1. Problem Statement

As climate change awareness grows, several U.S. colleges and universities are tracking their greenhouse gas (GHG) emissions and have signed the American and University Presidents Climate Commitment (AUPCC), pledging to achieve climate neutrality. Rochester Institute of Technology in Rochester, NY is among the signers of the AUPCC. A 2009 GHG inventory revealed that 33% of university total carbon emissions, or over 29,000 metric tons, are from student, faculty, and staff commuting. These emissions are accumulated from driving to and from the campus each day. This amount of carbon is equal to the electricity use of 2,869 homes for a year or the amount of carbon that can be sequestered by 589,882 tree seedlings grown over 10 years.

2. Project Summary Background

Traditional approaches to achieving carbon reduction in commuting have included free bike rentals, free bus passes, reduced parking fees for carpools, and priority parking spots for hybrid vehicles. Several universities have also instituted parking permit fees; however, it is unclear whether these systems optimally set prices that achieve a specific emissions target. At our university, there are several factors that make these traditional approaches ineffective, such as the lack of convenient public transportation, safe bike routes, and the free cost of parking. Literature has proposed cap-and-trade policies to meet emission targets for urban transportation (Bulteau, 2012), personal transportation via fuel purchases (Wadud, 2011), and household energy use (Fleming, 1997). However, there is a gap in climate mitigation research to understand the social benefits and costs of cap-and-trade policy in campus settings where parking permits are the mode of emissions
regulation. To address the challenge of reducing GHG from campus commuting activities we have developed a neo-classical cap-and-trade model to determine the socially optimal price of parking permits. This approach is innovative in its use of survey data, market dynamics, and renewable energy offsets to achieve climate neutrality.

However, there are potential environmental and social tradeoffs to this approach. For example, when the quality of public transit is poor, increasing permit price puts undue burden on those least able to afford it. Also, if carbon offsets are purchased and developed a significant distance away from the local community, the expected air quality benefits will not be realized locally.

3. Relationship to Sustainability

This project increases environmental and social welfare by (1) reducing local health impacts of transportation emissions, (2) eliminating global climate change impacts, and (3) increasing community access to campus via the improvement of the public transit system and bike routes. Local transportation emissions produce particulate matter and sulfur dioxide, which contributes to smog and increased asthma rates. Fewer vehicles on the road means traffic congestion, biking hazards, smog, and asthma rates decrease. Furthermore, renewable energy offsets, e.g. installing solar photovoltaic arrays that effectively neutralize carbon emissions, mitigate potential global ecological damage such as drought and rising sea levels due to climate change. Lastly, if the campus chooses to invest in low-carbon commuting alternatives such as public transit there will be increased access to campus for students and other community members. These changes have the potential to increase access to nearby jobs and attract new business or new homeowners.

4. Materials and Methods
4.1 Cap-and-Trade Economic Model

Since we are interested in understanding how to reduce emissions at the firm level we follow (Bohringer & Lange, 2005) to develop a cap-and-trade scheme that maximizes the firm’s profit by deciding on the price, $p$, and quantity, $q$, of parking permits sold, as well as the number of parking lots or new bus routes to meet demand. The profit, $\pi$, is equal to the net present value of 10 years of revenue minus variable and fixed costs. Revenues are accrued from issuing parking citations and parking permits. Variable costs are calculated from labor, $L$, with a given wage, $w$. Labor includes parking officers who issue citations, parking lot maintenance e.g. snow plowing, and bus drivers. Fixed costs include the administration of the parking office, bus equipment, and the construction of parking lots. There are many ways to monetize the damage to human health and natural ecosystems due to carbon emissions. For example, putting a price on carbon equal to the damage caused or setting the price equal to the cost of mitigating and offsetting carbon emissions. In this paper, we choose the latter of the two options because mitigation and offset costs are straightforward to quantify and can be scaled linearly, whereas damage functions are typically non-linear (Tol, 2005). This mitigation cost or offset cost per ton of carbon dioxide emitted is denoted by $g$. The methods of direct mitigation we investigate in our model are (1) subsidizing a bus service for commuters and (2) investing in a renewable energy offset. Here an offset refers to a clean energy project e.g. solar photovoltaic (PV) array that is large enough to replace emissions generated by a coal power plant sources. Total carbon emissions due to commuting are denoted by $c$.

$$\pi = pq - wL - F - gc$$
The equation above is subject to several constraints such as the parking lot capacity, carpool capacity, bus capacity, the population of commuters, willingness to pay for permits, and the per capita emissions cap. In order to compute the net present value we also assumed a discount rate of 3%.

4.2 Data Collection

In order to understand the costs of parking operations, we interviewed the campus Director of the Parking and Transportation. The director provided information on parking lot capacity, parking operations costs, and university subsidized public transit costs. We were also able to learn about revenue from parking citations and labor costs from our discussion with the Director.

Next we met with the Senior Sustainability Officer (SSO) on campus who had recently completed a campus wide survey on commuting. The survey respondents self identified as students, faculty, or staff and disclosed their commuting behaviors e.g. distance, frequency, and vehicle fuel efficiency thorough a series of eight questions. From our interview with the SSO we learned about the expected return on investment of university clean energy projects and strategies the college has identified to reduce carbon emissions related to commuting.

Several literature and government sources were required to obtain model emissions, population, and offset parameters. The carbon content of gasoline, natural gas, and coal was obtained from the EPA (Energy Information Administration, 2008). The cost of a solar photovoltaic array was obtained from (Perez, Burtis, Hoff, Swanson, & Herig, 2004). We also utilized the university website to obtain data on faculty/staff wages (Naud, 2007) and the university population.
In addition, we consulted with professors in economics, sustainability, and public policy in order to fine tune our economic model, validate our assumptions, and provide feedback on developing subsequent surveys on commuter behavior.

4.3 Team Member Roles

The team leader was primarily responsible for developing the key variables/assumptions, for the Cap-and-Trade model, analyzing SSO commuting survey results, writing the report, and communicating with sources outside of the team. The other team member was primarily responsible for gathering background information on other university parking models, programming the Cap-and-Trade model, and interpreting the model results. Both team members collaborated to develop the math model.

5. Results, Evaluation, and Demonstration

5.1 Commuter Behavior Survey

The commuting survey performed by the SSO found that the majority of survey respondents live less than 10 miles from campus. Although, half of full-time students live on campus, only 25% of all students report commuting by bike, walking, or bus. On average, off-campus students live 8 miles closer to campus than faculty/staff. This gap may explain why students are more likely to bike or take public transportation than faculty and staff as shown in Table 1. Students were also more likely than faculty to have a diverse mix of commuting, e.g. 3 days a week personal vehicle 2 days a week public transit or carpool. Interestingly, off-campus students reported that that due to inadequate public transportation and bike routes they have no alternative transportation options beyond carpooling. As expected, those traveling further for each one-way commute had a
greater total annual commuting distance. Unexpectedly, those who live closer to campus commuted 6 or more times a week. This compares to those who live more than 5 miles who commuted 5 times or fewer per week. In the end, these three groups had several behaviors in common, namely their average vehicle fuel economy and a general preference for driving their personal vehicle over other alternative modes of transportation.

Table 1. Summary of University Commuter Survey Data

<table>
<thead>
<tr>
<th>Group</th>
<th>Population</th>
<th>Commutes Per Week</th>
<th>Personal Vehicle (%)</th>
<th>Bike, Walk or Bus (%)</th>
<th>Avg. Commuting Distance (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty</td>
<td>1,536</td>
<td>4.5</td>
<td>0.93</td>
<td>.02</td>
<td>14.8</td>
</tr>
<tr>
<td>Staff</td>
<td>2,217</td>
<td>5.0</td>
<td>0.93</td>
<td>.01</td>
<td>14.1</td>
</tr>
<tr>
<td>Students</td>
<td>9,054**</td>
<td>5.6 **</td>
<td>0.71*</td>
<td>.25*</td>
<td>6.5**</td>
</tr>
</tbody>
</table>

*All students **Off-Campus Only

5.2 Cap-and-Trade Model Results

There were three configurations of cap and trade schemes that we explored: (1) carpooling, (2) public transit by bus, and (3) renewable energy offsets. Each scheme is compared against the business as usual (BAU) case in Table 2. In the BAU case all off-campus students, staff, and faculty commute in a single-occupancy vehicles. In the carpooling scheme, we assume that off-campus students, staff, and faculty who do not buy a vehicle permit commute by carpool. In the public transit scheme, the university invests in new bus routes so that those who do not to buy a vehicle permit have access to public transit for their commute. The renewable energy offset scheme assumes the university invests in both public transit and installed solar photovoltaic technology in order to achieve carbon neutrality for commuting emissions.

The model results show that each Cap-and-Trade scheme achieves lower emissions and greater profit than BAU by increasing the permit price and reducing the number of
people commuting to campus in single-occupancy vehicles, Table 2. Both the carpooling and public transit schemes had CO2 emissions savings of greater than 50% the BAU. The renewable energy offset scheme achieves carbon neutrality with a combination of bus subsidies and solar photovoltaic installations. The Cap-and-Trade schemes achieve these CO2 milestones primarily through permit pricing. We noted initially in our sensitivity analysis that CO2 savings are less sensitive to a carbon cap of 1.9 CO2e tons per person, equal to 1990 levels, than to a change in the group’s willingness to pay for parking permits. CO2 emissions and savings were most sensitive to the assumed discount rate.

With the implementation of Cap-and-Trade, the majority of existing parking lots are empty which provides more options for offset projects such as tree planting or habitat restoration. These unoccupied parking lots are due to less than 50% of university commuters taking personal vehicles to campus. Of these, faculty and staff are least likely to commute by personal vehicle. This behavior occurs because the faculty/staff average commuting distance is greater and more carbon intensive than students. For this reason, the model seeks to find solutions where a smaller percent of faculty/staff commute by single-occupancy vehicles. The model’s behavior confirms that students contribute least to CO2 emissions per capita; therefore it is optimal for a larger portion of students to drive personal vehicles despite their greater average number of commutes per week.

Surprisingly, the Cap-and-Trade scheme that subsidizes public transit by bus has only an incremental impact on CO2 savings over carpooling. The public transit only scheme reduces CO2 emissions by only 2% more than carpooling alone. At the same time, the public transit scheme reduces profit over 10 years, reduces ROI, and increases payback time (PBT) by $7M, 500%, and 2.3 years respectively. Therefore, the economic
tradeoffs of public transit, from the university perspective may not be worth the incremental CO2 improvements.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Avg. Permit ($)</th>
<th>Vehicles (%)</th>
<th>%CO2 Savings</th>
<th>ROI (%)</th>
<th>PBT (yrs.)</th>
<th>Profit ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>0</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Carpooling</td>
<td>308</td>
<td>0.46</td>
<td>0.52</td>
<td>6.63</td>
<td>0.25</td>
<td>13.59</td>
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<tr>
<td>Public Transit</td>
<td>401</td>
<td>0.44</td>
<td>0.54</td>
<td>1.54</td>
<td>2.55</td>
<td>7.02</td>
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<tr>
<td>Renewable Offsets</td>
<td>442</td>
<td>0.40</td>
<td>1.00</td>
<td>0.37</td>
<td>3.08</td>
<td>2.89</td>
</tr>
</tbody>
</table>

Table 2. Optimal Permit Price, Percent Vehicles with Permits, Percent CO2 Savings, ROI, Payback Time (PBT), and Profit over 10 years for each Cap-and-Trade Scheme

The model results demonstrate a critical tradeoff between economic and environmental benefits. For each Cap-and-Trade Scheme, the greater the CO2 benefits, the more initial investment required, the longer the payback time (PBT), and the smaller profit over 10 years. When choosing between these three Cap-and-Trade schemes a university will need to weigh whether each meets their expected payback time and what their goal for CO2 reductions. Beyond economic benefits to the university, Cap-and-Trade schemes also have potential human health and natural ecosystem benefits. For the carpooling and public transit schemes a 50% savings in CO2 emissions is equivalent to the carbon sequestered annually by 10,782 acres of U.S. forest. The renewable offsets scheme goes further with 100% savings in CO2 emissions which is equivalent to GHG emissions avoided by recycling 9,853 tons of waste instead of sending it to landfill or burning 113 railcars’ worth of coal.

This approach can be transferred to many similar settings such as private or public organizations that desire to reduce their carbon footprint and generate revenue. In order to incorporate these ideas organizations need to understand the commuting behavior of employees or customers, incomes, return on investment, and parking capacity. These methods are scalable for organizations where a public transit infrastructure is already in
place, the majority of employees or customers commute by vehicle, and where parking options are limited.

6 Conclusions

The model results show that each Cap-and-Trade scheme achieved lower emissions and greater profit than BAU by increasing the permit price and reducing the number of people commuting to campus in single-occupancy vehicles. The Cap-and-Trade scheme that subsidizes public transit by bus has only an incremental impact on CO2 savings over carpooling but a much worse ROI. The model results demonstrate a critical tradeoff between economic and environmental benefits, that is, the greater the CO2 savings the smaller the ROI. Sensitivity to parameters values show that the assumed discount rate has the greatest impact on ROI and CO2 savings. The optimal permit prices set by the model are similar to those adopted in other universities that have worked to reduce the carbon footprint of commuting. Future work refining our model would include parameters that quantify driver preference for vehicle use over public transit such as travel time. We would also create more groups to account for variations in income and commuting distance within currently defined faculty/staff groups. The findings from this have a high potential impact as they will be presented at the Association for the Advancement of Sustainability in Higher Education (AASHE) conference and have been praised by the university’s Senior Sustainability Officer for their depth and innovation.
References


