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DISCLAIMER

1. Background

The importance of cleaner energy sources for automotive transportation is increasingly recognized. This concern is particularly acute in California, where the major metropolitan areas do not meet federal air quality standards. The 1990 amendments to the Federal Clean Air Act and recent regulations by the California Air Resource Boards require that vehicle emissions be reduced substantially. Cleaner-burning fuels for automobiles and light-duty tucks, together with trip reduction measures, are the central themes in the attempted reduction of vehicle emissions in California.

How consumers are likely to respond to alternative fuels is a key issue in the development of governmental and industry policies aimed at promoting a shift toward such fuels. These information needs are made evident by the scope of the intended promotion: California regulations stipulate that, by 1996, 10 to 20 percent of the new-car fleet should be "transitional low-emission" vehicles. By 2003, 25 to 75 percent of the fleet should be "low-emission" vehicles, and 2 to 15 percent should be "ultra low-emission" vehicles. A full 10 percent of the fleet is required to be "zero emission" (presumably electric) vehicles by the year 2003. Details are provided in Air Resources Board (1991). The year 2010 penetration goals for passenger car vehicle miles of travel (VMT) are: 17 percent electric, 33 percent other alternative fuels, and 50 percent gasoline and diesel.

Consumers' current knowledge regarding alternative-fuel vehicles is probably limited to media coverage of experimental programs, prototype products, or overseas experiences. Consumers are likely to harbor uncertainty, not only about the availability and price of these fuels, but also about the purchase price of alternative vehicles, their reliability, maintenance costs, service availability, and vehicle resale values. This, combined with the fact that purchasing an automobile is a major decision for most consumers, implies a large risk involved in the purchase of alternative-fuel vehicles. The most likely consumer response is risk avoidance, which could lead to a majority of consumers taking a "wait and see" attitude (Urban, et al., 1988). On the other hand, there is increasing evidence of "green" segments of consumers, who place personal value on the environmental characteristics of the products they buy (Uusitalo, 1983).

Forecasts of the market dynamics that will be exhibited after any introduction of alternative-fuel vehicles is critical for effectively staging policy actions. Forecasts of equilibrium market shares that will be attained eventually does not adequately support policy decision making; needed is an understanding of market dynamics and a prediction of the pace of market penetration.

Dissemination of information about new products has been the subject of numerous marketing and consumer behavior studies (e.g., Bass, 1980; Sheth, et al., 1988). However, collectible data to quantify alternative-fuel market dynamics are extremely limited at this time. One can only speculate how consumer perception of, and attitude toward, alternative fuels and vehicles may change in the next several years.

The problem is compounded because what a consumer gains by purchasing an alternative vehicle is heavily dependent on the actions of other consumers, as well as on public policy. Indeed, many supply characteristics--the number of fuel and service outlets, fuel and vehicle prices, and vehicle resale values--depend on the level of demand, which is a collective result of individual consumers' actions. And demand, in turn, depends on supply. This is similar to many other consumer goods (Hardin, 1982). However, a unique aspect exists: clean air, the ultimate reason for purchasing an alternative vehicle, cannot be attained individually.

Alternative-fuel vehicles are "social products" or "social goods", the purchase of which may not deliver direct benefit to the consumer, *per se*. Purchase of such a product may be motivated by the satisfaction that arises from the belief that the consumer is contributing to a social goal, in this case a cleaner environment. Rational economic calculation, may not justify the purchase of such goods. The purchaser bares the cost of the product, while its benefit is shared by a number of residents in the region. Government may then intervene by introducing a mechanism for cost transfer through subsidy.

From this perspective, it is logical to examine consumer reaction to alternative-fuel vehicles from game-theoretic viewpoints that emphasize they are social goods. It must be recognized that alternative fuels and vehicles are, at this point, largely nonexistent. The effect of resulting uncertainty needs to be revealed, and market dynamism in the initial stages of introduction - including information dissemination, and changes in perceptions and attitudes - needs to be understood (Turrentine and Sperling, 1989; 1991). And more traditional economic analysis needs to be performed on how technical and supply uncertainty and other disadvantages are traded off with economic and other incentives that may be set forward through policy.

Quantitative demand forecasts for alternative-fuel vehicles and fuels can be developed based on extrapolations of automobile type choice models (Train, 1980). However, these studies are unable to include many key attributes that distinguish alternative and conventional fuel vehicles, because the attributes do not effectively distinguish conventional fuel vehicles from one another. Those attributes, such as fuel availability and range between refueling, can be included in so-called stated-preference surveys, in which models are developed based on consumer choices among hypothetical future conventional-fuel and alternative-fuel vehicles defined in terms of attributes manipulated according to an experimental design. Stated preference studies of demand for electric vehicles are provided by Beggs, et al. (1981), Hensher (1982), and Calfee (1985), and an SP study of demand for alternative fuel vehicles of various types is provided by Bunch et al. (1991), Golob, et al. (1991), and Kitamura et al. (1991). These studies are limited, because of respondent comprehension, to a relatively small number of attributes.

It is unlikely that a quantitative stated-preference analysis of buyer behavior will lead to a forecasting model that captures the transient nature of consumer preferences. Market dynamics will generally be outside the scope of such studies. In fact, it is unlikely that any quantitative analysis of buyer behavior leads to a forecasting model that captures the transient nature of consumer preferences. Nevertheless, the need for such a quantitative tool for policy formulation is acutely evident.

The objective of the present study is to identify relationships that exist among: (i) intentions to purchase alternative-fuel vehicles prior to their large-scale introduction, (ii) attitudes toward the environment, (iii) perceived importance of convenience and economy of ownership and operation, and (iv) consumer uncertainties. The intent is to unveil what factors, if any, may impede the promotion of alternative fuels, and, in turn, offer some guidelines for successful marketing of alternative-fuel vehicles. The study results can also aid in future stated preference demand estimation surveys by identifying factors that are likely to play important roles in the purchase of alternative vehicles.

2. Hypotheses

A set of hypotheses can be generated regarding initial consumer response to alternative vehicles. From the viewpoint that alternative vehicles are social products, we may postulate that the major incentive for a consumer to purchase an alternative vehicle is to contribute to better air quality:

> Attitudes toward the environment are a fundamental influence on intention to purchase alternative-fuel vehicles.

Further hypotheses involve the potential uncertainty associated with alternative-fuel technologies:

> Because alternative-fuel vehicles are new products, uncertainty about product attributes will negatively affect the intention to purchase.
>
> Also, incentives lower the cost of an incorrect decision, therefore increasing intention to purchase alternative-fuel vehicles. Incentives are thus effective for segments of price-sensitive consumers and risk-averse consumers.

Because knowledge about alternative fuels would reduce the uncertainty a consumer perceives, it can be postulated:

> Familiarity with alternative fuels and vehicles will positively impact intent to purchase.

Finally, because uncertainty might be associated with the cost and convenience of repair and service:

> Consumers who are concerned with repair/service convenience and costs are less likely to purchase alternative-fuel vehicles.

The major focus of this paper is on the statistical test of these hypotheses using the results of a market research survey.

3. The Survey Data

A mail survey was designed to provide data to test these hypotheses. This survey was also intended to aid in the development of a stated preference survey of vehicle choice by identifying factors that should be considered in the stated preference survey. Results from this stated preference survey, in which respondents choose from among a set of conventional fuel and alternative fuel vehicles, are provided in Bunch, et al. (1991).

The survey was mailed in 1990 to a random sample of households in the California South Coast Air Basin, an area encompassing the most densely populated portions of Los Angeles, Orange, San Bernardino, and Riverside Counties. Approximately 1900 surveys were mailed, and the number of usable returns was 369, representing a response rate of a little over 19 percent.

Intentionally, the survey description of alternative-fuel vehicles was minimal:

> "The alternative fuels include ethanol, propane, methanol, compressed natural gas, and even electricity. Such vehicles are being proposed to improve air quality."

The seven-page survey questionnaire was divided into four sections. Part A concerned self-proclaimed familiarity with alternative-fuel vehicles, concerns about the environment, and beliefs about the future capital and operating costs of alternative-fuel vehicles. The beliefs were elicited using anchored five-point scales. As an example of one of these scales, respondents were asked on a scale from "cost much less" to "cost much more":

> "Compared to conventional gasoline what do you think the costs of alternative <u>fuels</u> are likely to be?"

Part B of the questionnaire concerned importance ratings of 36 product attributes on a five-point scale from "not at all important" to "extremely important". These ratings were elicited by asking:

> "Imagine that you are considering purchasing an alternative-fuel vehicle. How important would each of the following characteristics be in <u>your</u> decision to purchase such a vehicle."

uncertainty about seven aspects of alternative-fuel vehicles. All questions in this section were in terms of a five-point agree/disagree scale. The seven potential aspects of uncertainty were: (1) fuel availability, (2) vehicle resale value, (3) convenience of maintenance and repair facilities, (4) performance, (5) costs of repair, (6) pollution improvements, and (7) vehicle life expectancy. The purchase intention question entailed the extent to which the respondent agreed with the statement:

> "If an alternative-fuel vehicle were available, I would purchase one for my next car."

Finally, Part D concerned recycling behavior of the respondent and socio-demographic questions.

Useful insights can be gained into current consumer attitudes by simple tabulation of importance ratings given by the respondents. A total of 36 vehicle attributes are given in the survey; respondents were asked to rate the respective importance of each in their vehicle purchase decision. The results are summarized in Tables 1 and 2. The response distributions for each attribute are given in Table 1, and three descriptive statistics, median, mean, and mode (most frequent response category), are given in Table 2. These statistics are based on the scale values assigned to the five categories shown in the header of Table 1, which range from 1. "not at all important" to 5. "extremely important." Caution must be exercised in interpreting the mean values, as these statistics assume interval (cardinal) scales. The median and mode statistics are consistent with the less-restrictive assumption of ordinal scales used in the models documented in the remainder of this paper.

It is not surprising that attributes such as "safety" and "braking" rank high in importance, but, quite notably, attributes that might potentially distinguish new alternative-fuel vehicles from tried-and-true conventional vehicles also rank high. Most significant among these attributes are "fuel (or recharge) availability," "service and repair frequency," "time in the repair shop," "service and repair convenience" and "refueling (or recharge) safety." It is also notable that most attributes ranked by median value in the top one-third are intangible factors for which no fixed dollar values are associated.

Cost factors--"fuel price," "service and repair cost," and "purchase price" of the vehicle--appear in the second one-third of the list. This group also includes vehicle characteristics such as "interior noise level" and "smoothness of ride."

In the bottom one-third are various monetary incentives that may be offered as governmental intervention to promote alternative vehicles, e.g., "interest payments tax deductible," "vehicle depreciated on taxes" or "reduced vehicle registration fees." Such tangible incentives appear to be of minor importance when a consumer considers the purchase of alternative-fuel vehicles. The importance ratings given by the respondents clearly indicate that their attention is focused primarily on those attributes that are unique to alternative-fuel vehicles.

ATTRIBUTE	1. not at all important	2. somewhat important	3. important	4. very important	5. extremely important
purchase price	0.3	14.9	36.7	27.7	20.5
service and repair cost	0.0	8.8	27.6	38.1	25.5
reduced vehicle registration fees	18.0	27.3	26.3	18.3	10.1
whether regular financing is available	18.7	16.4	28.5	22.8	13.6
ability to personally perform repair work	23.7	22.4	18.8	19.3	84.1
whether interest payments are tax deductible	19.1	22.4	23.2	17.8	17.5
whether depreciation is tax deductible	19.7	25.9	21.0	19.2	14.1
expected resale price	4.1	16.8	34.5	30.7	13.9
service and repair frequency	0.0	3.4	16.8	37.7	42.1
range between refueling	0.5	3.9	22.9	36.5	36.2
time in repair shop	0.8	4.4	17.0	36.5	41.4
whether low interest loans available	22.5	22.2	25.3	16.3	13.7
insurance costs	1.0	4.9	25.2	32.1	36.8
safety	0.0	1.8	11.8	30.3	56.2
life expectancy of vehicle	0.0	2.8	19.0	40.4	37.8
service and repair convenience	0.8	3.6	17.1	35.8	42.6
acceleration	3.9	23.3	36.3	27.6	9.0
size of trunk	6.7	31.0	41.5	16.2	4.6
published ratings in magazines	18.6	32.2	30.4	14.2	4.6
fuel (or recharge) price	0.3	4.4	28.6	38.4	28.4
smoothness of ride	1.3	10.6	49.6	28.2	10.3
if there is a cold-start delay	12.1	27.9	34.4	17.3	8.3
interior noise level	0.5	15.7	37.8	31.4	14.7
ability to perform well in different climates	3.3	15.9	30.8	31.3	18.7
distinctive styling	18.0	33.2	32.7	10.8	5.2
interior space, general roominess	0.8	15.6	46.2	26.2	11.3
top speed	6.2	30.3	35.4	17.7	10.5
braking	0.3	1.8	17.4	34.1	46.4
fuel (or recharge) availability	0.3	1.3	17.9	32.1	48.5
how many such vehicles have been sold	10.8	26.2	36.2	18.2	8.7
refueling (or recharge) safety	0.5	1.5	24.4	31.3	42.3
degree of improvements in emissions	1.0	6.7	20.3	35.0	37.0
overall size	4.4	18.2	45.4	23.3	8.7
manufacturer of vehicle	23.1	24.1	29.7	15.1	7.9
refueling (or recharging) waiting time	1.8	10.3	29.2	33.8	24.9
road handling	0.3	3.1	26.0	40.9	29.8

***Table 1*. Frequency distributions for 36 attribute importance scales (in percent)**

ATTRIBUTE	MEDIAN	MEAN	MODE
purchase price	3	3.53	3
service and repair cost	4	3.80	4
reduced vehicle registration fees	3	2.75	2
whether regular financing is available	3	2.96	3
ability to personally perform repair work	3	2.82	1
whether interest payments are tax deductible	3	2.92	3
whether depreciation is tax deductible	3	2.82	2
expected resale price	3	3.34	3
service and repair frequency	4	4.19	5
range between refueling	4	4.04	4
time in repair shop	4	4.13	5
whether low interest loans available	3	2.77	3
insurance costs	4	3.99	5
safety	5	4.41	5
life expectancy of vehicle	4	4.13	4
service and repair convenience	4	4.16	5
acceleration	3	3.15	3
size of trunk	3	2.81	3
published ratings in magazines	2	2.54	2
fuel (or recharge) price	4	3.90	4
smoothness of ride	3	3.36	3
if there is a cold-start delay	3	2.82	3
interior noise level	3	3.44	3
ability to perform well in different climates	3	3.46	4
distinctive styling	2	2.52	2
interior space, general roominess	3	3.32	3
top speed	3	2.96	3
braking	4	4.25	5
fuel (or recharge) availability	4	4.27	5
how many such vehicles have been sold	3	2.88	3
refueling (or recharge) safety	4	4.13	5
degree of improvements in emissions	4	4.00	5
overall size	3	3.14	3
manufacturer of vehicle	3	2.61	3
refueling (or recharging) waiting time	4	3.70	4
road handling	4	3.97	4

Table 2. **Descriptive statistics for 36 attribute importance scales (in percent)**

4. Analytical Method

This research involves aspects of consumer attitudes, knowledge, beliefs, and behavioral intentions. The principal attitude of interest centers on concern for the environment and is conditioned by the perceptions of the impact of personal vehicle travel on air pollution. The knowledge aspect involves what is known or thought to be known about alternative-fuel technologies. Beliefs concern expectations of: (1) future technological innovations, (2) governmental and private sector actions, and (3) resulting relative prices of vehicles and alternative fuels. Finally, the behavioral intention is in terms of the purchase of alternative-fuel vehicles, if they were available.

Measurements of such variables are typically obtained in psychology, sociology, and market research using attitude scales of the semantic differential and importance rating types. These scales typically have from five to seven categories; and five-point scales are used in the present survey. Usually, data from such semantic differential and importance rating scales are defined to be interval-scaled (cardinal), so that they can be readily analyzed using conventional statistical techniques applied to normally distributed dependent variables. This assumes that differences between any two adjacent scale categories are always the same: e.g.. the difference between "strongly disagree" and "disagree" is the same as the difference between "neither agree nor disagree" and "agree" on a semantic differential scale. However, individuals might (i) view differences involving scale extremes differently from those in the neutral region, (ii) view the positive side differently from the negative side, or (iii) simply use the scales in other nonlinear ways. It is far less restrictive to assume that such scales yield ordinal data. Interval-scaled data is then one possible special case, rather than a restrictive assumption. The method used to test the present hypotheses assumes only ordinal-scaled attitudinal survey data.

The hypotheses are thus specified in terms of a set of simultaneous linear equations, with the attitude scale variables in the equations measured in terms of ordinal scales. This calls for structural equations with latent variables and a comprehensive measurement model capable of handling non-normally distributed (ordinal) endogenous variables (Muthén, 1984; Bentler, 1983).

The first step in specifying the equation system and its estimation procedure is to separate and define the endogenous and exogenous variables. The endogenous variables must include all dependent variables in the equation system, but not all endogenous variables are dependent variables. All attitude scale variables are potentially endogenous in the present set of hypotheses and are thus defined as endogenous variables. There are nine such endogenous variables in the present system. All other variables in the system are consumer socio-demographic measures, and are thus exogenous. There are ten exogenous variables.

The complete non-normal simultaneous equations model can be broken into two components: (1) a measurement model specifying normally distributed endogenous latent variables in terms of the ordinal observed endogenous variables, and (2) a structural equations model capturing the hypothesized causal relationships among the endogenous latent variables and between the observed exogenous variables and the endogenous latent variables. The measurement model is defined as follows.

Let **y** denote the (p by 1) column vector of observed ordinal-scale endogenous variables, each variable, y_i, being measured in terms of five ordered categories. (In the present application, p=9 scale variables.) Denoting $\mathbf{y}^*$ as a (p by 1) column vector of continuous, normally distributed latent endogenous variables, the relationship between each variable pair, y_i and y^*_i, is given by

$$y_i = \begin{cases} 4 \text{ iff } k_{i4} < y^*_i \\ 3 \text{ iff } k_{i3} < y^*_i \leq k_{i4} \\ 2 \text{ iff } k_{i2} < y^*_i \leq k_{i3} \\ 1 \text{ iff } k_{i1} < y^*_i \leq k_{i2} \\ 0 \text{ iff } \quad y^*_i \leq k_{i1} \end{cases} \qquad \text{for } i=1,2,\ldots,p \qquad (1)$$

where k_{i1} through k_{i4} are unknown thresholds. Estimation of the unknown threshold values is accomplished using the ordered-response probit model originally developed by Aitchison and Silvey (1957) and Ashford (1959):

$$\begin{aligned} P(y_i=j|\mathbf{x}) &= P(k_{ij} < y^*_i \leq k_{ij+1}) \\ &= \Phi(k_{ij+1} - \boldsymbol{\pi}'\mathbf{x}) - \Phi(k_{ij} - \boldsymbol{\pi}'\mathbf{x}) \qquad \text{for } i=1,2,\ldots,p \qquad (2) \end{aligned}$$

where Φ represents the standard cumulative normal distribution function, $\mathbf{x}$ is the vector of exogenous variables and $\boldsymbol{\pi}$ is a vector of reduced form regression coefficients (slopes). The unknown parameters of equation (2) are typically estimated using maximum likelihood (Maddala, 1983).

Next, let $\boldsymbol{\eta}$ denote a (m by 1) column vector of endogenous latent variable linear constructs, called factors. These factors are related to the $\mathbf{y}^*$ latent variables by the measurement equation system:

$$\mathbf{y}^* = \Lambda \, \boldsymbol{\eta} + \boldsymbol{\epsilon} \qquad (3)$$

where Λ is a (p by m) coefficient matrix of hypothesized factor loadings, and $\boldsymbol{\epsilon}$ is a (p by 1) vector of measurement errors. The variance-covariance matrix of these errors is defined to be $\Theta = E[\boldsymbol{\epsilon\epsilon}']$. Equations (2) and (3) define the comprehensive ordinal-variable measurement model. The diagonal and lower triangle off-diagonal elements θ_{ij} of Θ are potential free parameters to be estimated.

The second component of the model is the structural equations. These involve the endogenous latent factors, $\boldsymbol{\eta}$, and the observed exogenous variables, denoted by the (q by 1) column vector $\mathbf{x}$. (Here, q = 10 exogenous variables.) The structural equations component is given by

$$\boldsymbol{\eta} = \mathbf{B} \, \boldsymbol{\eta} + \Gamma \, \mathbf{x} + \boldsymbol{\zeta} \qquad (4)$$

where $\mathbf{B}$ is an (m by m) coefficient matrix of hypothesized causal effects among the endogenous latent factors, Γ is an (m by q) coefficient matrix of hypothesized effects of the exogenous variables on the endogenous factors. Each element $\boldsymbol{\beta}_{ij}$ of the $\mathbf{B}$ matrix represents the direct causal effect of factor $\boldsymbol{\eta}_j$ on $\boldsymbol{\eta}_i$; the hypothesis to be tested establishes which of these elements is to be non-zero and freely estimated, and main diagonal elements are always zero. Each specified non-zero element $\boldsymbol{\gamma}_{ij}$ of the matrix represents the direct causal regression effect of exogenous variable x_j on $\boldsymbol{\eta}_i$. The error terms in the vector $\boldsymbol{\zeta}$ are assumed to be identically distributed across observations with zero means and variance-covariance matrix $\Psi = E[\boldsymbol{\zeta\zeta}']$. The diagonal and lower triangle off-diagonal elements ψ_{ij} of Ψ are also potential free parameters.

The complete model is comprised of equation systems (2) through (4). Model specification involves defining the $\boldsymbol{\Lambda}$, $\boldsymbol{\Theta}$, $\mathbf{B}$, $\boldsymbol{\Gamma}$, and $\boldsymbol{\Psi}$ matrices. A necessary identification condition is that $(\mathbf{I} - \mathbf{B})$ be non-singular. Additional identification conditions and tests are discussed in Bollen (1989).

Parameter estimation is accomplished in three steps: First, thresholds k_{i1} through k_{i5} are estimated using standard ordered-response probit maximum likelihood solutions (Maddala,1983). Second, the variance-covariances among the $\mathbf{y}^*$ variables, conditional on the thresholds of step 1, are estimated. For ordered-probit $\mathbf{y}^*$ variables, the variances are standardized at unity; the covariances are estimated as polychoric correlation coefficients of the original $\mathbf{y}$ variables, using a limited-information maximum likelihood method (Olsson, 1979; Muthén, 1983).

Third and finally, the thresholds, slopes, and variance-covariances estimated in the first two estimation steps compose the sample statistics in an asymptotically distribution-free weighted least-squares estimation of the specified free parameters of the $\boldsymbol{\Lambda}$, $\boldsymbol{\Theta}$, $\mathbf{B}$, $\boldsymbol{\Gamma}$, and $\boldsymbol{\Psi}$ matrices. Defining the vector of all model-free parameters in these five matrices to be ξ, the approach is based on a weighted least-squares comparison of the sample statistics; their estimated values are replicated by the model, which are a function of ξ.

From equations (3) and (4), the vector of first-moments of $\mathbf{y}^*$ replicated by the model is given by

$$E(\mathbf{y}^* | \mathbf{x}) = \boldsymbol{\Lambda}(\mathbf{I} - \mathbf{B})^{-1}\boldsymbol{\Gamma}\mathbf{x} \tag{5}$$

and the matrix of second-moments of $\mathbf{y}^*$ is given by

$$\boldsymbol{\Sigma} = \boldsymbol{\Lambda}(\mathbf{I} - \mathbf{B})^{-1}(\boldsymbol{\Gamma}\boldsymbol{\Omega}\boldsymbol{\Gamma}' + \boldsymbol{\Psi})(\mathbf{I} - \mathbf{B})^{-1\prime}\boldsymbol{\Lambda}' + \Theta \tag{6}$$

where $\boldsymbol{\Omega} = \mathrm{Cov}(\mathbf{x})$.

Browne (1982; 1984) has shown that estimates with asymptotically correct standard errors are obtainable for essentially any multivariate distribution by minimizing an objective function of the form

$$F(\xi) = \tfrac{1}{2}(\mathbf{s} - \boldsymbol{\sigma})'\mathbf{W}^{-1}(\mathbf{s} - \boldsymbol{\sigma}) \tag{7}$$

where **s** denotes the vector of sample statistics, including only the distinct lower triangle with main diagonal elements of the joint variance-covariance matrix of the $\mathbf{y}^*$ and **x** variables; $\boldsymbol{\sigma}(\xi)$ denotes the model-replicated values of **s**. **W** is a matrix of consistent estimates of the asymptotic covariance among elements of **s** (being the fourth-order sample statistics).

The model Chi-square goodness-of-fit statistic, which Browne(1982;1984) shows to be asymptotically correct regardless of the distributions of the observed variables, is given by the objective function. This function is evaluated at its minimum, multiplied by twice the sample size with t degrees of freedom, and is given by

$$t = p(p+1) + pq - r \tag{8}$$

where p is the number of endogenous variables (9 in this case), q is the number of exogenous variables (10), and r is the number of specified free parameters in the $\mathbf{\Lambda}$, $\mathbf{\Theta}$, $\mathbf{B}$, $\mathbf{\Gamma}$, and $\mathbf{\Psi}$ matrices (i.e., the length of the ξ vector).

The total effects of the exogenous x_i variables ($i = 1,2,\ldots,10$) on the η_j latent factors ($j = 1,2,\ldots,7$) are the sum of both the direct effects, represented by the $\mathbf{\Gamma}$ matrix, and the indirect effects, represented by links through intermediate endogenous factors (i.e., indirect paths from x_i to η_j through the **B** matrix of endogenous causal effects). The total effects of x_i on y^*_j can then be calculated by applying the measurement component relating η_j and y^*_i. From equations (3) and (4), these total effects of **x** on $\mathbf{y}^*$, representing the reduced-form equation system, are given by

$$\mathbf{T} = \mathbf{\Lambda}\,(\mathbf{I} - \mathbf{B})^{-1}\,\mathbf{\Gamma}. \tag{9}$$

5. Model Specification

A set of nine endogenous variables and ten exogenous variables are chosen to test the hypotheses. Some variables (e.g., importance rating of "safety") are not considered because of their weak correlation with other variables of interest; this is due in part to small variations in these variables.

The nine endogenous ordinal-scale variables are listed in Table 3, and the ten exogenous variables are listed in Table 4.

VARIABLE	ABBREVIATION
Importance of service and repair convenience (e.g., how far to drive for service)	Import. of Serv. Avail.
Importance of driving range between refueling stops (or recharging)	Import. of Refill Range
Importance of fuel (or recharge) availability (e.g., how far to drive for fuel)	Import. of Fuel Avail.
Concern about pollution and environmental quality	Environment Concern
Familiarity with alternative fuels and vehicles	Alt-Fuel Awareness
Belief about the costs of alternative fuels	Belief in high fuel cost
Agreement that there is likely to be some uncertainty about how widely available alternative fuels will be	Fuel Avail. Uncertainty
Agreement that there is likely to be some uncertainty about the resale value of alternative-fuel vehicles	Resale Value Uncertainty
Agreement that would purchase alternative-fuel vehicle for next new car	Purchase Intention

TABLE 3. The endogenous variables

VARIABLE	TYPE	ABBREVIATION
Gender (female)	dummy	Gender
Education: college graduate	dummy	Education high
Age 25-34	dummy	Age 25-34
Age 35-44	dummy	Age 35-44
Age 65+	dummy	Age 65+
Number of licensed drivers	continuous	Household. drivers
Number of vehicles	continuous	Household. vehicles
Drivers per vehicle	continuous	Drivers/vehicle
Household income: $95,000+	dummy	Income high
Average annual milage per vehicle	continuous	Ave. vehicle use

TABLE 4. **The exogenous variables**

The model structure for all but the exogenous variable linkages is depicted in the flow diagram of Figure 1. There, the measurement submodel (the Ψ matrix) and the endogenous variable structure (the **B** matrix) are combined in a single flow-diagram.

Three importance ratings are internally combined into one factor termed "convenience sensitivity." This is hypothesized to drive the uncertainty of fuel availability: The more sensitive a consumer is to convenience, the more uncertain he/she is likely to be about the availability of alternative fuels. Furthermore, this uncertainty about fuel availability is hypothesized to engender the perception that resale values of alternative-fuel vehicles are also uncertain. This uncertainty is expected to affect negatively the intention to purchase.

Self-proclaimed environmental concern is expected to be the most significant contributing factor to the stated intention to purchase. It also is hypothesized to influence negatively the uncertainty associated with resale values and the belief that alternative fuels will cost more.

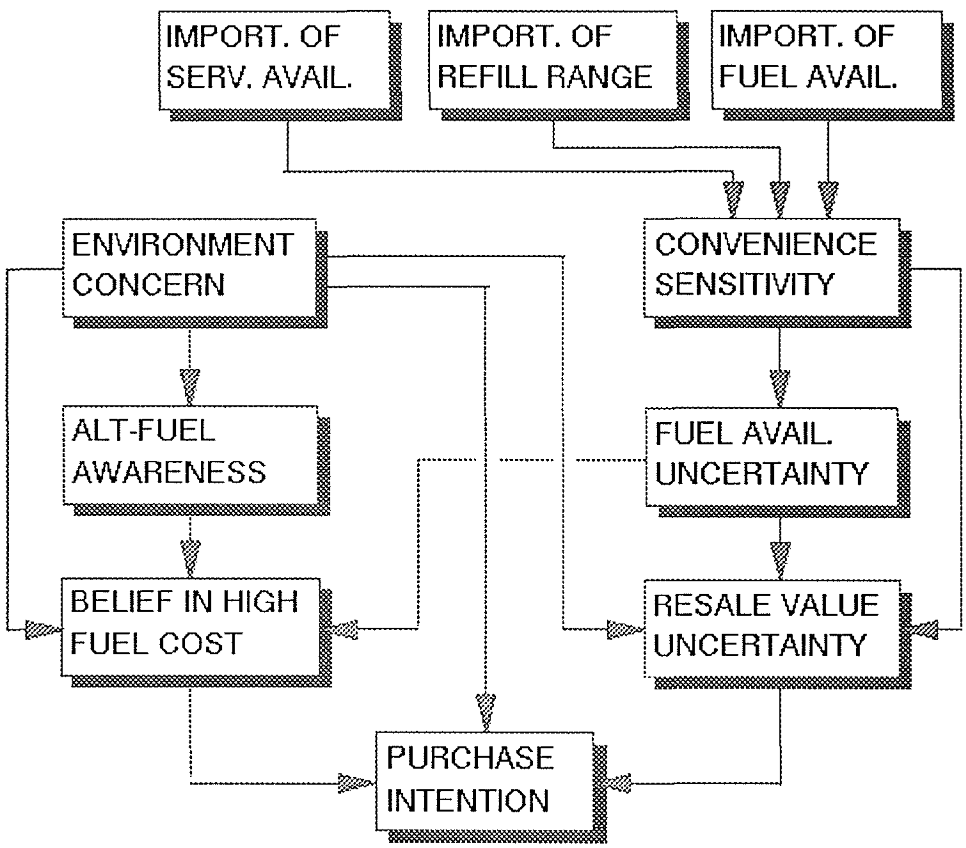

Figure 1: Flow diagram for endogenous variable causal relationships

The structural model can be depicted in terms of which elements in the parameter matrices of equations (2) and (3) are specified to be free or fixed at values zero or one. The subscripted matrix elements represent the free parameters to be estimated:

$$\Lambda = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \lambda_{21} & 0 & 0 & 0 & 0 & 0 & 0 \\ \lambda_{31} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{B} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \beta_{32} & 0 & 0 & 0 & 0 & 0 \\ 0 & \beta_{42} & \beta_{43} & 0 & \beta_{45} & 0 & 0 \\ \beta_{51} & 0 & 0 & 0 & 0 & 0 & 0 \\ \beta_{61} & \beta_{62} & 0 & 0 & \beta_{65} & 0 & 0 \\ 0 & \beta_{72} & 0 & \beta_{74} & 0 & \beta_{76} & 0 \end{bmatrix}$$

$$\Gamma = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{18} & 0 & \gamma_{1,10} \\ 0 & 0 & \gamma_{23} & \gamma_{24} & 0 & \gamma_{26} & 0 & 0 & 0 & 0 \\ \gamma_{31} & \gamma_{32} & 0 & 0 & 0 & 0 & \gamma_{37} & 0 & 0 & \gamma_{3,10} \\ 0 & \gamma_{42} & 0 & 0 & \gamma_{45} & 0 & \gamma_{47} & 0 & 0 & \gamma_{4,10} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{59} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \gamma_{69} & \gamma_{6,10} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Finally, except for the variance of the one latent factor which is not identically related to a $\mathbf{y}^*$ variable, the variances of the ζ endogenous variable error terms are set at unity. The variances of the ϵ measurement errors are set to zero, because the variances of the ordered probit $\mathbf{y}^*$ variables are not identified, making standardization necessary; the measurement model is extremely simple, so that the two error terms are not separately identifiable in most cases. The covariances of both the ζ and ϵ error terms are assumed to be zero. Thus, the model specification is completed by defining the variance-covariance matrix $\mathbf{\Theta}$ to be the triangular null matrix, and the variance-covariance matrix $\mathbf{\Psi}$ to be the triangular identity matrix except for the free element ψ_{11}.

Thus, 30 free parameters compose the final model: 2 confirmatory factor analysis loadings (λ parameters), 11 causal linkages between endogenous latent variables (β parameters), 16 regression effects of the exogenous variables on the latent endogenous variables (γ parameters), and 1 error-term variance (ψ parameter).

6. Results

The model Chi-square value, given by the minimized objective function (7), is 117.158, with 96 degrees of freedom (equation (8)). This corresponds to a probability value of $p = .0702$. Thus, the model *cannot* be rejected at either the $p = .05$ or $p = .01$ levels. The estimates and associated z-values of the 30 free structural parameters of the model are listed in Table 5. According to these z-values, all parameters are significantly different from zero at the $p = .05$ one-tailed level; 28 of the 30 parameters are significant at the $p = .01$ level.

The coefficient estimates for the parameters of the $\mathbf{\Lambda}$ and $\mathbf{B}$ matrices can be directly compared, because the variances of the ordinal endogenous variables are fixed at 1.0; (i.e., the variance- covariance matrix of the endogenous variables is standardized to a correlation matrix). The scales of the $\mathbf{\Gamma}$ matrix parameters depend on the relative variances of the exogenous variables.

PARAMETER	VALUE	Z-VALUE	PARAMETER	VALUE	Z-VALUE
LAMBDA: λ_{21}	1.026	24.86	GAMMA: γ_{23}	0.537	3.976
LAMBDA: λ_{31}	0.816	24.52	GAMMA: γ_{24}	0.550	4.594
BETA: β_{32}	0.124	2.846	GAMMA: γ_{26}	0.704	3.630
BETA: β_{42}	-0.138	-3.030	GAMMA: γ_{31}	-0.844	-7.474
BETA: β_{43}	0.101	2.325	GAMMA: γ_{32}	0.227	2.320
BETA: β_{45}	0.106	2.755	GAMMA: γ_{37}	0.116	3.044
BETA: β_{51}	0.328	7.193	GAMMA: $\gamma_{3,10}$	0.071	2.600
BETA: β_{61}	0.341	6.462	GAMMA: γ_{42}	0.387	3.845
BETA: β_{62}	-0.216	-5.007	GAMMA: γ_{45}	0.441	3.614
BETA: β_{65}	0.162	3.817	GAMMA: γ_{47}	0.121	2.727
BETA: β_{72}	0.459	12.47	GAMMA: $\gamma_{4,10}$	-0.118	-2.857
BETA: β_{74}	-0.076	-1.814	GAMMA: γ_{59}	-0.136	-2.285
BETA: β_{76}	-0.154	-4.217	GAMMA: γ_{69}	0.161	3.018
GAMMA: γ_{18}	0.342	3.299	GAMMA: $\gamma_{6,10}$	-0.057	-1.651
GAMMA: $\gamma_{1,10}$	-0.098	-3.300	PSI: ψ_{11}	0.770	19.39

TABLE 5. **Parameter estimates**

The direct link from environmental concern to purchase intention is the strongest one. Also relatively strong are the positive links from convenience sensitivity to uncertainties about fuel availability and resale value. Moderately strong negative links connect environmental concern to resale value uncertainty and to belief in high cost of alternative fuels. Though the direct link to purchase intention from environmental concern is positive, those from resale value uncertainty and from belief in high fuel cost are negative.

Direct links to purchase intention are absent from convenience sensitivity, awareness of alternative fuels, and uncertainty about fuel availability. However, each of these variables has an indirect effect on purchase intention through intervening variables: Convenience sensitivity and uncertainty about fuel availability lead to uncertainty about resale value and belief in higher fuel costs, both of which negatively explain purchase intention. Awareness leads to belief in high fuel cost, but this indirect linkage is relatively weak.

Two of the three attributes that compose the convenience sensitivity factor in the measurement submodel, service availability and fuel availability, have similar factor loadings. The importance of the third attribute, refueling range, is slightly less than the other two, as demonstrated by a lower factor loading.

The direct exogenous variable effects, represented by the gamma matrix parameters, show that self-proclaimed environmental concern is greater among persons 25-44 years old and persons from households with more drivers per vehicle. Convenience is more important to persons from high income households, but less important to persons from households with intensive car usage, an unexpected result. Knowledge about alternative fuels is greatest among college graduates and persons from households with higher levels of car ownership and more intensive car usage; also, females claim to know less about alternative fuels. Uncertainty about fuel availability is less among households with higher numbers of drivers, and uncertainty about resale value is less among households with more intensive car usage. Finally, beliefs that alternative fuels will cost more are held by older persons, college graduates, and persons from households with higher car ownership levels; beliefs that they will cost less come from persons in households with more intensive usage per car.

An important result is that there are no direct exogenous variable effects on purchase intention; all exogenous explanations of stated intention to purchase alternative-fuel vehicles are indirect, through other endogenous factors. (This was confirmed in a series of hypothesis tests of non-zero elements γ_{71}, $\gamma_{72},\ldots,\gamma_{7,10}$; all were rejected.) However, due to the direct exogenous effects on the other endogenous factors and the causal structure among the endogenous factors, there are significant total (direct plus indirect) exogenous effects on purchase intention, as calculated in equation (9).

In particular, purchase intention is highest among persons from households with more drivers per vehicle, and among persons 25-44 years old. Relatively weaker results indicate lower purchase intention among college graduates and older persons.

7. Discussion

These results indicate that those who believe they are familiar with alternative fuels tend to believe these fuels will cost more; the more they believe they know about alternative fuels, the more convinced they are that these fuels will be more costly. Evidently, at present, alternative fuels have gained some negative publicity.

The results are conditional on the absence of information about alternative-fuel vehicles. With almost no information, respondents who claim to be concerned about the environment would prefer alternative fuels because they represent a change. On the other hand, those who claim to know about alternative fuels may be aware of their disadvantages, and suspect they may cost more.

Uncertainty is driven by convenience sensitivity. Those who value convenience, as represented by three importance ratings--service availability, refill range, and fuel availability, tend to assign a larger uncertainty to the availability of alternative fuels in the future and also to resale values of alternative vehicles. In agreement with the hypotheses, this uncertainty negatively affects the intention to purchase.

The major limitation of the present survey data and the model of causal relationships reflected in these data is that demand for alternative-fuel vehicles is limited to *stated purchase intention*. The second limitation, which should be kept in mind when interpreting the results, is that there is a potential selectivity bias in the sample, which might occur if certain segments had a higher motivation to respond to the survey and are therefore over-represented in the sample. Also, attitude and perception may change drastically over time, and the present results are valid only in the current pre-introduction environment for alternative-fuel vehicles.

In spite of these limitations, the model is thought to make several methodological contributions: First, factor analysis, market segmentation, and demand are captured in a single, simultaneously estimated model. Second, attitude scales are treated as ordinal, minimizing the number of assumptions about how respondents view and treat such scales. Third and finally, both direct and indirect causal effects can be separately identified, providing detailed market research information for policy evaluation.

8. Conclusions

It is apparent from the model results that self-proclaimed environmental concern is paramount in explaining initial consumer reaction to alternative-fuel vehicles. One market strategy for promoting alternative-fuel vehicles would be to identify "green consumers" and effectively approach them. There is a direct link from "environmental concern" to "purchase intention". In addition, environmental concerns are correlated with an individual's perceived future; an individual's environmental attitude appears to influence how he/she perceives the attributes of alternative fuels, such as resale value uncertainty and belief in high fuel cost.

Uncertainty about the availability of alternative fuels drives uncertainty about vehicle resale and belief in the high cost of alternative fuels. If concerns about availability of alternative fuels can be alleviated, then uncertainties about vehicle resale values and perceptions of high fuel costs might dissipate. An effective public relation campaign, then, must address the issue of fuel availability. Reducing the uncertainty associated with fuel availability appears to be one of the most fundamental steps toward successful deployment of alternative fuels and vehicles. This is especially so in light of the negative publicity that appears to prevail, at present; i.e., self-proclaimed knowledge about alternative fuels (at present) tends to lead to a belief in higher fuel costs.

Prior to large-scale introduction of alternative-fuel vehicles, survey results indicate that economic incentives, by themselves, may not overcome various concerns and reservations apparently held by consumers. In particular, consideration of service availability, fuel availability, and driving range precede those of economic incentives.

Again, uncertainty associated with unique characteristics of alternative-fuel vehicles, especially fuel availability, appears to be the major concern of consumers. This uncertainty needs to be eliminated before consumers are ready to compare gasoline vehicles and alternative-fuel vehicles using monetary value as a common comparison basis. Hastily introduced monetary incentives may not serve their intended purposes. Conventional factors that explain car type choice (including purchase price) may be less effective in explaining choices of alternative-fuel vehicles.

Those who value convenience and are sensitive to costs appear to be more skeptical about alternative fuels. Do they belong to risk averse segments? One inference that can be drawn, subject to further investigation, is: New car buyers, those who frequently replace their vehicles with new vehicles, may be risk averse, attempting to minimize the inconvenience of service and repair. If new car buyers tend to be risk averse, they might be less receptive to the market introduction of alternative-fuel vehicles. If this is true, consumer reaction might be improved if alternative-fuel vehicles are initially purchased by fleet buyers using strong incentives or mandates, then trickle down to general consumers.

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