The power and value of green in promoting sustainable transport behavior

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Abstract

While it is increasingly popular to broadcast information regarding environmental impact, little is known regarding the effects that this information has on human behavior. This research aims to provide insight into whether, and to what extent, presenting environmental attributes of transport alternatives influences individual transport decisions. We designed and conducted three experiments in which subjects (UC Berkeley undergraduates) were presented with hypothetical scenarios of transport decisions, including auto purchase choice, mode choice, and route choice. We analyzed their decisions via a choice model to determine how they value reducing their emissions relative to other attributes. We found that our subjects are willing to adjust their behavior to reduce emissions, exhibiting an average willingness to pay for emissions reduction, or value of green (VoG), of 15 cents per pound of CO₂ saved. Despite concern that people cannot meaningfully process quantities of CO₂, we found evidence to the contrary in our subject pool in that the estimated VoG was consistent across context (the wide range of transport decisions that we presented) and presentation (e.g., whether the information was presented in tons or pounds, or whether a social reference point of the emissions of an average person was provided). We also found significant heterogeneity in VoG, with most of the respondents valuing green somewhere between 0 and 70 cents per pound and with women, on average, willing to pay 7 cents more per saved pound than men. While the findings are encouraging, further work is required to determine whether they hold outside of a lab environment and with a more representative pool of subjects.

Keywords: emissions reduction, transport behavior, choice model, mixed logit, value of green

1. Introduction

The key issue with understanding any sort of behavior is in knowing how the decision maker values and reacts to the information that is available. Not only do people make trade-offs regarding the readily available personal costs and benefits of their actions, but less blatant externalities may also be considered. One externality that has become a popular topic is the damage associated with greenhouse gas emissions. In the realm of transport behavior, information regarding environmental impact has begun appearing on numerous websites, including mode specific websites such as the Bay Area Rapid Transit Trip Planner and trip planning sites such as routeRANK (see figure 1). However, little is known regarding what impact, if any, such information has on transport decisions. The large contribution of passenger transport to overall emissions makes this critical to understand; direct emissions from motor vehicles are the largest contributor to total household emissions (Jones and Kammen 2011), and passenger transport is responsible for approximately 20% of greenhouse gas emissions in the US (Chester 2008) and as high as 40% in California (ARB 2009).
This research builds on a large body of literature that investigates drivers’ response to travel information (see Chorus (2007), for a review) and that investigates travelers’ values of travel time savings in making transport decisions (see Hess et al (2005), for a review). Whereas the focus in such literature has been on time, cost, and reliability of travel alternatives, we use similar methods and add environmental factors to the mix. We have several objectives. The first is to determine whether and to what extent travelers are willing to modify their behavior to save emissions. The second is to investigate whether subjects can process ‘pounds’ of CO2 in a meaningful way. The third is to investigate heterogeneity in response to emissions information. The fourth is to determine the sensitivity of response to presentation style of the emissions information. The policy implication of this work is that, if influential, emissions information could be used to encourage more sustainable transport choices.

2. Literature

Despite increasing awareness of the consequences of greenhouse gas emissions, there is a gap in the literature regarding if and how this type of environmental information influences transport decisions (Avineri and Waygood 2010). There have been several studies involving trade-offs people are willing to make in order to reduce emissions, but many are specific to certain decisions and are not easily generalized to transport behavior. For example, Saphores et al (2007) asked households whether or not they were willing to pay nothing, 1%, 5%, or 10% more for green cell phones and computers relative to conventional. They found the average household willing to pay only a 1% premium. Schubert et al (2010) investigated willingness to pay for green restaurants and found that 65% of respondents stated they were willing to pay at least a 10% premium over standard restaurants, whereas 15% were not willing to pay anything. Choudhury et al (2008) estimated willingness to pay for a variety of environmental improvement scenarios and found that while subjects with higher income have a higher willingness to pay for environmental improvement, this is mostly caused by their lower cost sensitivity rather than their environmentalism. While primarily focused on electricity and water, they also investigated driver behavior under various emissions fee scenarios. They were unable to estimate significant willingness to pay for increased fuel efficiency, but found significant socio-demographic influences (e.g., younger respondents or respondents with higher incomes were more likely to purchase clean vehicles).

Our specific interest is the impact that the presentation of equivalent pounds of CO2 has on individual transport decisions. There have been limited studies in this area. As with the literature above and our own work presented in this paper, most of the work employs stated preference techniques in which subjects are presented with hypothetical transport alternatives (described by relevant attributes) and then asked which they would select. Achtnicht (2009) studied car purchase behavior in Germany, and from this estimated a willingness to pay of $0.22 per pound of CO2 savings (€349 per tonne). Further, he found that willingness to pay was higher for females (relative to males), younger persons (under 45 relative to older than 45), and those with higher education. In our earlier work (Gaker et al 2010), we estimated a willingness to pay of $0.24 per pound of CO2 savings in auto purchase and route choice behaviors. Interestingly, while the Achtnicht (2009) and Gaker et al (2010) estimates are similar in magnitude, they are much higher than the $0.01 per pound
findings. Waygood and Avineri (2011) focus on how travelers perceive the sustainability of travel alternatives and found differences based on how emissions are presented, such as whether emissions are described in pounds or trees and whether the reference alternative is a bus or SUV.

3. Research approach and outline of the paper

In this paper, we retain the focus on pounds of CO₂ due to its prevalence, for better or for worse, as the dominant metric for reporting greenhouse gas emissions (Avineri and Waygood 2010). We build on the initial findings from Achtchnitt (2009) and Gaker et al (2010) by investigating the consistency with which subjects value reducing their emissions across context (meaning different transport decisions) and presentation (e.g., including a social reference or presenting yearly rather than daily emissions), and we further explore how this value varies across subjects.

Here we present experimental results in which our subjects (UC Berkeley undergraduates) are presented hypothetical scenarios regarding various transport decisions and asked to state their preferences. The choice contexts range from longer-term auto ownership decisions to shorter-term route choice decisions. We also vary the manner in which the CO₂ is presented (e.g., pounds versus tons) to study the sensitivity of presentation. In stating their preferences, the subjects reveal information regarding the trade-offs they are willing to make among attributes such as cost, time, and emissions. We then estimate logit and mixed logit models to infer the sensitivity of our subjects to the attributes. From these models we estimate a willingness to pay for greenhouse gas reduction, which we call value of green (and heretofore denote as VoG), and test whether VoG is significant and whether it varies across context, presentation, and individuals.

Section 4 describes the experiments. This is followed by a presentation of the estimation results. First we present the key findings regarding the estimated average VoG and its consistency across the choice contexts. Then we present estimation results aimed to explore the heterogeneity of VoG in the population. We then conclude with a discussion of our findings.

4. Experiments

Our experiments were conducted using UC Berkeley undergraduates in the Experimental Social Sciences Laboratory (XLab) in the Haas Business School. The subjects are recruited by the lab and paid $15 per h. We conducted three primary experiments: an auto ownership question of whether to buy a car (and what type), a mode choice question of whether to use the car or some other mode on a given trip, and a route choice question regarding which route to take on a specific auto trip. Each is described below. Note that while these experiments were designed to investigate a multitude of questions, our discussion here focuses on the influence of emissions information on the subjects’ decisions.

4.1. Auto ownership experiment

In this experiment subjects were presented with a hypothetical scenario in which they had graduated, found a job, and had a place to live in a described urban environment. They were then asked whether they were most likely to buy a hybrid vehicle, a conventional vehicle, or not to own a car. The two vehicle options were characterized by purchase price, annual operating cost, and annual greenhouse gas emissions. This experiment had a social norm focus, and so they were also given information on decisions made by their peers. Figure 2 provides an example screenshot from the experiment. The scenario shown is that of a suburban living situation, which was presented to half of the subjects; the other half was given a mixed-use neighborhood scenario. As with all of our experiments, we employed experimental design methods (see Louviere et al 2000) to generate different profiles, which varied over respondents. This experiment was conducted on 312 subjects in the summer and fall of 2009.

4.2. Mode choice experiment

In this experiment subjects were again presented with a post-graduation scenario and were asked questions regarding what mode they would select for their daily commute to work. They were provided screenshots of a smartphone application that displayed three alternative transport modes and their attributes, such as that shown in figure 3. Varying combinations of auto, train, bus, bike and walk alternatives were provided. All modes included information on time, cost, and greenhouse gas emissions. This experiment had an information provision focus, and so some auto and transit alternatives included real-time information, and some biking and walking alternatives included calories burned and information on facilities. The subjects were asked to indicate which mode they would select for their daily commute. This experiment was conducted on 334 subjects in the summer of 2010 (different from the 312 in the auto choice experiment), with each subject making a selection from a unique choice set five times.

4.3. Route choice experiment

Our third experiment concerns which route to take to reach a destination for an auto trip. This was a redesign of our earlier experiment reported in Gaker et al (2010), where in this case we honed in on issues related to greenhouse gas emissions. Subjects were told that they were going to make a trip by car and were asked to select a route from three alternatives. Each route was described by time, variation of time, cost (in terms of a toll), greenhouse gas emissions, and relative safety. We introduced several variations to test sensitivity to context and presentation. To test whether our subjects had a different VoG for different types of trips, some of the subjects were presented with a recreation trip and others were presented with a commute scenario. To determine whether the scale of the information impacted VoG, some of the commuters were given daily values as shown in figure 4 and others were given yearly values. To provide more intuition on the meaning of a pound of CO₂, some received information regarding the emissions caused by the average American commute. Our final
Suppose you are graduating this semester and you have been offered an exciting job that will pay $45,000 per year. Considering all your options, you will most likely take this job. You have also been offered a great deal to live in a nice house in a suburban neighborhood, which you will also accept. The neighborhood is a typical residential area on the outskirts of the city; the house is nice with a yard although you have limited walking access to retail and grocery stores. Driving from home to your job (one way) will take about 30 minutes and taking public transport will take about 60 minutes (also door to door, one way).

Given this scenario, we ask that you consider your car purchase. If you own or have access to a car now, assume you will not take it with you. Two car options are described below. Please carefully evaluate the attributes and state whether you would buy one of these cars (and which one) or if you would not buy a car and rely on walking, biking, and public transportation.

You may be interested in the choices made by some of your peers in the lab right now, which are displayed below:

- 4 of your peers chose a conventionally fueled vehicle.
- 6 of your peers chose a hybrid vehicle.
- 2 of your peers chose not to buy a car.

| Attributes                  | Conventional Vehicle | Hybrid Vehicle |
|-----------------------------|----------------------|----------------|
| Purchase Price ($)          | 16,000               | 22,000         |
| Annual Cost ($/year)        | 5,000                | 4,300          |
| Greenhouse Gas Emissions (tons/year) | 3.2                  | 3              |

Please Select One:  
- O Conventional Vehicle  
- O Hybrid Vehicle  
- O No Vehicle

Figure 2. Example screenshot from the auto ownership experiment.

Figure 3. Example screenshot from the mode choice experiment.

Subjects who made more selfish selections were paid $18 and subjects who made more environmentally conscious selections were paid $12 and a donation was made to an on-campus sustainability fund. The general structure of the payout (and donation) was described to subjects in the variable pay group; however, they were not told the specific values of the payouts. This experiment was conducted on the same 334 subjects as the mode choice experiment in the summer of 2010, with each subject making a selection from a unique choice set five times.

5. Model specification

We employ logit and mixed logit (or random parameter) specifications to model the choices of the subjects and infer how they value different attributes relative to each other. In such models, the utility $U$ that individual $n$ associates with alternative $i$ in choice context $t$ is given by the equation $U_{i,t,n} = \beta_n' X_{i,t,n} + \epsilon_{i,t,n}$, where $X_{i,t,n}$ is a column vector of explanatory variables (characteristics of the decision maker and attributes of the alternative and context), $\beta_n$ is a column vector of taste parameters, and $\epsilon_{i,t,n}$ is an error that is iid extreme value across alternatives and choice contexts and individuals. The utility equation can be more generally written as $U_{i,t,n} = V_{i,t,n}(\beta_n) + \epsilon_{i,t,n}$, where in this case $V_{i,t,n}(\beta_n) = \beta_n' X_{i,t,n}$. If the parameters do not vary across the population (i.e., $\beta_n = \beta$ for all $n$) and assuming that the alternative with maximum utility is chosen, then the probability with which person $n$ chooses alternative $i$ from choice set $C_{it}$ in context $t$ is logit:

$$P_n(i_t) = \frac{\exp(V_{i,t,n}(\beta))}{\sum_{j \in C_{it}} \exp(V_{j,t,n}(\beta))}.$$
If the taste parameters vary randomly across the population with density \( f(\beta) \), then the probability with which person \( n \) chooses a sequence of \( T \) choices \( i = (i_1, \ldots, i_T) \) is mixed logit:

\[
P_n(i) = \int \prod_{t=1}^T \frac{\exp(V_{i,n}(\beta))}{\sum_{j \in C_{i,n}} \exp(V_{j,n}(\beta))} f(\beta) \, d\beta.
\]

We use the mixed logit specification to capture both unobserved correlations across alternatives as well as random taste heterogeneity.

Our primary focus is to estimate the value of green (VoG). Value of time (VoT) is also of interest because we have some intuition as to what is a reasonable VoT, and so we can use this to judge the quality of the responses. VoG and VoT are both marginal rates of substitution (MRS), equal to the trade-off that one can make between two attributes and maintain the same level of utility. These are both willingnesses to pay where the trade-off is between a non-price attribute (CO2 for VoG and time for VoT) and the price. In a linear in parameters model where

\[
U_{in} = \beta_k x_{ink} + \beta_p p_{in} + \ldots + \epsilon_{in}
\]

the bottom line of the equation shows the specification that is estimated where \( \beta_{MRS} \) and \( \beta_p \) are estimated directly. We do this for both VoT and VoG, and all coefficients in the model other than those for time and green are unchanged in the re-parameterization. The probability equations as written above remain unchanged, although \( \exp(V_{i,n}(\beta)) \) is now non-linear in the parameters and the parameter vector \( \beta \) includes both WTP parameters (for VoG and VoT) as well as standard coefficients (for all but time and green). Ben-Akiva et al (1993), Train and Weeks (2005), and Sonnier et al (2007) have employed such specifications, and Scarpa et al (2008) provide a thorough discussion of its advantages.

The unknown parameters are the fixed parameters \( \beta \) and the parameters of \( f(\beta) \), and these are estimated via maximum (simulated) likelihood estimation using the free discrete choice estimation software Biogeme (Bierlaire 2003). Ben-Akiva and Lerman (1985) and Train (2009) provide further information on logit and mixed logit models.

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### Figure 4. Example screenshot from the route choice experiment.

| Alternatives                  | Route 1 | Route 2 | Route 3 |
|-------------------------------|---------|---------|---------|
| **Attributes**                |         |         |         |
| Time (minutes/day)            | 80      | 90      | 100     |
| Variation of Time (minutes)   | ±5      | ±18     | ±12     |
| Toll (dollars/day)            | $4.00   | $0.00   | $2.00   |
| Greenhouse Gas Emissions (pounds/day) | 5      | 3       | 2       |
| Safety                        | 1       | 3       | 2       |

Please Select One: O O O
6. Empirical results I—homogeneous value of green (and value of time)

In this section, we present and discuss results estimated from basic models that do not incorporate random taste heterogeneity in VoG and VoT. Section 7 will relax this constraint. The estimation results for the basic models are shown in tables 1–3, one table for each experiment. For each model, we include as explanatory variables all of the attributes that were presented to the respondents. The auto ownership and route choice models are logit. The mode choice model is mixed logit to capture unobserved correlation among the walk and bike alternative (all other correlations across alternatives were insignificant). The first thing to note is that the models perform well in that all parameters (whether preference coefficients or WTP) have expected signs and most are highly significant.

We focus our discussion on the key parameters of VoT and VoG, starting with the VoT. We can estimate VoT when we have cost and time data, which occurs in both the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.) Our results indicate that our subjects had similar VoT in the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.) Our results indicate that our subjects had similar VoT in the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.) Our results indicate that our subjects had similar VoT in the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.) Our results indicate that our subjects had similar VoT in the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.) Our results indicate that our subjects had similar VoT in the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.) Our results indicate that our subjects had similar VoT in the mode choice and route choice experiments. (For the auto experiment, time was part of the housing scenario and cannot be distinguished from the suburban dummy.)

Table 1. Estimation results from auto ownership experiment.

| Explanatory variable—applicable alternatives | Estimate | Units | StdErr | p-value |
|---------------------------------------------|----------|-------|--------|---------|
| Alternative specific constant—hybrid alternative | 0.990 | | 0.449 | 0.027 |
| Alternative specific constant—no car alternative | -1.010 | | 0.294 | 0.001 |
| Dummy = 1 if suburban scenario (vs urban)—no car alternative | -1.760 | | 0.289 | <0.001 |
| % of peers reported to choose alternative—all alternatives | 1.410 | | 0.545 | 0.010 |
| Vehicle purchase price—auto alternatives | -0.258 | 1/$1000 | 0.055 | <0.001 |
| Vehicle annual operating cost—auto alternatives | -0.231 | 1/$1000 | 0.105 | 0.028 |
| Value of green—auto alternatives | 0.143 | $/pound CO2 | 0.095 | 0.133 |

Number of observations: 312 subjects × 1 response each
Log-likelihood: -276.63
Adjusted rho-square: 0.173

Table 2. Estimation results from mode choice experiment.

| Explanatory variable—applicable alternatives | Estimate | Units | StdErr | p-value |
|---------------------------------------------|----------|-------|--------|---------|
| Alternative specific constant—bike | -3.270 | | 1.130 | 0.004 |
| Alternative specific constant—bus | 0.372 | | 0.138 | 0.007 |
| Alternative specific constant—train | 0.411 | | 0.129 | 0.001 |
| Alternative specific constant—walk | -0.841 | | 1.050 | 0.423 |
| Reported cost of mode—auto, bus, train | -0.710 | 1/$ | 0.126 | <0.001 |
| Value of time—all alternatives | 7.800 | $/h | 1.044 | <0.001 |
| Value of green—auto, bus, train | 0.166 | $/pound CO2 | 0.059 | 0.005 |
| Error correlation coefficient—walk, bike | 9.580 | | 2.210 | <0.001 |

Number of observations: 334 subjects × 5 responses each
Log-likelihood: -1471.04
Adjusted rho-square: 0.194

Table 3. Estimation results from route choice experiment.

| Explanatory variable (each enters all alternatives) | Estimate | Units | StdErr | p-value |
|--------------------------------------------------|----------|-------|--------|---------|
| Variation of travel time | -0.035 | 1/min | 0.010 | <0.001 |
| Reported cost (toll) | -0.494 | 1/$ | 0.047 | <0.001 |
| Free dummy = 1 if the route has no toll cost | 0.639 | | 0.133 | <0.001 |
| Safety (1 below average, 2 average, 3 above average) | 0.616 | | 0.048 | <0.001 |
| Value of time | 8.820 | $/h | 0.924 | <0.001 |
| Value of green | 0.144 | $/pound CO2 | 0.018 | <0.001 |

Number of observations: 334 subjects × 5 responses each
Log-likelihood: -1072.61
Adjusted rho-square: 0.412
wage at the time of the experiment was $8.00/h). This provides some assurance that our subjects were taking the choice tasks seriously and performing in a behaviorally realistic manner.

Turning to VoG, here we have much less to go on compared with VoT in terms of the expected value. We can estimate VoG from each of the three experiments because each involves cost and emissions information. As shown in the tables, our subjects had remarkably consistent VoG: 14 cents per pound for auto ownership, 17 cents per pound for the mode choice, and 14 cents per pound for route choice. Estimating the three models jointly where the VoG is constrained to be the same across the three experiments leads to an estimated VoG of 15 cents per pound and minimal changes to the other model parameters (detailed results are not shown due to space). A likelihood ratio test (see Ben-Akiva and Lerman 1985, p 164) does not reject the null hypothesis that the VoG is the same across experiments (the log-likelihood of the constrained model is \(-2820.289\) versus \(-2820.287\) for the unconstrained model, which results in a \(p\)-value of 0.998). This is encouraging considering the diversity of information presented to the subjects: tons of emissions and thousands of dollars in the auto ownership experiment versus pounds of emissions and single digit dollars in the mode choice and route choice experiments.

7. Empirical results II—heterogeneous value of green (and value of time)

In this section we investigate the heterogeneity of VoG across our subjects, first exploring random heterogeneity and second exploring systematic heterogeneity.

7.1. Random heterogeneity of VoG

While above we estimated a fixed parameter for VoG and VoT that applied to the entire population, here we use random parameter logit to explore how VoG and VoT are distributed in the population. Our approach employs methods used in the large body of literature on distribution of value of travel time savings (see Hess et al 2005). We specify that VoG and VoT vary across subjects according to independent lognormal distributions (lognormal so that the values are strictly positive). Each lognormal distribution has two parameters, location and scale, which are estimated.

The results of the models with lognormally distributed VoG and VoT are shown in tables 4–6. Application of likelihood ratio tests indicate that the random parameter specification did not lead to a statistically significant improvement in the case of the auto choice model (\(p\)-value of 0.97), but did significantly improve the fit of both the mode choice (\(p\)-value <0.001) and the route choice (\(p\)-value <0.001) models suggesting that there is taste heterogeneity in VoT and VoG. The auto ownership result is not too surprising given that we had only one auto choice response per person (rather than the five as in the other experiments), which makes it more difficult to capture random taste heterogeneity.

Both the estimated location and scale parameters of the lognormal distribution as well as the calculated means and standard deviations of the distributions are reported in the estimation tables. The distributions are plotted for comparison in figure 5 (for VoG) and figure 6 (for VoT). Here we note significant heterogeneity of these parameters within each experiment, as well as differences in the distributions across experiments. This is consistent with the findings in the transport literature and accepted in practice that value of travel time savings varies across context such as work trips and non-work trips (see, for example, Bradley et al 2010). However, despite the variability, there does seem to be some consistency in the range of VoG and VoT values where the majority of the population resides. The range for the VoT seems a bit high for these subjects; however, in most instances they were given a post-graduation scenario. In terms of the VoG distributions, the mode choice results show the greatest variability with a significant portion of the distribution concentrated near zero (subjects who do not consider CO2) and a long right tail (subjects who care a lot about CO2). However, 90% of the mode choice distribution is below $0.70/pound. For route choice, the 90th percentile is at $0.30/pound, and for auto ownership the 90th percentile is at $0.22/pound. The 50th percentiles show less variability, with mode choice at $0.06/pound, auto choice at $0.13/pound, and route choice at $0.09/pound.

7.2. Systematic heterogeneity of VoG

While above we estimated random heterogeneity of VoG, we did not investigate the source of the heterogeneity. The design of our route choice experiment (described above) allows us
slightly worse fit in terms of log-likelihood. The advantage in table 6 because it has five more parameters and yet a route choice model in table 3 (likelihood ratio test $p$-value). This model is a significant improvement over the homogeneous model related to demographics, context, and presentation of CO$_2$. The results were faced with commutes. Similarly, presenting commuters more per pound) than their male counterparts (consistent with Achtnicht 2009). Subjects who were presented with recreation heterogeneity. According to the results, our female subjects significantly valued reducing their emissions more (7 cents more per pound) than their male counterparts (consistent with Achtnicht 2009). Subjects who were presented with recreation trips did not have significantly different VoG than subjects who were faced with commutes. Similarly, presenting commuters with information on the emissions associated with the average American commute or presenting CO$_2$ on an annual basis.

### Table 4. Estimation results from auto ownership experiment with distributed VoG.

| Explanatory variable—applicable alternatives | Estimate | Units | StdErr | $p$-value |
|---------------------------------------------|----------|-------|--------|-----------|
| Alternative specific constant—hybrid alternative | 0.998 | 0.455 | 0.028 | |
| Alternative specific constant—no car alternative | −1.010 | 0.298 | 0.001 | |
| Dummy = 1 if suburban scenario (vs urban)—no car alternative | −1.780 | 0.299 | <0.001 | |
| % of peers reported to choose alternative—all alternatives | 1.420 | 0.549 | 0.010 | |
| Vehicle purchase price—auto alternatives | −0.258 | $1/1000 | 0.056 | <0.001 | |
| Vehicle annual operating cost—auto alternatives | −0.233 | $1/1000 | 0.106 | 0.028 | |
| Value of green—lognormal location parameter | −2.020 | 0.826 | 0.014 | |
| Value of green—lognormal scale parameter | 0.405 | 0.899 | 0.652 | |

Number of observations: 312 subjects × 1 response each.
Log-likelihood: −276.61
Adjusted rho-square: 0.170

### Table 5. Estimation results from mode choice experiment with distributed VoG and VoT.

| Explanatory variable—applicable alternatives | Estimate | Units | StdErr | $p$-value |
|---------------------------------------------|----------|-------|--------|-----------|
| Alternative specific constant—bicycle | 0.837 | 0.261 | 0.001 | |
| Alternative specific constant—bus | 0.523 | 0.126 | <0.001 | |
| Alternative specific constant—train | 0.624 | 0.123 | <0.001 | |
| Alternative specific constant—walk | 2.120 | 0.492 | <0.001 | |
| Reported cost of mode—auto, bus, train | −0.470 | 1/$ | 0.081 | <0.001 | |
| Value of time—lognormal location parameter—all alternatives | −1.590 | 0.156 | <0.001 | |
| Value of time—lognormal scale parameter—all alternatives | 0.746 | 0.077 | <0.001 | |
| Value of green—lognormal location parameter—auto, bus, train | −2.850 | 0.669 | <0.001 | |
| Value of green—lognormal scale parameter—auto, bus, train | 1.990 | 0.206 | <0.001 | |
| Error correlation coefficient—walk, bike | 1.220 | 0.298 | <0.001 | |

Number of observations: 334 subjects × 5 responses each.
Log-likelihood: −1380.38
Adjusted rho-square: 0.247

### Table 6. Estimation results from route choice experiment with distributed VoG and VoT.

| Explanatory variable (each enters all alternatives) | Estimate | Units | StdErr | $p$-value |
|---------------------------------------------------|----------|-------|--------|-----------|
| Variation of travel time | −0.048 | 1/min | 0.011 | <0.001 | |
| Reported cost (toll) | −0.647 | 1/$ | 0.063 | <0.001 | |
| Free dummy = 1 if the route has no toll cost | 0.511 | 0.150 | <0.001 | |
| Safety (1 below average, 2 average, 3 above average) | 0.660 | 0.061 | <0.001 | |
| Value of time—lognormal location | −2.100 | 0.104 | <0.001 | |
| Value of time—lognormal scale | −0.465 | 0.097 | <0.001 | |
| Value of green—lognormal location | −2.360 | 0.162 | <0.001 | |
| Value of green—lognormal scale | −0.895 | 0.134 | <0.001 | |

Number of observations: 334 subjects × 5 responses each.
Log-likelihood: −1044.21
Adjusted rho-square: 0.426

to investigate specific sources of heterogeneity. The results are shown in table 7 in which the baseline VoG and VoT are modified based on explanatory variables (all 0/1 dummies) related to demographics, context, and presentation of CO$_2$. This model is a significant improvement over the homogeneous route choice model in table 3 (likelihood ratio test $p$-value $<0.001$), although it is inferior to the random parameter model in table 6 because it has five more parameters and yet a slightly worse fit in terms of log-likelihood. The advantage of this model is that it provides insight into the source of the heterogeneity. According to the results, our female subjects significantly valued reducing their emissions more (7 cents more per pound) than their male counterparts (consistent with Achtnicht 2009). Subjects who were presented with recreation trips did not have significantly different VoG than subjects who were faced with commutes. Similarly, presenting commuters with information on the emissions associated with the average American commute or presenting CO$_2$ on an annual basis.
evidence that our subjects could meaningfully process the homogeneous models indicate a value of green (VoG) of subjects have a higher VoG than the population at large. The Berkeley 2010). These characteristics would suggest that our sample, UC Berkeley undergraduates. Relative to the population at large, this group is highly educated, young, idealistic, and part of a community that is regularly recognized as being a national leader on environmental issues (UC Berkeley 2010). These characteristics would suggest that our subjects have a higher VoG than the population at large. The results are also influenced by the fact that the subjects were in a lab instead of making choices in the real world, which introduces a number of possible biases. One is that the subjects may answer in a way they believe we, the researchers, want them to answer and/or in ways that enhance their self-image. Further, in a lab there is no real impact on time or money budgets even though the choice situations are about making such trade-offs, and therefore it is easier for subjects to be swayed by other motives. While we attempted to address this for a subset of respondents by linking payout to responses, our design is still artificial. Also, even though we observed a consistency in value of green, this does not necessarily mean that the respondents understood the questions posed of them or are processing the data as we hypothesize. We aimed to design the choice experiments simple enough and yet realistic enough to minimize this effect, but it cannot be eliminated entirely. Finally, converting such values to actual reduction in auto emissions requires understanding of behaviors regarding who in the population would seek out such information. Indeed, our sample is likely to be overrepresented with individuals who would more actively seek out environmental information.

8. Discussion and conclusion

In this investigation into how our subjects respond to environmental feedback, we found surprising consistency in how they value CO2. Most seem to be willing to adjust their transport behavior to reduce CO2 emissions. Our basic (homogeneous) models indicate a value of green (VoG) of $0.15/pound of CO2, regardless of context (auto, mode, route) or presentation (pounds versus tons, daily versus annual). Our random parameter models exhibit greater variability, suggesting a median VoG of $0.06–$0.13/pound with over 90% of the distribution falling between $0.00 and $0.70/pound. Further, we found that females have a higher VoG than males (by $0.07/pound). Our results provide evidence that our subjects could meaningfully process the rather abstract notion of CO2 and that they value CO2 enough to vary their actions. This suggests that the wider provision of emissions information has potential for encouraging more sustainable transport decisions, at least for some members of the population.

There are a number of important caveats with this work. The first is that our numerical results are influenced by our sample, UC Berkeley undergraduates. Relative to the population at large, this group is highly educated, young, idealistic, and part of a community that is regularly recognized as being a national leader on environmental issues (UC Berkeley 2010). These characteristics would suggest that our subjects have a higher VoG than the population at large. The staff at UC Berkeley’s Experimental Social Sciences

### Table 7. Estimation results from route choice experiment with systematic VoT and VoG modifiers.

| Choice: which of three auto routes to take | Estimate | Units | StdErr | p-value |
|------------------------------------------|----------|-------|--------|---------|
| Variation of travel time                 | −0.040   | 1/min | 0.010  | <0.001  |
| Reported cost (toll)                     | −0.527   | 1/S   | 0.054  | <0.001  |
| Free dummy = 1 if the route has no toll cost | 0.577    |       | 0.136  | <0.001  |
| Safety (1 below average, 2 average, 3 above average) | 0.628    |       | 0.054  | <0.001  |
| Base value of time (VoT)                 | 9.780    | $/h   | 1.146  | <0.001  |
| VoT modifier—recreational trip (versus commute trip) | −0.948   | $/h   | 1.092  | 0.385   |
| VoT modifier—yearly travel time reported (versus daily) | −2.772   | $/h   | 0.972  | 0.004   |
| Base value of green (VoG)                | 0.063    | $/pound CO2 | 0.029 | 0.029   |
| VoG modifier—recreational trip (versus commute trip) | −0.017   | $/pound CO2 | 0.030 | 0.575   |
| VoG modifier—yearly travel time reported (versus daily) | −0.022   | $/pound CO2 | 0.024 | 0.362   |
| VoG modifier—female (versus male)        | 0.067    | $/pound CO2 | 0.023 | 0.003   |
| VoG modifier—average personal emissions provided (versus not) | −0.005   | $/pound CO2 | 0.024 | 0.827   |
| VoG modifier—payout a function of green behavior (versus not) | 0.112    | $/pound CO2 | 0.023 | <0.001  |

| Number of observations | 334 subjects × 5 responses each |
| Log-likelihood         | −1044.57 |
| Adjusted rho-square    | 0.424    |
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References

Achtnicht M 2009 German car buyers’ willingness to pay to reduce CO2 emissions Working paper (Centre for European Economic Research)  
ARB 2009 Facts About California Greenhouse Gas Emissions Inventory (www.arb.ca.gov/cc/factsheets/ghginv.pdf)  
Avineri E and Waygood O 2010 CATCH Carbon-Aware Travel Choice in the City, Region and World of Tomorrow. Behavioural inception report Project Report (European Commission)  
Ben-Akiva M, Bolduc D and Bradley M 1993 Estimation of travel choice models with randomly distributed values of time Transp. Res. Rec. 1413 88–97  
Ben-Akiva M and Lerman S R 1985 Discrete Choice Analysis: Theory and Application to Travel Demand (Cambridge, MA: MIT Press)  
Bierlaire M 2003 BIOGEME: a free package for the estimation of discrete choice models Proc. 3rd Swiss Transportation Research Conf. (Ascona)  
Bradley M, Bowman J L and Griesenbeck B 2010 SACSIM: an applied activity-based model system with fine-level spatial and temporal resolution J. Choice Modelling 3 (1) 5–31 (available at www.jocm.org.uk/index.php/JOCM/article/view/34)  
Chester M V 2008 Life-cycle environmental inventory of passenger transportation in the United States PhD Dissertation University of California, Berkeley  
Chorus C G 2007 Traveler response to information TRAIL Thesis Series nr.T2007/2 (The Netherlands TRAIL Research School)  
Choudhury C, Tsang F, Burge P, Rohr C and Sheldon R 2008 Measuring willingness to pay for green options European Transport Conf. (The Netherlands)  
Emissions 2010 www.ecx.eu (accessed 11/07/2010)  
Gaker D, Zheng Y and Walker J L 2010 Experimental economics in transportation: a focus on social influences and the provision of information Transp. Res. Rec. 2156 47–55  
Hess S, Bierlaire M and Polak J W 2005 Estimation of value of travel-time savings using mixed logit models Transport. Res. A 39 221–36  
Jones C M and Kammen D M 2011 Quantifying carbon footprint reduction opportunities for US households and communities Environ. Sci. Technol. 45 4088–95  
Louviere J J, Hensher D A and Swait J D 2000 Stated Choice Methods: Analysis and Application (Cambridge: Cambridge University Press)  
Saphores J D M, Nixon H, Ogunseitan O A and Shapiro A A 2007 California households’ willingness to pay for ‘green’ electronics J. Environ. Plan. Manag. 50 113–33  
Scarpa R, Thieme M and Train K 2008 Utility in willingness to pay space: a tool to address confounding random scale effects in destination choice to the Alps Am. J. Agric. Econ. 90 994–1010  
Schubert F, Kandampully J, Solnet D and Kralj A 2010 Exploring consumer perceptions of green restaurants in the US Tour. Hosp. Res. 10 286–300  
Sonnier G, Ainslie A and Otter T 2007 Heterogeneity distributions of willingness-to-pay in choice models Quant. Mark. Econ. 5 313–31  
Train K 2009 Discrete Choice Methods with Simulation 2nd edn (Cambridge: Cambridge University Press)  
Train K and Weeks M 2005 Discrete choice models in preference space and willingness-to-pay space Applications of Simulation Methods in Environmental and Resource Economics ed A Alberini and R Scarpa (Boston, MA: Kluwer Academic) pp 1–16  
UC Berkeley 2010 Campus Sustainability Report: Talking Louder Doing More (Berkeley, CA: UC Berkeley)  
Waygood E O D and Avineri E 2011 Does 500 g of CO2 for a five mile trip mean anything? Towards more effective presentation of CO2 information Presented at the 90th Annual Mtg of the Transportation Research Board