Abstract—Climate policy has favored costly measures that implicitly or explicitly subsidize low carbon fuels. We simulate four transportation sector policies: cap and trade (CAT), ethanol subsidies, a renewable fuel standard (RFS), and a low carbon fuel standard. Our simulations confirm that alternatives to CAT are 2.5 to 4 times more costly but are amenable to adoption due to right-skewed distributions of gains. We analyze voting on the Waxman-Markey (WM) CAT bill. Conditional on a district’s CAT gains, a district’s RFS gains are negatively correlated with the likelihood of voting for WM. Our analysis supports campaign contributions as a partial mechanism.

I. Introduction

ECONOMISTS often point to Pigouvian taxes and cap-and-trade programs as the preferred policy tools for reducing externalities. In contrast, to reduce greenhouse gas emissions, policymakers 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 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 (LCFS) that requires the average greenhouse gas content of fuels to fall over time; Holland, Hughes, and Knittel (2009) show that an LCFS acts as an implicit subsidy for any fuel with a greenhouse gas content below the standard and that it 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 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 equilibrium in the liquid fuels market by exploiting feedstock-specific ethanol supply curves that solve a GIS-based optimal ethanol plant location problem for the United States in 2022. Our simulations confirm that the alternatives to CAT are quite costly. Under CAT, average abatement costs are $20 per metric ton of carbon dioxide equivalent ($/MTCO2e). Costs under the alternative policies are substantially higher, at $50 to $80 per MTCO2e.2

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 makes 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.3 For example, under SUBs, we find that 5% of 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 HR 2454, better known as the Waxman-Markey cap-and-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 it is that the House member voted for Waxman-Markey. In addition there is some evidence of the opposite effect: that holding a

1 Prominent policies in the electricity sector also implicitly or explicitly subsidize low carbon fuels. Ethanol is a biofuel produced by converting corn or other plant material into alcohol.

2 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% lower than these.

3 According to the theory of collective action in Olson (1971), policies with relatively concentrated benefits and diffuse 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.
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 it is that 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 a 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 received roughly $33,000 more from organizations opposing Waxman-Markey compared to a member whose district was in the bottom 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 across both policies and types of ethanol producers.4 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-and-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 and trade and its alternatives. Under the cap-and-trade programs that has been either proposed or implemented, including WM, allocation of free permits in the transportation sector has 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 vary dramatically across policies.

Under subsidies, the RFS, and the LCFS, producer surplus increases by approximately $20 billion per year. Therefore, the alternatives to cap and trade not only alter the distribution of net gains and losses, but 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 a function of both ideology and the interests of legislators’ constituents. Both papers find strong evidence that 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 a state’s senators explains gains even when conditioning on the states’ needs. Knittel (2006) models the adoption of state-level electricity regulation during the beginning of the twentieth century and finds that interest group strength explains adoption. More recently, Crugg and Kahn (2009) correlate voting behavior on anticarbon 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, a substantial literature shows that other potential channels (e.g., employee voting) through which stakeholders can affect voting and campaign contributions (see Stratmann, 1992, 1995; Bombardini & 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; Kroszner & 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 & 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 a regulation is adopted or removed with proxies of interest group gains and losses.

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4 By assumption, gasoline producers receive no surplus in our main model. We relax this assumption in section C.8 of the online appendix.
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 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 II summarizes the current set of transportation-related GHG policies. Sections III and IV describe our theoretical framework, data, and simulation methodology. Sections V and VI present our main results. Section VII describes a number of robustness checks, and section VIII concludes.

II. Policy Background

A variety of policies exist that either directly or indirectly promote biofuels at 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.\(^5\) 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 fewer 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 a per energy basis. One gallon of ethanol has roughly 66% of the energy content of 1 gallon of gasoline, implying that 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 48 cent per gge subsidy, with 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.\(^6\) 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 life cycle 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 life cycle emissions at least 20% below those of gasoline. However, the 20% requirement holds only for renewable fuel facilities that began construction after December 19, 2007. Existing facilities are grandfathered; therefore, the actual greenhouse gas savings from these facilities are unknown. The first category is corn-based ethanol. The second category is “advanced biofuel,” defined as renewable fuel with life cycle emissions at least 50% below those of gasoline. Biomass-based diesel is biodiesel with emissions at least 50% below petroleum-based diesel. Finally, cellulosic biofuel is a renewable fuel with life cycle emissions at least 60% 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-and-trade system would price the carbon emitted by all transportation fuels. The 2009 House of Representatives bill, HR 2454, or the Waxman-Markey bill, would have established a broad national cap-and-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.\(^7\) In addition, the bill contained specific provisions aimed at addressing leakage and deforestation and supporting research and development for low carbon technologies. HR 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 life cycle emissions of ethanol. While the magnitudes of the EPA-assigned indirect land use effects for each of the ethanol is unknown, the figures used for recent California legislation imply that many corn-based ethanol producers would no longer qualify as having emissions that are 20% 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.\(^8\) Just prior

\(^5\) 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.

\(^6\) 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.

\(^7\) Also known as the American Clean Energy and Security Act of 2009.

\(^8\) 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-break-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/).
to the House vote, Peterson and the bill’s cosponsor, 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 five years. After that period, the secretaries of agriculture and energy, along with the EPA, must agree on the indirect land use change adjustments.

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 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 delaying the indirect land use change adjustments for five years but warned 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 2009, HR 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 & 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. A more recent policy is the LCFS, adopted in California in 2009, requiring the state to reduce the average carbon intensity of transportation fuels 10% 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.

### III. 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 \( i \)th fuel (with \( mc_i' \geq 0 \)) and \( \beta_i \) 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. 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 et al. (2009), we model a single, representative, price-taking firm that produces all types of fuels. These market results hold for heterogeneous firms under trading, which is allowed for by all currently proposed policies.

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. In particular, for transfers from the general funds (required only 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.

#### A. 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 the marginal cost less the subsidy equals the market clearing price. This implies

\[
p = mc_i(q_i) - s_i
\]

for each ethanol fuel. For gasoline, the firm produces until the 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:

\[
D(p) = \sum_{i=1}^{n} q_i.
\]

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.

#### B. Renewable Fuel Standard

An 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. Consumers perceive low-level ethanol blends as substantially different from gasoline.

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9 http://www.greencarcongress.com/2009/06/peterson-20090626.html.

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

11 Recent studies by Anderson (2012) 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.

12 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.

13 Holland (2012) shows that the relative efficiency of policies may change in the presence of additional market distortions such as incomplete regulation or market power.

14 See Goulder (1995) for a discussion of the double dividend.
Table 1 of the online appendix shows the current standards for 2010, 2015, and 2022. The three categories are additive: 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 energy crops, which are expected to have the lowest life cycle 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), that 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. Let $\sigma_{RFSj}$ be the $j$th RFS ratio with $j \in \{ \text{cell, adv, tot} \}$. For each gallon of gasoline produced, the representative firm would be required to produce $\sigma_{RFSj}$ gges of the $j$th type of ethanol. Note that whether the regulation meets the volumetric ethanol target will depend on the accuracy of the EPA’s forecast of gasoline production.16

To allow ethanol production by the least-cost firms, renewable identification numbers (RINs) are created for each gge of renewable fuel.17 These RINs are then freely traded and 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 $j$th 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,

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

where ethanol $i$ is of type $j$ and $p_{RINj}$ is the price of a RIN of type $j$. The RINs also act as 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

$$ p = mc_n(q_n) + p_{RINC} \sigma_{cell} + p_{PRINadv}(\sigma_{adv} - \sigma_{cell}) + p_{PRINtot}(\sigma_{tot} - \sigma_{adv}). $$

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

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., $\sigma_{RFS\text{tot}} q_n = q_1 + \cdots + q_{n-1}$). 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 $p_{PRINC} \geq p_{PRINadv} \geq p_{PRINtot}$.

### C. Low Carbon Fuel Standard

Under an LCFS, the average emissions intensity, defined as emissions divided by total energy output, may not exceed the standard $\sigma_{LCFS}$ (Holland et al., 2009). This constraint is given by

$$ p_{PRINC} \geq p_{PRINadv} \geq p_{PRINtot}. $$

An LCFS has been adopted by California and is currently under development by various federal and state policymakers. In our simulations, $\sigma_{LCFS}$ is set to produce the same reduction in emissions as the RFS and CAT systems.
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

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

(6)

where $\lambda_{LCFS}$ is the shadow value of the constraint in equation (5), or, equivalently, the price of carbon under an LCFS. Notice that if the emission intensity $\beta_i$ is greater than the standard, the last term in equation (6) is positive. This implies that fuel $i$ faces an implicit tax equal to $\lambda_{LCFS}(\beta_i - \sigma_{LCFS})$. But 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 an LCFS that results in the efficient allocation of energy production and emissions since each fuel with positive carbon emissions should be taxed (not subsidized) (Holland et al., 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).

**D. Carbon Trading**

Consider a cap ($\sigma_{CAT}$) on the total emissions of carbon. Since the total emissions summed over all fuels produced must not exceed the cap, the constraint is

$$\beta_1q_1 + \beta_2q_2 + \cdots + \beta_nq_n \leq \sigma_{CAT},$$

(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

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

(8)

where $\lambda_{CAT}$ 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; it is therefore 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).

**IV. 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 section B of the online appendix and Parker, 2011, 2012, for more details.)

We use ethanol supply curves for corn ethanol and 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. We construct county-level supply curves using estimates of biomass feedstock availability and agglomeration 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.

The supply side of the model is completed by aggregating the supply from each type of ethanol with the supply of conventional gasoline. We assume that the long-run gasoline supply is perfectly elastic at $2.75 in our baseline. 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 life cycle 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 life cycle emissions, we explore the robustness of our results to a variety of assumptions about life cycle emissions. These two policies that 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 and 16 billion gallons is cellulosic (23.67 billion gge, 13.81 billion gge, and 10.52 billion gge respectively).

19 In our simulations, the cap ($\sigma_{CAT}$) is set to produce the same total emissions as the RFS.

20 Section C.9 of the online appendix investigates the sensitivity of our results to ethanol costs that are higher or lower than expected.

21 Section C.8 of the online appendix shows that our results are not overly sensitive to this assumption.
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 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.\(^\text{22}\)

Consumer surplus and carbon market revenue changes are allocated per capita to the districts.

V. 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.

A. Energy Prices, Quantities, and Emissions

Table 1 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 gge. Under the RFS, fuel prices increase to approximately $2.94 per gge and total fuel consumption decreases 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.

Finally, we also simulate the equilibrium under the current set of subsidies. Under direct subsidies, fuel prices are unchanged.\(^\text{23}\) 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 ethanol using waste feedstocks.

B. 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\(_2\text{e}\)). The marginal cost, or price, of an emissions permit, at this level is approximately $40.83 per MTCO\(_2\text{e}\) 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.

\(^\text{22}\) 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.

\(^\text{23}\) This is a consequence of the perfectly elastic supply curve for gasoline.
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 MTCO2e. Producer surplus increases by $17.12 billion per year. Average abatement costs under the LCFS are $48.58 per MTCO2e.24 Finally, the average abatement costs under the subsidy programs are the highest at $82.30 per MTCO2e.24

Finally, the average abatement costs under the LCFS are $48.58 per MTCO2e (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 estimates of the externalities associated with GHGs exist. Tol (2008) provides a metastudy 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 MTCO2e, while the mean ranges from $61 to $88 per MTCO2e (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. Table 2 of the online appendix 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. A number of estimates of the externalities associated with GHGs exist.

VI. The Political Economy of Climate Change Policy

VI. 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 policymakers chosen the VEETC and RFS over CAT? We investigate the distributional impacts of the different policies as a potential answer.25 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.26 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, 1971).27 We then aggregate these to the congressional district level and correlate these changes with congressional voting behavior on HR 2454, the Waxman-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 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.28 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 are created with roughly equal populations and therefore coincide more closely with the aggregate measures.29

Beginning with the county-level statistics for CAT in the table, 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 $11.49. The 95th percentile of the SCC estimates assuming a 3% discount rate. In contrast, CAT increases welfare for all of the reported results with discount rates below 5%.

Table 2.—The Distribution of County- and District-Level Gains and Losses across the Different Policies

|                  | CAT        | LCFS       | RFS        | SUBS       |
|------------------|------------|------------|------------|------------|
| County-level distributions |            |            |            |            |
| Mean             | $2.98      | $209.42    | $159.85    | $186.83    |
| 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  | 50.14      | 209.70     | 133.19     | 166.53     |
| 90th percentile  | 34.98      | 688.43     | 537.34     | 625.59     |
| Maximum          | 73.21      | 1,363.58   | 1,109.67   | 1,252.99   |
| District-level distributions |            |            |            |            |
| Mean             | −11.49     | −29.10     | −34.33     | −32.97     |
| 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      |
| Maximum          | 7.69       | 134.07     | 97.45      | 111.81     |

Table 2.—The Distribution of County- and District-Level Gains and Losses across the Different Policies

24 We note that this figure is below many of the results in Holland et al. (2009), reflecting the long-run nature of our ethanol supply curves.

25 Other possible reasons include the higher fuel prices that 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.

26 See section IV for a discussion of the aggregation methodology.

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

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

29 Unfortunately, we cannot calculate the distribution of gains within a county.
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 is 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% 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% gain over $1,100. 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.

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 political dynamics that lend themselves to passing such policies despite their overall inefficiency (Olson, 1971).

The trends in the district-level data in Table 2 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.

### A. 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. 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

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The distributions of gains under each policy are also shown graphically in figures A.7 and A.8 of the online appendix.

Section C.10 of the online appendix provides additional intuition into the sources of gains by investigating the role of underlying agricultural endowments.

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 we have not verified the standard error.
difference between per capita gains under the RFS and under CAT. The simple cross-tabulations 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 who 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 contributions in detail below, but the third panel suggests that Democrats who 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 larger, with the 75th and 90th percentiles over $23,000 and $28,000 larger, respectively, for Democrats who voted against. The tail of this distribution is less clear for Republicans. The contributions from organizations supporting WM do exhibit differences across Republicans who voted for and against, however. Republicans voting for WM received, on average, over $64,000 more in supporting contributions. The Republicans at the 90th percentile among those who voted for WM received more than $425,000 more than the Republicans at the 90th percentile who voted against WM.33

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-and-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)—HR 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 II, many congressional members likely viewed WM and the RFS as substitutes. We center our analysis on these two policies.

Table 3 shows the marginal impacts of a probit model of whether a House member voted for WM.34 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.35 We report the marginal effects at the means of an indicator for whether the member is a Democrat and our estimate per capita benefits across the district from a cap-and-trade program that reduces GHG emissions by 10%. “Gains from CAT” is average per capita benefits across the district from the current federal RFS program in 2022. “Political contributions against” is the amount of political contributions received by the House member from organizations opposing HR 2454, measured in $1,000s. “Political contributions for” is the amount of political contributions received by the House member from organizations supporting HR 2454, measured in $1,000s.

This table lists points in the distribution across Democrats and Republicans who voted for and against HR 2454: 211 Democrats voted for the policy, while 43 voted against, and 8 Republicans voted for the policy, while 169 voted against. The standard errors are calculated via Stata’s `reg 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-and-trade program that reduces GHG emissions by 10%. “Gains from RFS” is average per capita benefits across the district from the current federal RFS program in 2022. “Political contributions against” is the amount of political contributions received by the House member from organizations opposing HR 2454, measured in $1,000s. “Political contributions for” is the amount of political contributions received by the House member from organizations supporting HR 2454, measured in $1,000s.

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

34 Results from a linear probability model are qualitatively similar.

35 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.

36 Section C.7 of the online appendix demonstrates that our results do not depend on including measures of political ideology.
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 the gains from both CAT and the RFS. Once we account for both, greater gains from CAT are correlated with voting for WM, though the coefficient is not precisely estimated.37 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 CAT gains, relative to the RFS, are correlated with an increased likelihood of voting for WM even accounting for state fixed effects.38

The effects from the RFS and CAT are also politically significant. Using model 2, if a district moves from the 25th percentile to the 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 nonlinear. 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.39 The estimated effects are substantial. When a district’s gains under CAT are held 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.40

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 representatives’ votes. Indeed, Cragg and Kahn (2009) find that district-level per capita GHG emissions are strongly correlated with

38 Since WM did not explicitly repeal the RFS, the test is not perfectly clean. Section A.2 of the online appendix 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 that 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 the effects of a mixed CAT and RFS separately from the effects of the RFS.

39 Section C.11 of the online appendix provides additional evidence of the increasing marginal effect of gains.

40 The quartiles across CAT and RFS are obviously correlated; however, 8% of the districts in the upper RFS quartile are in the bottom two CAT quartiles. Figure 2 of the online appendix illustrates the source of identification.
congressional voting on GHG-reducing legislations more 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 ten coal-producing state.41 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. 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.43 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 ten 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 testimony, news databases and trade association websites to assign interests.44 We assume that donors from a given interest group share this group’s position on HR 2454. Because political donation patterns follow election cycles, we focus on donations during a two-year period from January 1, 2009, to December 31, 2010.45 One may worry that this period is too broad to capture donations specific to HR 2454. As a robustness check, we limit our data to a sixty-day window around

41 Similar results are obtained for top five coal-producing states or controlling for coal consumption.
42 DW-nominate is the voteview.org measure of political ideology based on all roll call votes, not simply votes on environmental issues.
43 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.
44 A list of opposing and supporting organizations, as well as the documentation of this categorization by Maplight.org is available at http://maplight.org/us-congress/bill/111-hr-2454/371786/total-contributions-table.
45 Recall the House vote on HR 2454 occurred on June 26, 2009.
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.46 The first two columns focus on contributions from opposing donors. Greater district-level gains from CAT are correlated with fewer contribution dollars from donors opposing WM. Moving from the first to the fourth 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 first to the fourth 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 or losses are working through contributions or through gain or losses more generally.47 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 and loss 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 1 standard deviation increase in the log of contributions supporting WM is associated with a 3 percentage point increase in the likelihood of voting for WM, while a 1 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

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46 We add 1 to allow us to account for observations with 0 contributions.
47 As noted in section I, a 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 & Trebbi, 2011).
fixed effects. The point estimates for contributions in support of and opposed to WM decrease in magnitude slightly 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.

B. 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 voting and the dollar amount of gains may change considerably between the House and the Senate, we focus on specifications that measure relative gains with quartiles and include indicators for Democrat and Top 10 Coal-Producing State (model 1 in table 6). To calculate the gains quartiles, we aggregate the county-level gains and losses to the state level and then reconstruct these quartile indicators. We then use our point estimates for nine coefficients from model 1 in table 6 (the intercept is not reported) to predict the voting probability for each senator.

We present the predicted voting probabilities in three ways. First, we predict the results of the Senate vote by assuming each senator votes for WM if his or her predicted voting probability is greater than 0.5. Second, we plot the distribution of predicted voting probabilities. Finally, we simulate 1,000 different votes using the predicted voting probabilities. In particular, we take the fitted value of the latent variable and draw a random error term, which by definition has a normal distribution with mean 0 and standard deviation of 1. For each iteration, we calculate the number of votes and plot the distribution of votes across all iterations.

Using only the predicted voting probabilities and the 0.5 rule, we end up with 54 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 predicted voting probabilities. This distribution is as we would expect given the large coefficient associated with party affiliation, and all 54 of the senators with voting probabilities greater than 0.5 are Democrats. We do, however, find that 4 Democrats have voting 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) and North Dakota (Kent Conrad and Byron Dorgan). The senators have predicted voting probabilities of 0.45 coming from being in a state in the fourth quartile of RFS and CAT gains and in a coal mining state.

\[ D_{Coal1}(type = \text{CoalTop10}) \]

where \( \Phi \) is the CDF of the standard normal distribution and the \( D \)'s are indicator variables for the quartiles of CAT and RFS gains, party affiliation, and state coal production.

### Table 7: Correlating Campaign Contributions by Groups in Support of or Opposed to Waxman-Markey with Estimated Gains and Losses: Quartile Model

| Group                  | ln(Contributions) | ln(Contributions) | ln(Contributions) | ln(Contributions) |
|------------------------|-------------------|-------------------|-------------------|-------------------|
|                        | Opposing WM       | Opposing WM       | Supporting WM     | Supporting WM     |
| Democrat               | −2.180***         | −1.746***         | 0.372***          | 0.399***          |
|                        | (0.347)           | (0.360)           | (0.122)           | (0.125)           |
| Per capita benefits    | −1.508***         | −1.914***         | 0.213             | 0.321             |
| from cap and trade,    | (0.525)           | (0.611)           | (0.185)           | (0.213)           |
| quartile 2             | −1.679***         | −1.960***         | 0.134             | 0.330             |
|                        | (0.627)           | (0.720)           | (0.221)           | (0.251)           |
| Per capita benefits    | −1.966**          | −2.488***         | −0.055            | 0.082             |
| from cap and trade,    | (0.764)           | (0.882)           | (0.269)           | (0.307)           |
| quartile 4             | 1.574***          | 1.568***          | 0.016             | −0.129            |
|                        | (0.552)           | (0.585)           | (0.195)           | (0.204)           |
| Per capita benefits    | 2.819***          | 3.081***          | 0.061             | −0.131            |
| from RFS, quartile 2   | (0.638)           | (0.718)           | (0.225)           | (0.250)           |
| Per capita benefits    | 4.741***          | 5.004***          | 0.3600            | 0.276             |
| from RFS, quartile 4   | (0.773)           | (0.898)           | (0.272)           | (0.313)           |
| State fixed effects    | No                | Yes               | No                | Yes               |
| Observations           | 430               | 430               | 430               | 430               |
| \( R^2 \)              | 0.23              | 0.37              | 0.03              | 0.23              |

All models are estimated via OLS. The dependent variable in first two columns is the amount of political contributions received by the House member from organizations supporting HR 2454, measured in $1,000s. The dependent variable in columns 3 and 4 is the amount of political contributions received by the House member from organizations supporting HR 2454, measured in $1,000s. “Democrat” is an indicator equal to 1 if the House member is a Democrat. The per capita benefits from cap and trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap-and-trade program that reduces GHG emissions by 10%. We simulate that this leads to a 10% 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. Statistical significance at *1%, **5%, and ***10% levels. Standard errors are in parentheses.
On the other side of the 0.5 cutoff are six senators with predicted voting probabilities of 0.62. These are all Democrats: two from Arkansas, one from Indiana, one from Iowa, one from Maine, and one from South Dakota. These states are all in the fourth quartiles of RFS and CAT gains, but not in coal-mining states. In addition, there are two Democratic senators from Montana with voting probabilities of 0.67. Montana is in the second quartile of RFS gains and the first quartile of CAT gains but is a top-ten coal-producing state. 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 four Democrats to change their votes, the next highest predicted voting probabilities are 0.23 and 0.15. Indeed, we find that WM receives a maximum of 60 votes three times across our 1,000 draws. Figure 3 plots the distribution of these draws. Interestingly, on average, WM garners fifty votes in the Senate, which is below our estimated vote from the 0.5 cutoff. Intuitively, this average is lower because it is easier to get senators to switch their votes from nay to nay than it is to switch from nay to nay. To see this, we point to the eight senators with predicted voting probabilities of 0.62 and 0.67, but there are only four senators close to this on the other side of the 0.5 cutoff (each with voting probabilities of 0.45).

The preceding analysis suggests that it would have been difficult, if not impossible, to attain the sixty votes in the Senate necessary to prevent a filibuster. The primary difficulty is that attaining sixty affirmative votes requires two votes from senators with predicted voting probabilities of 0.23 and 0.15. The probability of this is very low. However, several assumptions could change this calculation. First, cap-and-trade legislation allows considerable scope for redistributing benefits without affecting efficiency through free allocation of permits. Thus, carefully targeting the allocation of permits could increase the probability of passage. Unfortunately, the predictive power of the CAT gains is not particularly strong. If

| 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 and trade, quartile 2 | 0.024 | 0.026 | 0.005 | 0.005 | 0.034 |
| (0.041) | (0.047) | (0.046) | (0.054) | |
| Per capita benefits from cap and trade, quartile 3 | 0.081* | 0.094* | 0.042 | 0.042 | 0.057 |
| (0.044) | (0.054) | (0.048) | (0.058) | |
| Per capita benefits from cap and 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) | |
| ln(contributions opposing Waxman-Markey) | -0.031*** | -0.023*** | -0.021*** | -0.021*** | -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-$R^2/R^2$ | 0.59 | 0.64 | 0.69 | 0.67 | 0.71 |

The dependent variable equals 1 if the House member voted for HR 2454. The reported coefficients are the average of marginal coefficients taken at each observation level of the right-hand-side variables. For indicator variables, the coefficient represents the average change in the probability of voting yes from changing the indicator from 0 to 1. The per capita benefits from cap and trade quartile indicators are the quartiles of the average per capita benefits across the district from a cap-and-trade program that reduces GHG emissions by 10%. Per capita benefits from RFS quartiles 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% 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 HR 2454, measured in $1,000s. “Political contributions supporting” is the amount of political contributions received by the House member from organizations supporting HR 2454, measured in $1,000s. “Per capita CO2 emissions” is the Purdue University Vulcan estimate of a district’s annual per capita CO2 emissions. “Average power plant CO2 rate” is the EIA measure of the average CO2 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. Statistical significance at *1%, **5%, and ***10% levels. The coefficient for per capita benefits from RFS, quartile 4 in model 4 is significant at the 0.1% level, but the marginal effect p-values are slightly greater than 0.10.
allocating free permits moved a senator from the first quartile of CAT gains to the third or fourth quartiles of CAT gains, by our estimates this would increase the predicted voting probability by at most 0.106. Thus, judicious allocation of free permits is unlikely to secure sixty votes. Second, our results in table 8 suggest that campaign contributions are correlated with voting. If we assume that these estimates are causal and that the relationship is the same in the House and Senate, and that increased contributions supporting WM are not offset by increased contributions opposing WM, we can calculate the dollar amount of contributions required to increase the predicted voting probability of a senator from 0.23 to above 0.50. By increasing log contributions by 10 (about $22 million), the predicted voting probability would increase by about 0.3. Thus, additional campaign contributions would have been a very costly way of securing sixty votes. Finally, our analysis assumes independent voting probabilities. Thus, the probability of affirmative votes from two senators with predicted voting probabilities of 0.23 and 0.15 is approximately 0.03. However, if shocks are correlated, as they likely are, then this probability could be as high as 0.15, which is still quite low. In summary, adjusting our analysis for these key assumptions merely accentuates how difficult passage would have been in the Senate.

VII. Robustness

Section C of the online appendix 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. (See the online 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 HR 2454 were approximately $2.60 per gallon, below our preferred baseline fuel price of $2.75.49

To test the robustness of our political economy results, we run model 1 of table 6 under ten alternative parameter scenarios. (See section C of the online appendix for details.) The results are remarkably consistent across all scenarios: 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 0; and the Democrat and coal-state indicators are of the expected sign and significant.

49 Recent research by Anderson, Kellogg, and Sallee (2013) 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.
VIII. Conclusion

We analyze equilibrium outcomes for carbon cap and 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 United States 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 $49 per MTCO$_2$e for the LCFS to $82 per MTCO$_2$e for subsidies, compared with only $20 per MTCO$_2$e 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 create nearly $59 billion in carbon market revenue, which could be distributed to consumers. Under subsidies, consumer surplus is 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 losses. 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, 5% of counties gain more than $1,100 per capita, and no county loses more than $95 per capita. In contrast, under CAT, fewer counties experience gains as a 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 HR 2454 cap-and-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 HR 2454. Higher RFS gains are associated with more contributions from groups opposed to WM. Contributions from groups that 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 that would offer larger social benefits but with less concentrated private benefits. The pattern of campaign contributions around the vote on HR 2454 is consistent with political interest groups’ effectively influencing carbon regulation in a manner consistent with private interest theory.

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