Evaluating Carbon Tax Incidence, Market Effects, and Efficiency within the Transportation Fuel Sector

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Abstract

This research modifies the Regional Transportation Regulation and Credit Trading (TRACTR) to assess the impact of a carbon tax on the transportation fuel market. The paper demonstrates the decreasing marginal impact from greater carbon tax values. Additionally, results indicate that the final price of fuels rises approximately 1.3% with the implementation of a $25/metric ton carbon tax on the transportation sector. Although the carbon tax maintains a greater proportional increase in fuel prices, demand responses serve to alleviate market pressures.
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**Background**

Transportation energy initiatives have been enacted under the Climate Action Plan, passed by President Obama in 2013 (Executive Office of the President, 2013). Under this new strategy, the Renewable Fuel Standard (revised under the Energy Independence and Security Act and colloquially known as RFS2) was again revised, the heavy truck sector’s efficiency requirements were increased, and the push for alternative fuels and vehicle systems was continued to reduce the nation’s reliance on petroleum as well as its production of GHGs.

At present, the US transportation sector accounts for 28% of total US GHG emissions (US EPA 2010). The largest portion of the transportation sector emissions are from passenger cars and light duty trucks (which include SUVs, CUVs, and Minivans) which account for approximately half of the overall transportation emissions and thus 14% of total US GHG emissions. provides an overview of the historic makeup of these emissions over time, broken down by source.

Currently the US Energy Information Administration (EIA) projects overall transportation fuel usage to remain rather stable over the 2010 to 2035 time period; the usage in 2013 is estimated at 26.7 quadrillion BTUs (quads) whereas in 2035 US transportation energy usage is expected to be 26.4 quads (US EIA 2013). The main forces driving this stability in fuel usage despite economic and population growth are the increased fuel efficiency standards recently passed by the Obama administration (US NHTSA 2012) and the projection of sustained higher oil prices.
Context
In 2014, there exists a national volumetric standard for biofuels as well as distinct regional regulations which influence the transportation fuels market. RFS2 is a volumetric requirement for transportation fuel blenders in order to meet national biofuel production targets for four renewable fuel categories. Multiple sources, including the Energy Information Administration’s Annual Energy Outlook (US EIA, 2013), predict that the ambitious volumetric mandates as defined by the Bush Jr. Administration will not be met. Per legislation, the regulatory enforcement by the US EPA has been revised at the beginning of each fiscal year, generally waiving or relaxing certain components.

The regional transportation fuel policy initiatives to lower GHG emissions which are most germane to this paper’s purpose are Low Carbon Fuel Standards (LCFS) such as California’s (CA LCFS). A LCFS is a cap on the average fuel carbon intensity (AFCI) of transportation fuels (Yeh and Sperling 2010; Yeh, Sperling et al. 2012). Aside from California, multiple other regions/states (Oregon, New England, the Mid-Atlantic, and British Columbia) are now implementing or drafting legislative policies for the implementation of a similar system to the CA LCFS. The impacts of a National LCFS (NLCFS) have been analyzed by multiple research initiatives (Huang et al, 2012; Rubin and Leiby, 2012; Yeh and Sperling, 2012); regional implications of a NLCFS have also been assessed with the concern of lower-CI fuel shuffling\(^1\) across regions (Rubin et al. 2014). A widely mentioned benefit of a LCFS is its technological neutrality, that is there is no defined winner except for that which can reduce carbon intensity relative to other fuels.

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\(^1\) Shuffling is loosely defined as the transportation of fuel from one region to another due to policy impacts
Fuel efficiency requirements set forth by the Corporate Average Fuel Economy (CAFE) standards are also impacting the transportation fuel and GHG spectrum (Hartgen et al. 2011). The interaction of CAFE with current RFS2 policy is that with reduced fuel usage, as expected with greater fuel efficiency, it will be more difficult to meet a volumetric renewable fuel standard. This brings even greater saliency and relevance to the proponents of a LCFS carbon intensity standard or carbon tax policy which don’t require a certain amount of fuel to be consumed. In terms of either, the CAFE standards also generally support the deployment of alternative fuel vehicles (AFVs) in cases where they provide greater miles per gallon of gasoline equivalent (MPGGE). A significant barrier to the deployment of many AFV systems, however, is the limited availability of stations combined with range anxiety (Tate et al 2008).

Internationally, several nations have adopted or are considering adoption of a CT including China, India, the EU, Finland, the Netherlands, Sweden, New Zealand, Norway, Canada, and South Korea. Domestically, however, there have only been a few smaller initiatives at either the municipal or regional level to tax carbon. Boulder Colorado was the first U.S.[?] municipal entity to impose a carbon tax on utility bills in order to encourage the production of electricity from renewable resources. The Bay Area Air Quality Management District which covers nine counties near San Francisco, California also imposed a tax of 4.4 cents per ton of carbon on electricity producers. Lastly, Montgomery County in Maryland imposed a $5/ton CT for any stationary source emitting a certain amount of GHGs per year. To date, no carbon tax has been explicitly imposed on the transportation sector anywhere within the US.

The concept of a carbon tax (CT) has been debated in the US political system since the early 1970s. More recent analysis has begun comparing the efficacy and efficiency of the RFS2 volumetric standard, a NLCFS, as well as a CT (Chen and Khanna 2012; Holland et al 2014).
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Chen and Khanna found that a $60/metric ton CT would increase gasoline and diesel prices by 17%, reduce consumption of overall fuels by 3%, and increase biofuel consumption by 13% relative to their business-as-usual (BAU) scenario. Importantly, Chen and Khanna find that the $60/metric ton CT would reduce US GHG emissions [??% reduction in the transportation sector alone or nationwide – need to be clear whether talking about transportation CT of which LCFS is a variant vs. economy-wide CT which will have more effect] by approximately 9% relative to the BAU scenario. Researchers at Resources for the Future (RFF) found that a $30/metric ton CT would reduce energy-related GHG emissions by 8.5% relative to their BAU Scenario (Parry and Williams, 2010).

Method

This paper modifies the Regional Transportation Regulation and Credit Trading model (TRACT_R; Rubin et al, 2014) to look at a carbon tax. The original model was designed to evaluate the impact that a National Low Carbon Fuel Standard (NLCFS) on the transportation fuel market. Additionally, the costs (in terms of deploying alternative fuels) and benefits (in terms of GHG reductions) were calculated to compare the efficiency of a NLCFS with other policies.

The regional component of the model was added to evaluate similar regional policies. The most pertinent example of a similar regional policy is California’s Low Carbon Fuel Standard (CA LCFS). This policy structure was replicated in the TRACT_R model. The primary goal of the LCFS is to reduce the average fuel carbon intensity (AFCI) of all transportation fuels in use. This differs notably from a cap-and-trade policy in that the LCFS attempts to lower the average
intensity of GHG emissions per unit energy, whereas a cap-and-trade policy would generally seek to reduce the aggregate quantity of GHG emissions.

Each policy does have certain degrees of flexibility. The TRACT_R model had four main sources of flexibility to assess: trading across fuel categories (gasoline and diesel sector), trading across regions (e.g. Midwest can trade with New England), ability to borrow credits from future time periods, and the ability to bank credits for future use. Within the carbon tax framework, these areas of flexibility are not generally considered since the ‘right-to-pollute’ is not endowed beforehand nor are permits earned; rather the emissions are ‘punished’ by a fixed dollar-per-MTCO2E disincentive. The critical difference between a Carbon-Tax, a LCFS and a Cap-And-Trade system is that a carbon tax fixes the marginal cost of GHG emission and lets emission quantity be determined; a Cap-And-Trade system fixes the quantity of emissions and lets the marginal cost be determined; and a LCFS fixes the intensity of emissions and lets both the price and total quantity be determined in the market.

The original objective function of the TRACT_R model represents the profit maximizing decisions of fuel providers in multiple regions over time given an LCFS:

\[
\begin{align*}
\text{Max} \\
E, N, B, S \\
t=1 \sum_{t} \delta t \sum_{v=1}^{2} \sum_{f \in F_v} \sum_{r \in R} [ P_{fr} E_{fr} - C(E_{fr}) ] - \pi_{vrt} N_{vmft} - P_{s} S_{vmrt} - H_{frq} S_{hip_{frq}}
\end{align*}
\]

Where:
\( \delta_t \): Discount factor computed at time \( t \)
\( P_{fr} \): Price of fuel \( f \) in region \( r \)
\( E_{fr} \): Energy supplied of fuel \( f \) in region \( r \)
\( C(E_{fr}) \): Cost of supplying fuel \( f \) in region \( r \)
\( \pi_{vrt} \): Market price of credits purchased in vehicle category \( v \) in region \( r \) at time \( t \)
\( N_{vmft} \): Number of credits purchased in vehicle/fuel category \( v \) for fuel \( f \) at time \( t \)
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$P_s$: Price of ‘safety valve’ credit $s$

$S_{vrt}$: Number of safety valve credits purchased in vehicle category $v$ in region $r$ at time $t$

$H_{frq}$: Cost to ship fuel $f$ from region $r$ to region $q$

$Ship_{frq}$: Amount of fuel $f$ shipped at time $t$ from region $r$ to region $q$

The maximization of these individual fuel provider objectives are subject to constraints on the average CI and on credit banking/borrowing balances. Credit prices $\pi$ are endogenously determined by the aggregate market-wide constraints on carbon intensity. Fuel prices $P$ are also endogenous given fuel supply-demand balance constraints.

We have modified the model to compare the impact of a carbon tax to the LCFS credit system of the original.

$$\sum_{r} \sum_{t} \sum_{v} \sum_{f} \sum_{r} \sum_{q} \left[ P_{fr} E_{fr} - C(E_{fr}) \right] - K_{rt} * Q_{fr} - H_{frq}Ship_{frq}$$

Where:

$K_{rt}$: Regional tax of carbon at time $t$ in region $r$ (exogenous)$^2$

$Q_{fr}$: Emissions from fuel $f$ at time $t$ in region $r$

Within TRACT_R, the carbon intensity of final fuels depends on the fuel choice, including e.g. the mix of ethanol and biofuel production pathways used. Emissions associated with each fuel combination used are computed in grams of CO2 equivalent (CO2e) per megajoule (g/MJ). The sources of these various data are discussed in the next section. The amount of energy used is estimated in quadrillion BTUs (quads). Lastly, the objective function is measured in billions of dollars and therefore the final costs of emissions will need to be enumerated as such. We can thus calculate emission quantity $Q_{fr}$ as:

$$Q_{fr} = \left[ \frac{I_{frt} MT}{EER_f g Quads} \right] E_{frt}$$

Where:

$Q_{fr}$: Total quantity of emissions from fuel $f$ at time $t$ in region $r$ (in Metric tons [MT] of CO2e)

$I_{frt}$: Carbon intensity of fuel $f$ in region $r$ at time $t$ (in gCO2e/MJ)

$^2$ The necessity of these subscripts becomes apparent when matching results under each policy structure
$EER_f$: Energy efficiency ratio of fuel $f$, an adjustment factor for greater motive efficiency of some fuels, e.g. electricity

$\frac{MT}{g}$: Metric tons per gram = 0.000001

$\frac{MJ}{Quads}$: Megajoules per quadrillion BTU = $\frac{MJ}{BTU \text{ Quad}} = \frac{10^{15}}{947.81712}$

$E_{frt}$: Energy used of fuel $f$ in region $r$ at time $t$ in Quads

Thus, $K_{rt}$ is in terms of Billions of $ per MT CO2e. The initial value of the carbon tax is set at the social cost of carbon (SCC) as indicated by the US Environmental Protection Agency’s 2013 estimates (US EPA, 2013), as presented in Table 1. The default discount rate used in the TRACTR model is 5%. The modeling endeavor will also explore the various discount rates.

<table>
<thead>
<tr>
<th>Year</th>
<th>Discount Rate and Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>2015</td>
<td>Average</td>
</tr>
<tr>
<td>2020</td>
<td>$12</td>
</tr>
<tr>
<td>2025</td>
<td>$15</td>
</tr>
<tr>
<td>2030</td>
<td>$17</td>
</tr>
<tr>
<td>2035</td>
<td>$20</td>
</tr>
<tr>
<td>2040</td>
<td>$22</td>
</tr>
<tr>
<td>2045</td>
<td>$26</td>
</tr>
<tr>
<td>2050</td>
<td>$28</td>
</tr>
</tbody>
</table>

The aforementioned ‘matching’ process is taking the results from the NLCFS model runs and matching a carbon tax which accounts for those same variable values. To do this, the variable outcomes (primarily energy supplied, energy demanded, and emissions from each fuel) from the NLCFS model run are fixed. Then, the only free variable allowed to account for the deviation from the business-as-usual scenario is the carbon tax component applied to the emissions (in a similar fashion). A theoretical examination would foresee that the carbon tax would equal the cost of the permit credit, only if the energy efficiency ratios (EER) are accounted for. EERs are used in LCFS policy scenarios (or at least in the California and TRACT_R implementations of such) so that vehicle’s fuel efficiency is taken into account. For example,
a megajoule of stored energy in an electric vehicle would allow further travel than in a conventional internal combustion engine.

**Data**
The main sources of data for the TRACT_R model are the 2013 Annual Energy Outlook (US EIA, 2013), the VISION model (Argonne National Laboratory, 2013), the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET; Argonne National Laboratory, 2013), and the BioTrans model (Uria-Martinez et al, 2013). The Annual Energy Outlook provides aggregate, regional energy estimations. The other models are used to delineate energy usage by final category. The VISION model from ANL is a vehicle stock and energy usage model from which the estimates and assumptions for electric vehicles are gathered. BioTrans is used to construct regional supply curves for cellulosic ethanol production. To gather region-specific biodiesel usage, national consumption is weighted by regional capacity.

The main source of carbon intensity (CI) data is GREET. Regional cellulosic ethanol CI is computed using GREET cellulosic ethanol CIs weighted by the regional feedstock sources as estimated in the BioTrans model. Regional electricity CI is computed using average of electricity CI by source from GREET weighted by electricity generation by source from AEO 2012. Petroleum fuel CIs by PADD are used to compute census division gasoline and diesel CIs by weighting with 2011 state-level energy usage (US EIA, 2013). Corn ethanol, imported sugarcane ethanol, biodiesel, FT-diesel, CNG and hydrogen CIs are set at national estimates from GREET (ANL, 2012). PHEV CI is computed as the product of regional electricity and E10 CIs and respective energy proportions from VISION 2012.
Results
A primary result from this modeling is the final level of carbon emissions. Figure 1 presents the values from a business-as-usual (BAU) scenario as well as scenarios with higher carbon tax levels. A main conclusion from these scenarios is that there are declining returns in terms of carbon abatement from increasing tax values. This is represented in the decreased gap between the $40/MT and $50/MT scenarios; relative to all other scenario differences, the smallest gap in aggregate emission reductions occurs between these scenarios.

The declining returns of carbon reduction to an increasing carbon tax level are evident from the changing decrements in U.S aggregate GHG emissions across tax levels in Figure 2. These results are summarized in Table 2, which reports the cumulative reductions over the 24 year scenario period. The rows of Table 2 can be summed to account for differences among scenarios (e.g. from BAU to $20 / MT would be 1313 + 1217 = 2530 Million MT CO2e). The most apparent difference in the carbon reductions across scenarios is when the carbon tax is increased from $40
/ MT to $50 / MT and the reduction in carbon is 216.8 million MT CO2e. This is consistent with standard economic theory which suggests that the marginal cost of emission reductions should increase with the stringency of the policy. That is, there no threshold effects or non-convexities in the abatement marginal cost function (supply curve) implied by this model.

Table 2: Aggregated Emissions Reduction for Various Carbon Tax Levels

<table>
<thead>
<tr>
<th>Scenarios compared</th>
<th>Additional Amount of Emissions Reduction (Million MT CO2e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From BAU to $10 / MT</td>
<td>1313.3</td>
</tr>
<tr>
<td>From $10 / MT to $20 / MT</td>
<td>1217.8</td>
</tr>
<tr>
<td>From $20 / MT to $30 / MT</td>
<td>1128.6</td>
</tr>
<tr>
<td>From $30 / MT to $40 / MT</td>
<td>918.1</td>
</tr>
<tr>
<td>From $40 / MT to $50 / MT</td>
<td>216.8</td>
</tr>
</tbody>
</table>

Another concern is the demand response that a carbon tax would have on the final fuels. Given the higher prices of fuels, consumers will respond with a reduction in final fuel consumption. This is in contrast to the LCFS in that the LCFS will incentivize the consumption of lower-carbon fuels (those with a carbon-intensity below the standard) instead of disincentivizing all fuels consumed in proportion to their carbon intensity. Observing Figure 2, it becomes apparent that the reduction of consumption in the higher carbon intensive fuels (CNG, gasoline, and diesel) remains the most pertinent impact of the carbon tax. Overall, the $25 / MT carbon tax amounts to a 6.4% reduction in national fuel usage relative to the BAU scenario over the 2012-2035 time period.
This leads to the assessment of final fuel prices given the carbon tax implementation. On average, final fuel prices rose approximately 1.3% from the BAU case to the $25 / MT scenario. The largest contributor to this increased average price is E10 which rose approximately 1.5% with the implementation of the carbon tax. The same relative increases are applicable in the primary fuel supply prices where the higher carbon intensity fuels see the greatest price increase relative to the lesser-CI fuels. It is important to note here that it is not solely the ‘price at the pump’ driving demand reductions. The primary driving factor behind reduced consumption is that the production of these fuels is more costly and thus there is a two-way, downward pull from both producers and consumers.

It is important to evaluate the government revenues from the carbon tax, which are the product of aggregate emissions and the level of carbon tax. Tax revenues are presented in Table 3. As demonstrated earlier, the decreasing additional abatement given equal increases in the carbon tax leads to much greater tax revenues across carbon tax levels. The tax revenue varies between
approximately $470 billion and approximately $2.2 trillion, for a CT between $10 / MT and $50 / MT respectively.

Table 3: Tax Revenue from Selected Carbon Tax Amounts ($millions)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>BAU</th>
<th>$10 / MT</th>
<th>$20 / MT</th>
<th>$30 / MT</th>
<th>$40 / MT</th>
<th>$50 / MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax Revenue (total 2012-2035)</td>
<td>0</td>
<td>469,974</td>
<td>915,591</td>
<td>1,339,529</td>
<td>1,749,313</td>
<td>2,175,798</td>
</tr>
<tr>
<td>Average Annual Tax Revenue</td>
<td>0</td>
<td>19,582</td>
<td>38,149</td>
<td>55,813</td>
<td>72,888</td>
<td>90,658</td>
</tr>
</tbody>
</table>

Lastly, given the strengths of the regional expansion of the model, the distributional effect of the carbon tax on the various census divisions\(^3\) will be assessed. Given the total cost of $1.13 trillion over the 2012-2035 time period (average annual cost of $47.1 billion), Figure 3 provides the regional contributions of each census division. There are two primary factors at play in determining the overall contribution of each region to the aggregate amount of taxes paid. The first is the overall quantity of fuel consumed and the second is the availability and deployment of low carbon fuels. The easiest example of this is that the East North Central region (Wisconsin, Michigan, Illinois, Indiana, and Ohio) consumes, on average from 2012 to 2035, 17% of fuel in the United States yet is left accountable for only 13% of the tax liability. This reflects the much greater estimated deployment of biofuels relative to the rest of the nation. Another viewpoint that is useful, presented in Table 4, is the total tax liability per capita (since energy usage changes by scenario).

\(^3\) A map of the census division breakdown can be found here: http://www.eia.gov/forecasts/aeo/pdf/f1.pdf
Table 4: Tax Liability per Capita by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>$1000 per Capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England</td>
<td>3.092</td>
</tr>
<tr>
<td>Middle Atlantic</td>
<td>2.734</td>
</tr>
<tr>
<td>East North Central</td>
<td>3.148</td>
</tr>
<tr>
<td>West North Central</td>
<td>4.328</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>3.841</td>
</tr>
<tr>
<td>East South Central</td>
<td>4.226</td>
</tr>
<tr>
<td>West South Central</td>
<td>4.474</td>
</tr>
<tr>
<td>Mountain</td>
<td>3.951</td>
</tr>
<tr>
<td>Pacific</td>
<td>3.079</td>
</tr>
</tbody>
</table>

Discussion and Limitations

This paper has evaluated the impact that a carbon tax on transportation fuels would have on the (isolated) US transportation fuel market. The analysis assesses both the price and supply impacts of a carbon tax, concluding with an evaluation of the tax revenues and regional incidence associated with the various levels of a carbon tax. One main conclusion is to illustrate the expected decreasing marginal abatement for equal increases across carbon tax amounts.

The transportation sector has been seen as very rigid in its capability for larger drawdowns of carbon. The Waxman-Markey assessment estimated that reduction in transportation-related emissions would be modest with an economy-wide carbon tax (Center for Climate and Energy...
Solutions, 2010). The reductions would contribute between only 1% to 3.5% of total reductions by 2020 and 2.6% to 8.5% of total reductions by 2030. Our results indicate a carbon tax of $50/MT is needed for about a 10% reduction in vehicle GHG emissions. In this analysis, the carbon tax was more effective than an LCFS, but reduced emissions primarily through the reduction of total fuels consumed and not from substituting in lower-CI fuels such as an LCFS (Rubin et al. 2014).

One primary feature of this investigation is that the transportation fuel market is the only market affected by the carbon tax. In this sense, the analysis isolates the impacts that the carbon tax would have on the economy and limits the investigation to only the transportation fuel market. The results should be taken in this sense and the reader should be aware that a more complete cost-effectiveness assessment would include other sources of emissions as well (e.g. power companies and distributors). The estimated impact is therefore limited to the light and heavy duty vehicle sectors in the United States.

Another limitation is that the rates of carbon of emission per unit of primary fuel are considered fixed. An extension could be to include the capabilities for fuel producers to reduce the carbon intensity of their fuel blends through various means. One method is through carbon capture and sequestration in the production of fossil fuels. Another conflicting source of carbon intensity inaccuracies is in the potentially greater (or lesser) usage of higher-carbon intensity oil from the Canadian Oil Sands. A further extension of this modeling effort would be to evaluate the how changing domestic and international market for crude oil supply and trade could alter the estimated CI of petroleum fuels.
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