(0.044)	(0.057)
Average HEC Yield, Quartile 3		0.0510	0.0630
		(0.046)	(0.069)
Average HEC Yield, Quartile 4		0.0570	0.181**
		(0.046)	(0.080)
Average Corn Yield, Quartile 2		-0.151***	-0.171***
		(0.047)	(0.053)
Average Corn Yield, Quartile 3		-0.133***	-0.097*
		(0.042)	(0.049)
Average Corn Yield, Quartile 4		-0.133***	-0.0850
		(0.043)	(0.053)
State Fixed Effects	No	No	Yes
Observations	428	428	379
Chi-Square Statistic	304	323	330
P-Value	0.000	0.000	0.000
Log-Likelihood	-144.66	-134.97	-97.61
Pseudo-R2	0.51	0.55	0.63

Notes: The dependent variable equals one if the House member voted for H.R. 2454.

Appendix Table 21: Probits with additional endowment controls

	Model 1	Model 2	Model 3
Democrat	0.752***	0.755***	0.732***
	(0.031)	(0.031)	(0.033)
Per Capita Benefits from Cap & Trade, Quartile 2	0.0430	0.0430	0.0200
	(0.042)	(0.043)	(0.043)
Per Capita Benefits from Cap & Trade, Quartile 3	0.106**	0.103**	0.0630
	(0.045)	(0.045)	(0.046)
Per Capita Benefits from Cap & Trade, Quartile 4	0.0650	0.0790	0.0230
	(0.057)	(0.056)	(0.059)
Per Capita Benefits from RFS, Quartile 2	-0.174***	-0.182***	-0.156***
	(0.049)	(0.049)	(0.047)
Per Capita Benefits from RFS, Quartile 3	-0.234***	-0.228***	-0.166***
	(0.061)	(0.061)	(0.061)
Per Capita Benefits from RFS, Quartile 4	-0.383***	-0.376***	-0.236***
	(0.070)	(0.073)	(0.084)
Top 10 Coal Producing State	-0.068*	-0.071**	-0.084**
	(0.036)	(0.036)	(0.036)
Agricultural Employment Share		-7.2290	-3.4840
		(4.520)	(4.457)
Automobile Industry Employment Share		4.4220	1.0480
		(6.573)	(6.069)
Refining Industry Employment Share		-21.0040	-23.0230
		(18.765)	(19.357)
ln(Population Density)			0.043***
			(0.013)
State Fixed Effects	No	No	No
Observations	431	431	396
Chi-Square Statistic	284	337	335
P-Value	0.000	0.000	0.000
Log-Likelihood	-156.35	-129.84	-106.79
Pseudo-R2	0.48	0.56	0.61

Notes: The dependent variable equals one if the House member voted for H.R. 2454.

Appendix Table 22: Probit model correlating voting behavior for Waxman-Markey with estimated gains and losses: Higher order models.

	Model 4	Model 4	Model 4	Model 5	Model 5	Model 5
Democrat	2.723***	2.728***	2.805***	3.105***	3.097***	3.208***
	(0.206)	(0.211)	(0.217)	(0.280)	(0.280)	(0.290)
ln(Benefits from CAT) - ln(Benefits from RFS)	0.569***	0.364**	0.612***	0.730***	0.465**	0.766***
	(0.105)	(0.143)	(0.172)	(0.155)	(0.211)	(0.246)
[ln(Benefits from CAT) - ln(Benefits from RFS)]^2		0.185**	0.411***		0.217*	0.531***
		(0.087)	(0.121)		(0.117)	(0.169)
[ln(Benefits from CAT) - ln(Benefits from RFS)]^3			-0.149**			-0.200**
			-0.0580			-0.0820
Avg. Marg. Effect: ln(Benefits from CAT)	0.094***	0.106***	0.105***	0.105***	0.116***	0.111***
- ln(Benefits from RFS)	(0.016)	(0.018)	(0.018)	(0.021)	(0.022)	(0.022)
State Fixed Effects	No	No	No	Yes	Yes	Yes
Observations	431	431	431	394	394	394
Chi-Square Statistic	334	338	345	341	344	350
P-Value	0.000	0.000	0.000	0.000	0.000	0.000
Log-Likelihood	-131.87	-129.51	-126.40	-102.66	-100.92	-97.93
Pseudo-R2	0.56	0.57	0.58	0.62	0.63	0.64

Notes: The dependent variable equals one if the House member voted for H.R. 2454.