CONSUMER PREFERENCES FOR REFUELING AVAILABILITY: RESULTS OF A HOUSEHOLD SURVEY[1]

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Abstract
The market acceptance of hydrogen vehicles is contingent upon the availability of convenient refueling. An online survey was conducted with the goal of improving our understanding of the value placed on refueling availability by consumers. The survey was conducted in representative households in three major urban areas (Los Angeles, CA, Houston, TX, and New York, NY) and collected information on consumer perspectives on alternative fuel vehicles (AFVs) and the value of refueling availability at the local, regional, and national levels. Results from the survey were used to calibrate parameters in a multinomial discrete choice model of consumer behavior. The survey choices posed to respondents included the range, purchase price, and monthly fuel cost of two hypothetical vehicles identical to their most recently purchased vehicle, with one being a conventionally fueled vehicle and the other being an AFV. The AFV was described as emitting no smog forming pollutants, requiring virtually no oil imports, and emitting 30%-70% fewer greenhouse gas emissions, but potentially having limited refueling availability. Each AFV choice was accompanied by metropolitan, regional, and national maps indicating the location and prevalence of stations where the AFV could be refueled. This detailed and visual representation of station coverage allows for an improved quantitative estimate of the stated preference value of refueling availability.

1. Introduction

Consumers will be reluctant to purchase alternative fuel vehicles (AFVs) that can only be refueled at a small number of locations. Several studies have attempted to characterize this reluctance, including retrospectives on the introduction of diesel and natural gas vehicles [1-3], surveys of consumer preferences [4-7], and analytic models [8-12]. Though these studies have made significant contributions, a general representation of the value of refueling availability to consumers has yet to be characterized. This study examines consumer preferences on multiple geographic scales, and uses a discrete choice framework

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to represent these preferences [13, 14]. Because the results of this analysis are based upon stated consumer preferences, rather than revealed preferences, they should be viewed with a moderate dose of skepticism; stated preferences are often overstated. Nevertheless, these results provide important insights into consumer preference trends, and can inform ongoing efforts to quantify the benefits of infrastructure development.

The National Renewable Energy Laboratory (NREL) worked with PA Consulting and Knowledge Networks to conduct an online discrete choice survey in representative households located in three major urban areas: Los Angeles, CA, Houston, TX, and New York, NY. The surveys asked respondents to compare a hypothetical AFV to their most recently purchased vehicle, with the main advantage of the AFV being that it would require virtually no imported oil and would reduce smog emissions and greenhouse gas emissions. However, refueling availability for the AFV would likely be limited. The survey included maps, as well as quantitative descriptions, to indicate the extent of refueling availability associated with any particular vehicle choice. Consumer responses were used to determine the monetary value placed upon various vehicle and refueling availability attributes, and a simple market share equation (multinomial logit) was used to estimate hypothetical adoption rates by market share.

The defining characteristic of this discrete choice survey is the detailed representation of refueling availability on multiple geographic scales. The value of *metropolitan* refueling availability was found to be greater than most recently reported estimates. Moreover, our results differ from previous studies in that significant value was attributed to *regional* and *national* levels of refueling availability. The metropolitan results can be expressed in terms of station density (stations per square mile) rather than simply the percent of existing stations. This basis allows for more consistent comparisons among different urban areas.

Section 2 describes the online questionnaire, and Section 3 describes the utility function used to represent the survey results. Section 4 summarizes the results of the survey and the discrete choice analysis. Section 5 compares these results with those found in similar studies and examines their implications for a simplified discrete choice market share calculation. Section 6 summarizes the paper.

2. Survey design

The online discrete choice survey asked respondents to indicate their preference between two hypothetical vehicles, a conventional vehicle or an AFV, given a certain set of vehicle and refueling availability attributes. This survey was a revised version of a survey conducted in early 2007, the results of which were used to calibrate the consumer choice sub-model within the HyDIVE model [15]. The major improvement to this revised version of the survey was the use of maps to indicate the hypothetical location of alternative fueling stations for various geographic scales of refueling availability. In choosing which vehicle they would prefer, the respondents took into consideration both quantitative descriptions and visual representations of the different levels of refueling availability. In addition to representations of refueling availability, which only applied to the hypothetical AFV, other vehicle attributes included the vehicle purchase price, fuel cost, driving range, and social and environmental benefits. The survey was completed by 1,486 respondents in three major urban areas: Houston, TX, Los Angeles, CA, and New York, NY.

A series of introductory questions acquainted the respondents with the setup of the survey, the definitions used to describe vehicle and refueling attributes, and the maps used to represent refueling availability on three levels: their metropolitan area, metropolitan region, and nationwide along interstate highways connecting major cities. Questions also inquired about the make, model, and year of the vehicle most recently purchased by the respondents, and this information was used later in the survey to remind them – by labeling the different alternatives – that the hypothetical vehicle choices they were making were associated with a vehicle of the same make, model, and year.

Following this initial series of questions were ten discrete choice comparisons in which respondents were presented with a choice between a conventional vehicle (CV) and an AFV. The hypothetical AFV was described in generic terms, and was not described as being associated with any particular alternative fuel. Based upon answer to the introductory questions, respondents qualified to take the full survey if they had purchased a new vehicle within the last 3-4 years. It was made clear to qualifying respondents that the AFV would be identical to their recently purchased vehicle in all respects except two: 1) the number of locations where the vehicle could be refueled might be more limited than for a gasoline vehicle, and 2) the AFV would offer significant social and environmental benefits. The social and environmental benefits associated with the AFV were the following: 1) it would require virtually no imported oil, 2) it would produce no smog emissions, and 3) it would produce 30%-70% fewer greenhouse gases than a gasoline vehicle.

The attributes of each vehicle were shown side by side, and respondents were asked to indicate which one of the two vehicles they would purchase. The vehicle attributes varied between choices, according to a discrete choice algorithm developed by Zwerina, Huber, and Kuhfeld [16]. The algorithm employs a search strategy to generate balanced, efficient designs for choice experiments where multiple choices are presented. The attributes and descriptions used in the series of discrete choice questions are summarized in Table 1. The first column contains a description of the attribute, and the second and third columns show the attribute values and variables. Some of these variables are similar for all three cities and others are calculated with reference to the urban area where the respondent lives, relying upon demographic data and analyses of gasoline station networks [17].

After each respondent choice, the variables indicated in Table 1 would change among a set of different levels. The levels associated with each attribute are described in the Vehicle Attribute and Refueling Availability Attribute sections of Table 2 (consumer socio-demographics are explained in Section 3 below). For example, the vehicle purchase price (VPP) for each discrete choice would be shown as one of three values: equal to the price of the respondent's recently purchased vehicle (0% difference), 15% greater than this price, or 15% less. For the social and environmental benefits attribute, the AFV would always have these attributes and the conventional vehicle would not. For each choice, one level would be indicated for the AFV for the four types of refueling availability attributes: metropolitan area coverage (MAC), metropolitan regional coverage (MRC), long distance coverage (LDC), and interstate highway coverage (IHC). For example, for a choice in which the levels indicated for Los Angeles were MAC_2, MRC_2, LDC_1, and IHC_1, the refueling availability would be an average of 2.7 miles to the nearest metro area station, 39 stations within the metro region, no stations covering long distance trips, and no stations along interstate highways to major urban areas near Los Angeles. Note that IHC is not a different type of refueling availability, but rather an elaboration on the maps used to represent LDC.

The maps used to represent each level and scale of refueling availability for Los Angeles are shown in Figure 1, Figure 2, and Figure 3. Red dots indicate the location of alternative refueling stations. Comparable maps were used for respondents in Houston and New York. Though respondents had become familiar with these various maps during the introductory questions, thumbnail versions of the maps (large enough to see, but also clickable so that they could be expanded) were embedded on the screens along with the descriptions of each attribute (see Table 1). Therefore, for each discrete choice posed to the respondents, they were able to read the attribute descriptions indicated in Table 1 and see three different refueling availability maps (for MAC, MRC, and LDC) such as those indicated in Figure 1, Figure 2, and Figure 3. The frequency of stations along interstate highway routes (IHC) was shown as a distinct attribute.

3. Model formulation

A variety of models were applied to the data received from the discrete choice survey. One model formulation was found to provide the best fit to the preferences expressed by survey respondents. Some of the models that did not provide as good a fit used continuous variables to represent refueling availability attributes, and others used binary representations for all levels of refueling availability. The best fitting model used binary representations for different levels of refueling availability, but it did not explicitly include all of the levels; some levels were collapsed into single levels to improve the representativeness of the utility function (a rationale of this parameter change is provided below). This best fitting model is therefore referred to as the *collapsed binary* model. The model formulation described in this section outlines the general binary model, and the results presented in Section 4 describe the parameters associated with the different collapsed binary models used for each metropolitan area.

Table 1. Discrete choice questions.

Attribute and Definition	Conventional Vehicle	Alternative Fuel Vehicle
Social and Environmental Benefits. Since the alternative fuel is not gasoline or diesel, no oil is used or imported for the alternative fuel vehicle. For the alternative fuel vehicle, zero smog-causing emissions (which affect local air quality) are emitted from the vehicle. For the alternative fuel vehicle, greenhouse gas emissions (which are believed to contribute to global warming) are significantly reduced.	-	SEB
Driving Range. The total distance you can drive on a full tank. A shorter Driving Range implies that you would have to refuel your vehicle more frequently. For example, a vehicle with a 200 mile Driving Range would require refueling twice as often as a vehicle with a 400 mile Driving Range.	400 mi	DR_i
Metropolitan Area Coverage. Average distance to the nearest metro area refueling station is the distance you would have to travel, on average, to refuel your vehicle while remaining within the metro area where you live. 	Average Distance	MAC_i
Metropolitan Regional Coverage. Number of stations in the region within 150 miles of the metro area. With an alternative fuel vehicle, all trips within this region would be possible, but some destinations would require advance planning. 	Number of Stations	MRC_i
Long Distance Coverage. Long distance trips are trips outside the 150-mile radius surrounding the metro area where you live. Some long distance trips will not be possible with the alternative fuel vehicle due to limited station coverage. 	All destinations possible	LDC_i
Interstate Highway Coverage. This is the distance between stations when traveling between major cities.	Varies	IHC_i
Fuel Cost. This is the average monthly cost for fuel, assuming the type of vehicle you currently own and the number of miles you drive each month.	FC_{CV}	FC_{AFV}
Vehicle Purchase Price. This is the "net price" of the vehicle and already takes into account possible tax incentives or credits.	VPP_{CV}	VPP_{AFV}
Choose the vehicle you are MOST likely to purchase	□	□

Table 2. Attributes and levels used in the discrete choice survey.

#	Attribute	Abbreviation	Description	Levels	Units	Level Values
Consumer Socio-Demographics						
1	Respondent Age	Age	Respondent age	Cont.	years	Any driving age
2	Respondent Gender	Gndr	Respondent gender	2	binary	male/female
3	Respondent Early Adopter Status	Early	Based upon response to question about owning new technology	2	binary	yes/no
Vehicle Attributes						
4	Vehicle Purchase Price	VPP	Difference in VPP relative to recently purchased vehicle	3	$/vehicle	-15% / 0% / +15%
5	Fuel Costs	FC	Difference in FC relative to recently purchased vehicle	3	$/month	-50% / 0% / +50%
6	Driving Range	DR	Driving range per tank refill	3	miles	200 / 300 / 400
7	Social and Environmental Benefits	SEB	Oil, smog and GHG reductions	2	binary	yes/no
Refueling Availability Attributes						
8	Metropolitan Area Coverage - Level 1	MAC,1	Average distance to the nearest metro area refueling station	2	binary	4.5 miles
9	Metropolitan Area Coverage - Level 2	MAC,2	" "	2	binary	2.7 miles
10	Metropolitan Area Coverage - Level 3	MAC,3	" "	2	binary	1.2 miles
11	Metropolitan Area Coverage - Level 4	MAC,4	" "	2	binary	Same as gasoline
12	Metropolitan Regional Coverage - Level 1	MRC,1	Number of stations within 150 miles of metro area center	2	binary	No regional coverage
13	Metropolitan Regional Coverage - Level 2	MRC,2	" "	2	binary	39 (LA), 37 (HOU), 42 (NY)
14	Metropolitan Regional Coverage - Level 3	MRC,3	" "	2	binary	106 (LA), 103 (HOU), 118 (NY)
15	Metropolitan Regional Coverage - Level 4	MRC,4	" "	2	binary	Same as gasoline
16	Long Distance Coverage - Level 1	LDC,1	Long distance trips possible (>150 mi from metro center)	2	binary	No long distance coverage
17	Long Distance Coverage - Level 2	LDC,2	" "	2	binary	Coverage to nearby cities
18	Long Distance Coverage - Level 3	LDC,3	" "	2	binary	Coverage to regional cities
19	Long Distance Coverage - Level 4	LDC,4	" "	2	binary	Same as gasoline
20	Interstate Highway Coverage (4 Levels)	IHC,i ($i = 1\text{-}4$)	Distance between highway stations	4	miles	No stations / 100 mi / 50 mi / Same as gasoline

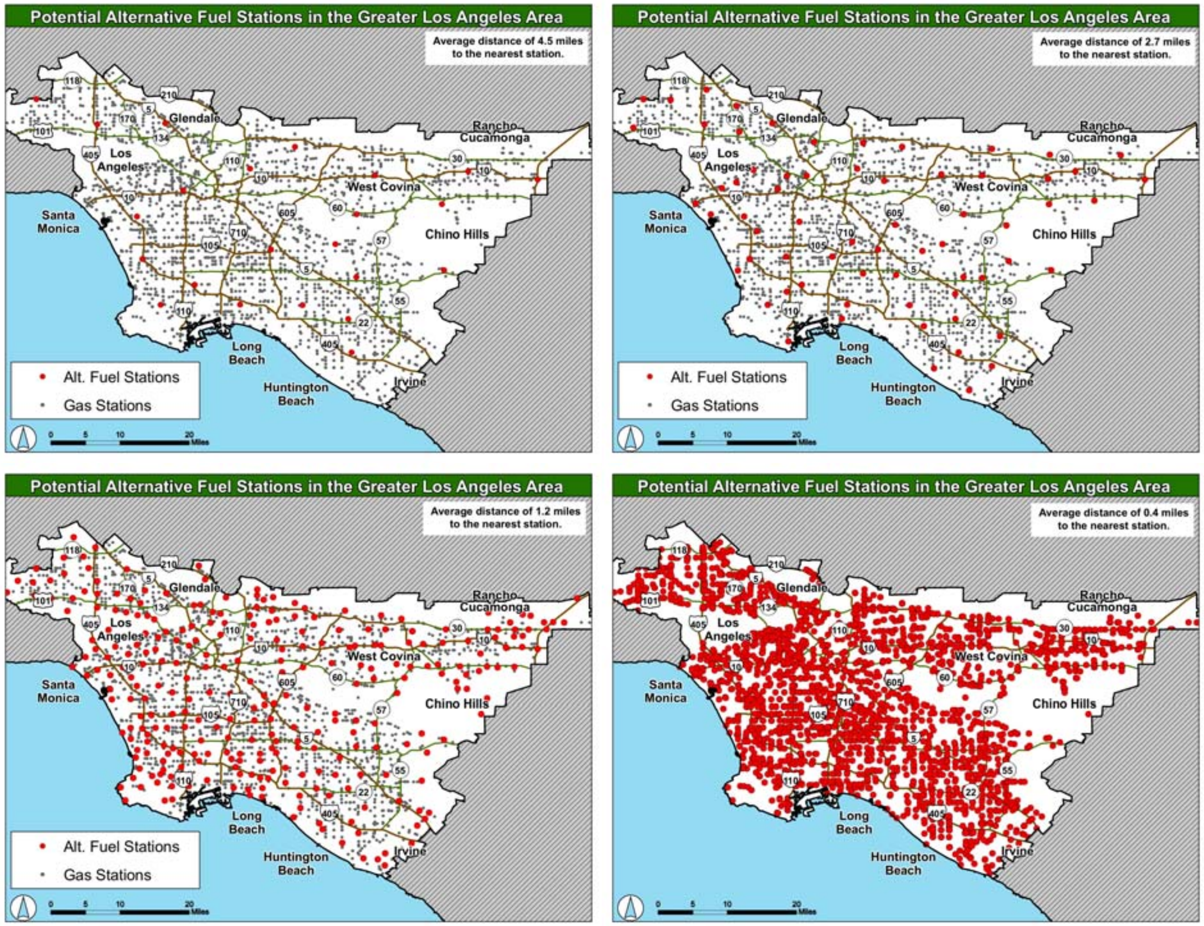

Figure 1. Maps for four levels of Metropolitan Area Coverage in Los Angeles.

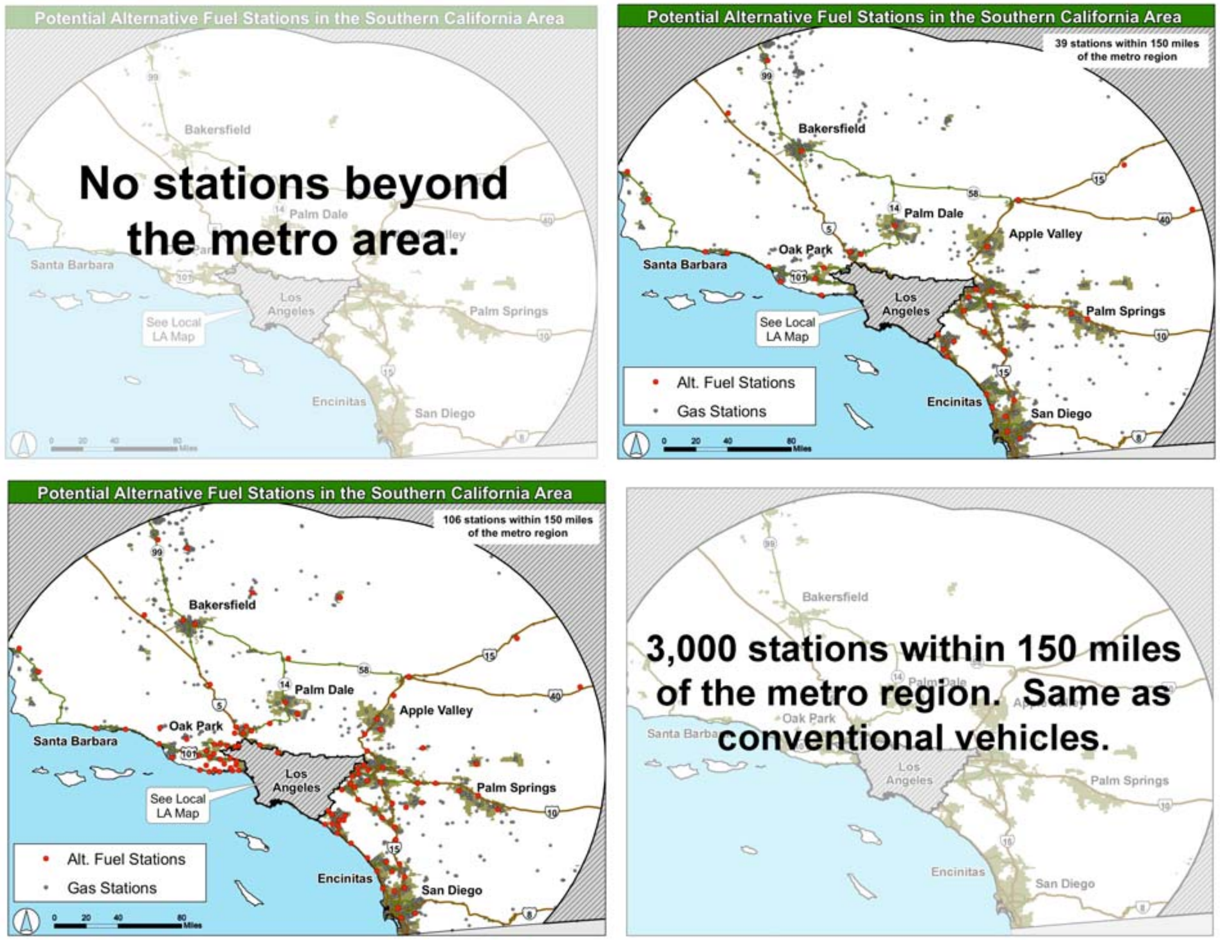

Figure 2. Maps for four levels of Metropolitan Regional Coverage in Los Angeles.

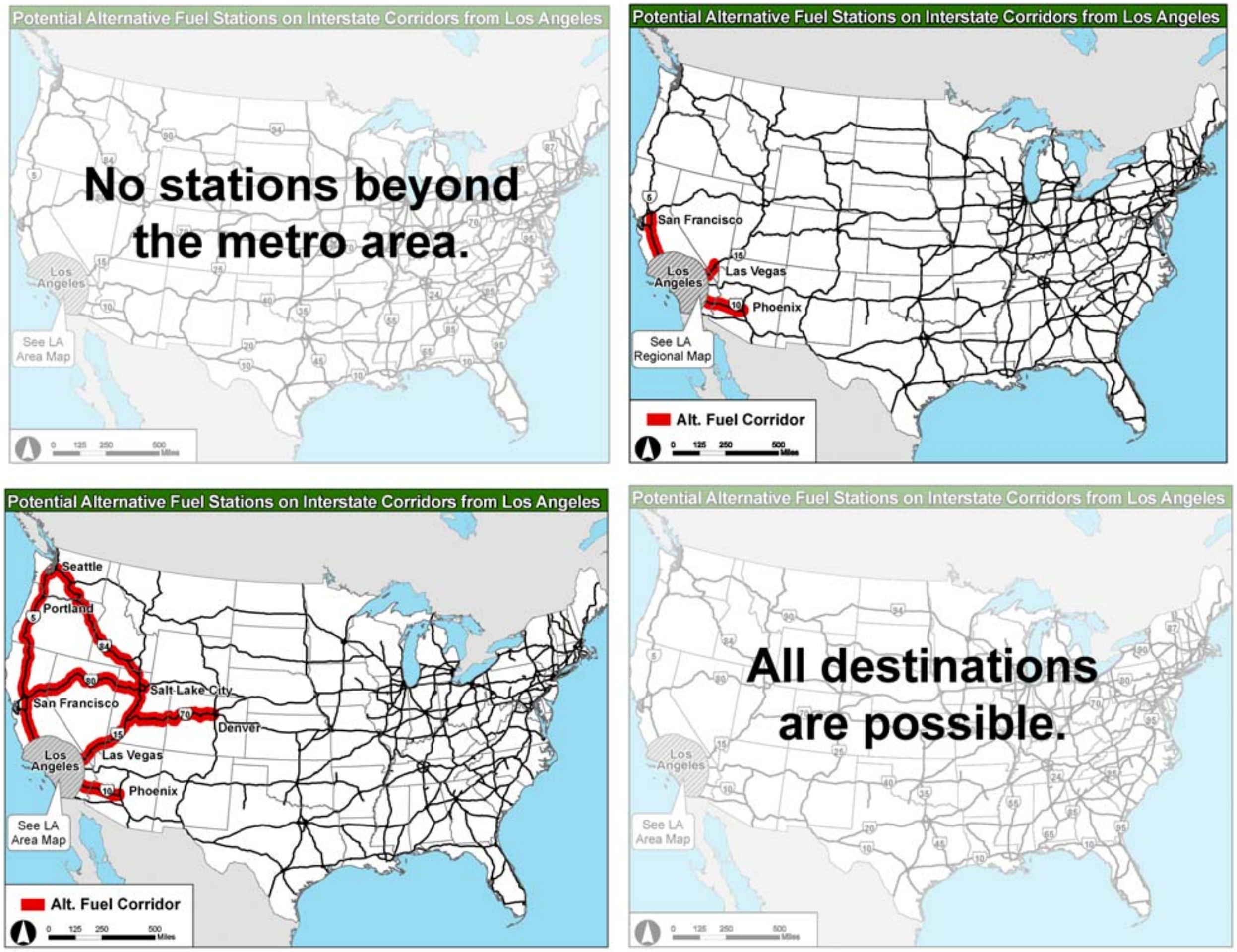

Figure 3. Maps for four levels of Interstate Highway Coverage in Los Angeles.

The utility function in the general binary model includes three components:

$$U_{General} = U_{CSD} + U_{VA} + U_{RA}$$

These three components are: consumer socio-demographics (CSD), vehicle attributes (VA), and refueling availability (RA). Each is described in detail below.

The inclusion of alternative specific constants (ASC) for three consumer socio-demographic attributes significantly improved the model's representation of consumer preference. These three attributes are: respondent age, gender, and early adopter status. Attributes that did not improve the model's predictive power include: education, income, the number of autos owned within the household, and the number of drivers in the household. The consumer socio-demographic ASCs are represented by the following function:

$$U_{CSD} = \alpha_{Age} X_{Age} + \alpha_{Gndr} X_{Gndr} + \alpha_{Early} X_{Early}$$

Where X_{Age} is the respondent's age in years, X_{Gndr} is unity for male and zero for female, X_{Early} is unity for early adopters and zero for non-early adopters, and the corresponding α values are ASC coefficients. Age is therefore a continuous variable and gender and early adopter status are binary variables. Early adopter status was assigned to respondents who gave the most affirmative response ("Very excited: I enjoy being one of the first to use a brand new technology") to the question: "How would you rate your thoughts and feelings about having this new technology in a vehicle you own?" Eleven percent of all respondents chose the most affirmative response. This question was preceded by a description of the AFV that included the social and environmental benefit characteristics (see above), as well as the precaution that the vehicle would have limited refueling availability. Including these socio-demographic attributes in the model explicitly is a relatively simple method of representing market segmentation. Other equally valid and perhaps more sophisticated approaches to doing this have been proposed by Santini and Vyas [18].

The vehicle attributes included in the model are: Vehicle Purchase Price (VPP), Fuel Costs (FC), Driving Range (DR), and Social and Environmental Benefits (SEB). These are represented by the following utility function:

$$U_{VA} = \beta_{VPP} X_{VPP} + \beta_{FC} X_{FC} + \beta_{DR} X_{DR} + \beta_{SEB} X_{SEB}$$

Where the vehicle purchase price, X_{VPP}, has units of \$/vehicle, fuel costs, X_{FC}, have units of \$/month, and the vehicle driving range, X_{DR}, has units of miles. The SEB attribute is a binary variable equal to zero for conventional vehicles and unity for AFVs.

The utility function for Refueling Availability (RA) only applies to AFVs, under the assumption that there are no substantive limitations in refueling availability for conventional vehicles. This utility – or disutility – has four distinct attributes, with each attribute having four levels representing various degrees of refueling availability. The first level is the lowest level (i.e., very sparse or no refueling availability) and the fourth level is refueling availability equivalent to gasoline. The fourth levels therefore do not require explicit representation in the model as they are not associated with any disutility. The RA utility function is:

$$U_{RA} = \beta_{MAC,i} X_{MAC,i} + \beta_{MRC,i} X_{MRC,i} + \beta_{LDC,i} X_{LDC,i} + \beta_{IHC,i} X_{IHC,i}$$

with the four types of refueling availability being: metropolitan area coverage (MAC), metropolitan regional coverage (MRC), long distance coverage (LDC) and interstate highway coverage (IHC). Note that LDC and IHC both refer to refueling availability on the same geographic scale (see Table 1, Table 2, and Figure 3). The subscript *i* indicates the four levels of coverage, though only the first three levels are represented in the model (i = 1, 2 or 3). Attribute units, descriptions, number of levels, and level values are summarized in Table 2.

4. Results

The target response rate was 500 respondents per urban area. As indicated in Table 3, this on-panel response rate target was met in New York (554 responses), nearly met in Houston (489 responses), and was partially met in Los Angeles (409 respondents). The survey panel, maintained by Knowledge Networks, is representative of the U.S. population. For both Houston and New York, off-panel respondents were relied upon to increase the total number of respondents. The off-panel responses were weighted to ensure that they were incorporated in a representational manner. Statistical results for the collapsed binary models used for each city are indicated in Table 4.

The resulting utility function coefficients for the collapsed binary model are summarized in Table 5, along with standard deviations and robust p-values. In each metro area MAC levels 1 and 2 were collapsed into a single attribute. Moreover, levels 3 and 4 were collapsed for MAC in Houston, and for MRC in Houston and New York. P-values greater than 5% are shown in bold. It should be noted that although the statistical significance of the coefficients with high p-values is low, those coefficient values are still the best estimates of consumer preferences for the associated attribute.

As discussed by Greene [13], the VPP coefficient is a critical parameter, and can be used to translate consumer preference for other attributes into equivalent dollar values. The general equation for this conversion is:

$$V_i = \frac{X_i \beta_i}{\beta_{VPP}}$$

Where V_i is the present value for attribute i, X_i is the value of attribute i, and β_i is the discrete choice coefficient for attribute i. The units of this equation depend upon the units of X.

Table 3. Sample size, panel status, and survey completion rate.

Urban Area	Panel Status	Invited to Participate	Initiated Survey	Qualified for Full Survey	Qualification Rate
Los Angeles	On-Panel	1665	1129	409	36%
Houston	On-Panel	600	401	147	37%
	Off-Panel		931	407	44%
	Total		1332	554	42%
New York	On-Panel	2008	1415	413	29%
	Off-Panel		174	76	44%
	Total		1589	489	31%

Table 4. Statistics for the collapsed binary model in each urban area.

Statistics	Los Angeles	Houston	New York
Number of parameters	16	14	13
Observations	4084	5370	4084
Null log-likelihood	-2830.81	-3722.2	-2830.81
Init log-likelihood	-2830.81	-3722.2	-2830.81
Final log-likelihood	-2347.79	-3130.79	-2354.63
Likelihood ratio test	966.04	1182.82	952.358
Rho-square	0.171	0.159	0.168
Adjusted rho-square	0.165	0.155	0.164
Final gradient norm	0.004	0.009	0.01

The equivalent dollar value of various geographic scales and levels of refueling availability are indicated in Table 6 and shown graphically in Figure 4, Figure 5, and Figure 6. The figures indicate symmetric error bars that include two standards of deviation (The actual distributions are not necessarily symmetric, but these bars indicate the magnitude of the variation). These MAC cost penalties can be approximated with an exponential function when the basis is the percentage of sufficient station density (i.e., sufficient stations per square mile). Sufficient and total stations are compared in Table 6. The sufficient number of metropolitan stations is determined as a function of population density, as described in [17]. If the cost penalties are expressed as a function of the total number of stations, they are not as consistent as those shown in Figure 6. The results suggest that providing an alternative fuel from only 10% of sufficient stations (which is less than 10% of existing stations) would impose a cost penalty of approximately $1,000 to $4,000 on a new vehicle purchaser. At 2%-3% of sufficient stations, the penalty could range from $4,000 to $14,000.

The cost penalty trends suggested by the exponential functions are consistent with the trend in population density – the New York study area is slightly more densely populated than the Los Angeles study area, and the Houston study area is approximately half as densely population as the Los Angeles study area. These results are consistent with the expectation that higher population density cities can be served more easily by lower density station networks. It should be kept in mind, however, that the exponential function for Houston is only based upon two data points (one from the survey, one from the sufficient stations analysis).

Table 5. Coefficient values and statistics for each attribute by urban area.

Attribute	Los Angeles, CA		Houston, TX		New York, NY	
	Value	Rp-value	Value	Rp-value	Value	Rp-value
Socio-Demographics						
Age	0.011	0.03	-0.007	**0.10**	-0.021	0
Gender	-0.552	0.00	-0.100	**0.36**	-0.273	**0.06**
Early Adopter Status	0.975	0.00	1.230	0.00	0.953	0
Vehicle Coefficients						
Vehicle Purchase Price	-0.133	0.00	-0.153	0.00	-0.128	0
Fuel Cost	-0.008	0.00	-0.009	0.00	-0.008	0
Driving Range	0.002	0.01	0.001	0.02	0.001	0.07
Social & Env. Benefits	-0.050	**0.89**	0.565	0.04	1.28	0.01
Refueling Coefficients						
Metro Area Coverage, L1-2	-0.327	0.01	-0.382	0.00	-0.213	**0.13**
Metro Area Coverage, L3	-0.134	**0.34**			-0.122	**0.13**
Metro Region Coverage, L1	-0.701	0.00	-0.583	0.00	-0.384	**0.13**
Metro Region Coverage, L2	-0.246	**0.06**	-0.049	0.64	-0.028	**0.47**
Metro Region Coverage, L3	-0.104	**0.42**				
Long Distance Coverage, L1	-0.738	0.00	-0.818	0.00	-0.96	0
Long Distance Coverage, L2	-0.429	0.00	-0.394	0.00	-0.343	0.04
Long Distance Coverage, L3	-0.131	**0.36**	-0.160	**0.25**	-0.261	**0.13**
Interstate Highway Coverage	0.100	0.03	0.042	**0.30**		

* Robust p-values shown in bold exceed 0.05.

The cost penalties for MRC can be approximated using a power function for New York and Houston, and an exponential function in Los Angeles, as shown in Figure 5. New York and Houston have very similar cost penalties, while Los Angeles has significantly higher cost penalties. The basis here, stations per square mile, provides a more consistent comparison than, for example, the percent of total stations in the region. The appropriateness of this basis could be contested. Los Angeles has fewer stations per square mile (as well as people per square mile) within the metropolitan region than New York or Houston. Due to this distinction, it might be the case that consumers in Los Angeles value regional stations more highly in general. When compared on a percent of stations basis, the general trends do not change, except that New York has slightly lower cost penalties than Houston. The remarkable aspect of MRC cost penalties is that they approximate the cost of a new vehicle near station densities of around 0.03 stations per 100 square miles, but drop off quickly at around 0.1 to 0.2 stations per 100 square miles. This result emphasizes the importance of a low level of regional coverage in the commercialization of AFVs.

As indicated in Figure 6, LDC cost penalties can be approximated with a logarithmic function when the horizontal axis is the percent of long distance interstate trips that are not feasible due to limited interstate coverage. This basis was estimated by comparing the interstate coverage maps shown in the survey to inter-urban long distance trips between major urban areas, as reported in the 1995 American Travel Survey [19]. We see that cost penalties drop from $4,000-$9,000 between level 1 (100% of trips not covered) and level 2, which enables trips to major nearby urban areas and approximately 70% of all long-distance inter-urban trips. The cost penalty for LDC level 2 is comparable to the metropolitan area penalty for 10% to 20% coverage of sufficient station density. Interestingly, the cost penalty for not covering the last few percent of long distance trips, level 3 to level 4, is around $500 to $3,000. Note that the statistical results for IHC in New York were not satisfactory.

Table 6. Equivalent costs for refueling availability coverage attributes.

Refueling Availability Attribute	Metric Value and Cost Penalty					
	Los Angeles		New York		Houston	
	Metric	Cost	Metric	Cost	Metric	Cost
Metropolitan Area Coverage (MAC)						
[Percent of sufficient station density]						
Level 1-2	1.6%	$10,175	1.7%	$6,951	3.5%	$10,155
Level 3	10.8%	$2,256	12.2%	$2,089	*NA*	*NA*
Level 4	100%	$0	100%	$0	100%	$0
Metropolitan Regional Coverage (MRC)						
[Stations per 100 square miles]						
Level 1	0.04	$24,985	0.03	$18,724	0.03	$20,812
Level 2	0.07	$7,623	0.06	$1,203	0.06	$1,500
Level 3	0.20	$2,441	0.18	*NA*	0.17	*NA*
Level 4	0.46	$0	0.69	$0	1.51	$0
Long Distance Coverage (LDC)						
[Percent of long distance trips that are not covered along interstate highways]						
Level 1	99%	$5,549	99%	$7,500	99%	$5,346
Level 2	27%	$3,226	36%	$2,680	31%	$2,575
Level 3	7%	$985	6%	$2,039	4%	$1,046
Level 4	1%	$0	1%	$0	1%	$0
Interstate Highway Coverage (IHC)*						
(distance between stations in miles)						
Level 1 (no interstate stations)	-	$3,008	-	*NA*	-	$1,098
Level 2	100	$1,504	-	*NA*	100	$549
Level 3	50	$752	-	*NA*	50	$275
Level 4 (same as gasoline)	25	$0	-	*NA*	25	$0

* Increased highway coverage results in a positive value rather than a cost penalty.

5. Literature comparisons and market share implications

Metropolitan area cost penalties are compared with estimates from other studies in Figure 7. Cost penalties are shown as a function of the percent of existing stations in a given urban area. The Los Angeles sufficient station cost penalties have been transformed to an existing station basis, and the resulting exponential function is indicated by a solid black line. These cost penalties are most similar to the representation of consumer preferences in the TAFV model and the CVCS model (a sub-model within NEMS) [20, 21], which are also based upon stated preference data [4]. The high and low penalties from Tompkins [6] represent a range of outcomes based upon survey results, with the high range penalties being more severe than those found in this study. The much lower penalties from the HyTrans study [22] (c.f., Nicholas et al. 2004 [8]) and Melaina and Bremson ("M&B NHA 2008") [23] are based upon analytic representations of "rational" consumer behavior. From this comparison across multiple studies, we conclude that stated preference results tend to estimate higher penalties than analytic models. Moreover, the differences in penalties associated with the two methods vary by a factor of 4 or more at very low station densities (e.g., less than 20%).

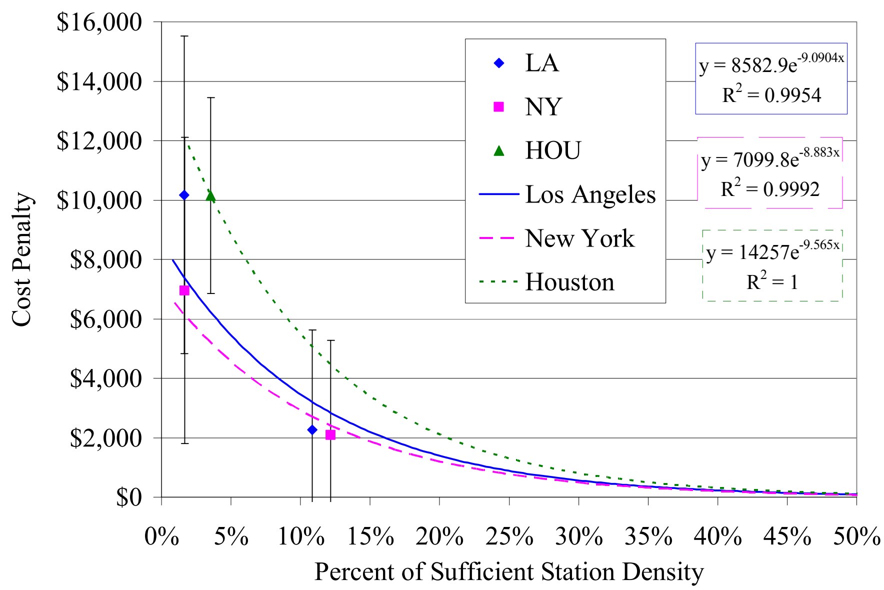

Figure 4. MAC cost penalty as a function of urban area sufficient station density.

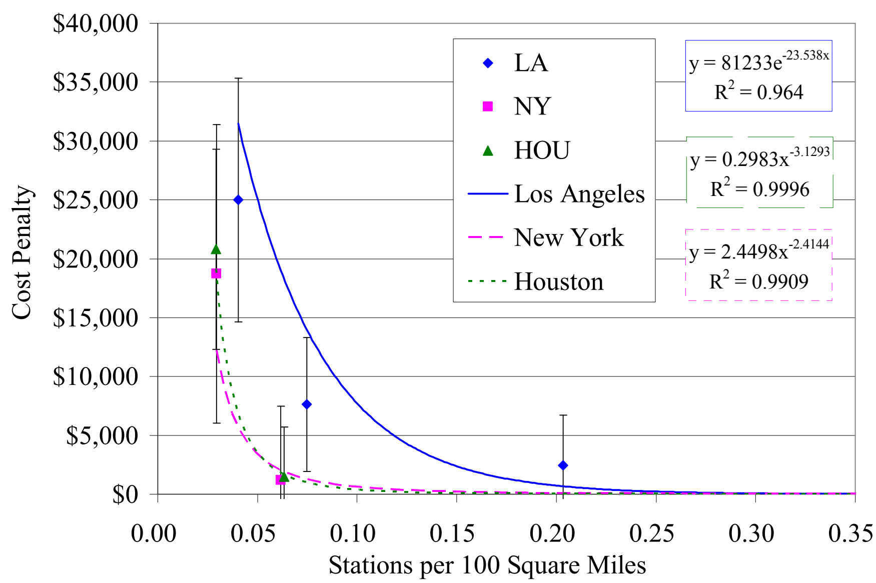

Figure 5. MRC cost penalty as a function of the percent of regional stations.

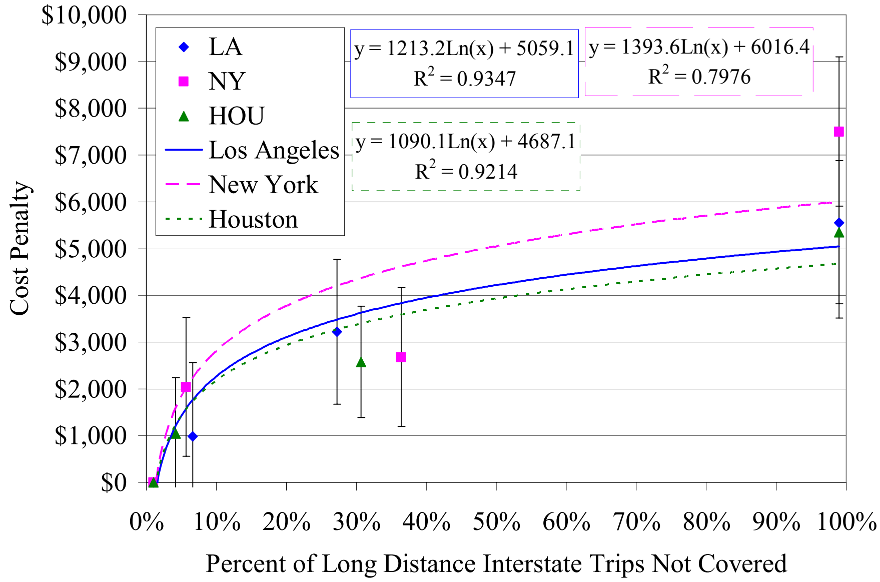

Figure 6. LDC cost penalty as a function of the percent of long distance interstate trips that are not covered.

One of the strengths of the discrete choice analysis methodology is the potential to compare preferences for similar products on an equivalent basis, and the derivation of a theoretical market share equation that represents the probability of distinct consumer choices in response to changes in product attributes. In the example below, the valuation of different attributes described above are translated into dollar values, and the price slope for vehicle purchase decisions reported by Greene [13] is used to estimate the resulting market share. The following market share equation is used to determine changes in the share of AFVs vs. CVs:

$$S_{AFV} = \frac{\exp\left(\beta_{PS} \cdot X_{CostDiff}\right)}{1 - \exp\left(\beta_{PS} \cdot X_{CostDiff}\right)}$$

Where $X_{CostDiff}$ is the difference in the present value of CVs and AFVs, taking into account the value of all attributes, and β_{PS} is the price slope (equal to -0.000893, from Greene [13]). In this comparison, all vehicle attributes are assumed to be equivalent, including vehicle purchase price (e.g., a subsidized AFV with equivalent performance). Only the value of refueling availability and social and environmental benefits are included to determine the difference in perceived value. Moreover, the socio-demographic alternative specific constants for an early adopter are included, therefore providing a perspective on the hypothetical market share among early adopters.

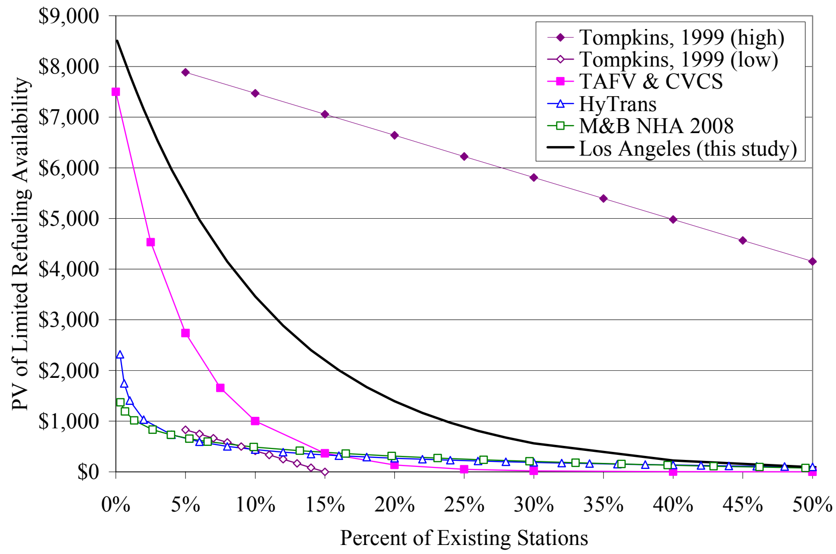

Figure 7. Penalty for limited refueling availability as a function of the percent of existing urban stations: comparisons with other studies.

Figure 8 indicates early adopter market share (blue triangles, left axis) changing as a result of the difference in perceived vehicle value (green squares, right axis) as successive levels of refueling availability are established. To the far left of this figure, refueling availability begins at metropolitan area level 1-2 and the resulting cost penalties far exceed the perceived early adopter premium. Successive layers of refueling availability are added moving towards the right of the figure, resulting in an increase in both perceived AFV value and market share. To the far right, equivalent coverage is achieved and the typical early adopter premium is about $9,500, resulting in essentially a 100% probability of purchasing an AFV. After regional level 2 and metropolitan area level 3 are added, market share increases to 7%. With long distance coverage level two and interstate frequency 2 (100 miles between stations), the AFV is greater than zero and market share is 60%. At long distance coverage level 3, market share is approaching 100%. These results apply to a typical early adopter, and represent average values for all three cities. The theoretical market share would increase more slowly using preferences of the general public.

6. Conclusion

An online survey has been conducted in representative households in three major cities: Los Angeles, CA, Houston, TX, and New York, NY. The survey asked respondents a series of preliminary questions, followed by 10 choices between two vehicles identical to their most recently purchased vehicle: a conventionally fueled vehicle (CV) and an alternative fuel vehicle (AFV). The AFV was described as being distinct from the CV in two respects: 1) it required virtually no imported oil, produced no smog emissions, and produced 30%-70% fewer greenhouse gas emissions, and 2) the refueling infrastructure serving the alternative fuel vehicle would be limited. Based upon consumer responses to the

10 choices between these two vehicles, each of which presented varying vehicle and refueling availability attributes, including vehicle purchase price and monthly fuel costs, it was possible to quantify consumer preferences for each attribute.

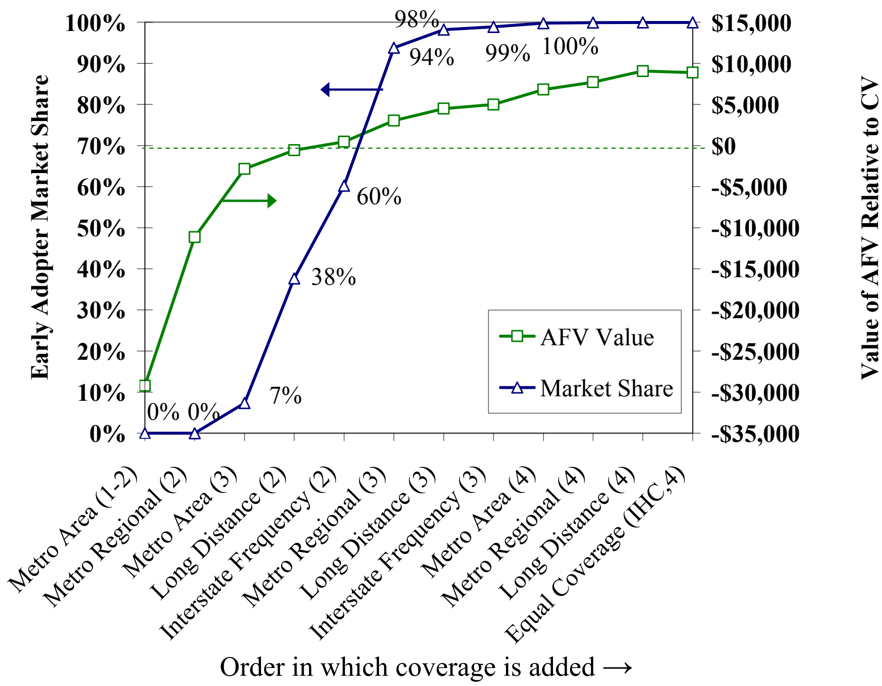

Figure 8. Differential in perceived vehicle value and early adopter market share (average results for all three urban areas).

This study is distinct from other discrete choice studies of vehicle preferences in that detailed descriptions and maps were provided to convey the level of refueling availability associated with each vehicle choice. Refueling availability was quantified on three geographic scales: metropolitan area, metropolitan region, and nationwide along interstate highways connecting major urban areas.

The results of the survey were translated into equivalent dollar values for each geographic scale and level of refueling availability. Parametric representations of the penalties associated with limited refueling availability were proposed for coverage on each geographic scale. Although the statistical significance of some of the discrete choice utility function parameters was low, the results were generally consistent with expected trends and the respective population densities of the three urban study areas. The cost penalties associated with limited metropolitan area coverage (e.g., local coverage) were higher than those proposed by recent studies. With 10% of existing urban stations providing the alternative fuel, consumers would face a perceived cost penalty within the range of $3,000 to $4,000. In general, these cost penalties were greater than analytically derived penalties reported in recent studies by a factor of 4 or more at low station percentages (i.e., less than 20% of existing stations). Regional and nationwide interstate penalties were also found to be significant for limited levels of coverage.

These results are based upon stated preferences, and may therefore overstate the cost penalties consumers would perceive in making real-world decisions. Though this study employed maps and detailed descriptions of refueling availability, the results are similar to other stated preference results. Because revealed preference data within a limited refueling availability context are rare, additional research is needed to reconcile analytic and stated preference cost penalties.

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