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A Framework for the Analysis of an Individual's Choice of Urban Transportation Modes

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A Framework for the Analysis of an Individual's Choice of Urban Transportation Modes

Abstract

Empirical analyses of commuter transportation mode choice are limited since they are mode specific rather than mode abstract. For example, it is often found that mode specific variables taken together with certain socio-economic variables (particularly income and car ownership) will explain most of the variation in mode choice. A final limitation of these analyses is their failure to account for the effect of uncertainty about arrival time on the choice of mode. This paper addresses these shortcomings by developing a model which assumes that commuters are sensitive to the possibility of arriving late and thus choose the mode that provides the highest expected utility. In this framework, at the individual level, we find that (1) changes in income have a generally indeterminate effect of modal choice; (2) a shorter time length of a trip, a higher probability of arriving on time, and a decrease in the cost of a mode increases the likelihood that individuals will use it. Since, in the aggregate, commuters' choices will affect the reliability of the modes we simulate the model to gauge the efficiency of various policies (such as changes in relative costs) designed to encourage bus ridership. The simulation results suggest that simply increasing public transportation capacity during peak commuting times is likely to be the most successful strategy to encourage bus ridership.

A Framework for the Analysis of an Individual's Choice of Urban Transportation Modes

I. Introduction

There has been much interest of late in the use of transportation system management (TSM) methods for improving the efficiency of urban transportation systems. Many of these TSM methods are associated with control strategies such as increased gasoline prices, increased parking fees, ramp metering, and control on congested highways, that are intended to encourage shifts in modal choice towards the use of mass transit. The recently enacted Intermodal Surface Transportation Efficiency Act of 1991 (November 27) will serve to further increase interest in transit strategies. This bill, signed by President Bush in December 1991, gives the states unprecedented flexibility to set their own priorities and transfer much of their highway accounts for use in transit or non-traditional areas.

Although the initial act authorized $119.5 billion for highways and $31.5 billion for transit programs, in reality much more of these funds may be appropriated for transit uses. For this reason, there has been considerable interest in research on mode choice analysis. Most advances in this area, however, have focused on empirical methods and the expansion of the scope of mode choice modeling to a wider variety of situations.

Theoretical developments are much slower, and the fundamental structure of models in current use is only slightly different from those developed in the previous two or three decades. Most of the earlier applications took the form of binary stochastic choice models (Warner 1962, Lisco 1967, Quarnby 1967, DeDonnea 1970). These models were further extended to situations involving multi-modal choices by applying a multinomial logit model specification (Akiva and Richards (1976), Hensher (1986), and McFadden (1974)).

Current approaches to modeling mode choice are limited since they have been structured to fit observed choices by the inclusion of the necessary number of variables. Thus, these models can be utilized to evaluate the consequences of minor and gradual changes in the choice environment on mode choices, but only in the sample in which they were calibrated. The transferability of models from one environment to another is not supported in the literature. While there is a temptation to generalize the results of these mode choice models there is nothing that can be said about the universality of parameter values or formulations.

Another weakness in these models is the fact that most of those which are successful in predicting behavior are mode specific rather than mode abstract. In fact, in most models one can find that the mode-specific variables together with certain socio-economic variables (in particular income and car ownership) will explain most of the variations in mode choice among individuals or households. This suggests that there remains considerable ignorance about the nature of mode choice behavior in general.

A final limitation of these models is that they fail to account for the impact of uncertainty on the choice of mode. Risk averse individuals' choices are likely to be affected by the uncertainty regarding arrival time on the alternative modes. Models which are mode-specific tend to overlook this phenomenon. The framework presented in this paper addresses these limitations by developing a more universally transferrable choice model, albeit a simplified one that explicitly takes uncertainty into consideration. This is accomplished by employing the von Neumann - Morgenstern Expected Utility Hypothesis to model the choice of mode.

In the analysis here it is found that many generally accepted explanations for the effect of exogenous variables are situation specific, or an empirical issue. For example, in our framework we find that the effect of an increase in income on the choice of mode depends on the relative efficiency of each mode and is thus in general indeterminate. Because of this and other similar results some of the policy implications implied by empirical analysis may be inaccurate. This possibility is the main concern in our analysis of the policy implications of our framework. We analyze the policy implications of the model through a simulation.

The purpose of this paper is twofold: 1) to set forth a theoretical environment in which to analyze commuters' choices of transportation modes and 2) analyze this environment in order to determine the conditions under which policies to encourage the use of public transportation are most likely to succeed. To accomplish this, the paper is organized as follows: in the next section the environment and decision framework is described. The third section considers the individual's choice when the decision has a negligible effect on the environment. The third section examines the effects of feedbacks between the individuals' choices and the environment, through simulation analysis. These results are used to discuss the effectiveness of various strategies which can and are currently used by public transportation managers to encourage its use. The shortcomings and possible extensions of this framework are discussed in the summary section.

II. The Environment

Our analysis takes place in an ideal and simple world characterized by the following assumptions:

1. There are a large number of individuals who live in a suburban area and who commute to their place of employment located in an urban area.

2. Each individual owns a car and is limited to choosing private automobile or public bus transportation.[1]

3. Individuals do not change transportation modes between the outbound and inbound segments of

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[1] Assumption 2 only simplifies the notation but does not involve any loss of generality since the analysis is easily extended to include three or more modes.

the trip.

4. There are two relevant random events regarding the choice of transportation mode: arriving on time and arriving late.

5. All individuals are risk averse and have preferences for income and leisure that can be described by a utility function

$$(1)\ U = U(Y,N)$$

where Y is real daily income and N is the amount of leisure time. The utility function is characterized by positive but diminishing marginal utilities (since individuals are risk averse) and that increases in income increase the marginal utility of leisure and vice versa.

6. If an individual arrives at work late there is a penalty α on his income. The penalty is a function of the level of income and measures the loss of pay from being late plus the anticipated present value of the effects of being late on future income. This penalty is assumed to be a positive function of the level of income. Because of this penalty the individual is actually concerned with the perceived net value of daily income. Late arrival on either or both of the segments of the roundtrip involve a loss of leisure time.

The Decision Criterion

Each roundtrip is characterized by two events, and since there are two modes, there are four possible levels of utility that could be obtained. The choice of mode is thus similar to a choice of lotteries.

We employ the following notation: let the marginal costs of making the roundtrip be M_c when making the trip by car and M_b when making the trip by bus. Furthermore we subscript relevant variables by o and t for on time and tardy arrivals in the morning, and define y as net daily income and N as daily leisure time. The achievable levels of utility are

$$(2)\ U_{jo} = U(y_{jo}, N_{jo});\ \ y_{jo} = Y - M_j$$
$$U_{jt} = U(y_{jt}, N_{jt});\ \ y_{jt} = Y - M_j - \alpha(Y)$$

for modes j = b,c.

There is also some uncertainty about the time length of the evening trip on either mode. The level of leisure in (2) is the sum of the leisure time in the morning and the expected amount of leisure time in the evening.

Suppose, for the moment, that driving is more expensive but less time consuming. If the probability of arriving late on either mode is negligible and if the marginal utility of the difference in income, measured by the difference between M_c and M_b, is less than the marginal utility of the difference in leisure time, $(N_{co} - N_{bo})$, driving a car makes an individual better off, otherwise the bus is preferred. On the other hand, if the probability of late arrival is considerably high and if the marginal utility of the difference in leisure time $(N_{ct} - N_{bt})$ is less than the marginal utility of the loss of income, driving a bus is preferred. The reversal in the magnitudes of the marginal utilities is quite likely since it is assumed that the individual is risk averse, which implies positive but diminishing marginal utility of income.

The trade-off between taking the bus and driving a car is complicated by the uncertainty regarding arrival time. Under conditions of uncertainty the individual is concerned with the expected utility of a choice of transportation mode. Defining π_j, j=b,c, as the probability of the event of not arriving late (i.e., of being at least on time) when taking mode j, the individual's expected utility resulting from the choice of mode is measured by the von Neumann-Morgenstern scaling function of net daily income and leisure:

$$(3)\ V(j) = \pi_j U(y_{jo}, N_{jo}) + (1-\pi_j) U(y_{jt}, N_{jt})$$
$$= \pi_j U_{jo} + (1-\pi_j) U_{jt}$$

for modes j = b,c. Individuals select the transportation mode yielding the highest expected utility. Equivalently the individual's decision depends on whether

$$(4)\ R = V(c) - V(b) \gtrless 0$$

If R > 0, then car transportation is selected, R < 0 bus transportation is preferred, and if R = 0, the individual is indifferent with each decision depending on random exogenous factors which have a sufficiently small impact to be ignored here.

The individual's decision framework is illustrated in Figure 1. In this figure the horizontal axis measures daily income and the vertical axis measures the level of utility as a function of income for a given amount of leisure time. In this figure it is assumed that driving is more expensive but less time consuming, and that in either event the marginal utility of leisure (N_c - N_b) is greater than the marginal utility of income (M_c - M_b), hence, car transportation yields higher utility. The lines connecting points 1 and 2, and 3 and 4 represent the levels of expected utility that can be achieved for various combinations of the probabilities π_c and π_b. The midpoint on these lines would represent the expected utility when the probability of late arrival is 1/2 for each mode. A high probability of arriving late when taking a car and a low probability of the same for a bus are represented by points X and Y. In that case the difference R would be negative and bus transportation preferred.

(Figure 1 about here.)

III. The Effect of the Environment on the Choice of Mode

The effects of the variables describing the individual's environment on the choice of mode can now be determined by performing straightforward comparative statics on (4). The analysis in this section assumes that an individual's reaction has no impact on the environment. That is, each individual's choice has no impact on the marginal costs, time length of trip, and probability of arrival times of either mode. Although each individual may not have a measurable impact, if there exist many other similar individuals then their aggregate actions would have an impact on their environment. This is addressed in the following section of the paper where the results from the comparative statics exercises and simulation experiments are examined in terms of their policy implications.

Comparative Statics

We begin by first considering the impact of an increase in gross daily income Y. Differentiating (4) with respect to Y and rearranging yields:

$$(5)\quad \frac{\partial R}{\partial Y} = \left[\pi_c \frac{\partial U_{co}}{\partial y_{co}} - \pi_b \frac{\partial U_{bo}}{\partial y_{bo}}\right] + \left(1 - \frac{\partial \alpha}{\partial Y}\right)\left[(1-\pi_c)\frac{\partial U_{ct}}{\partial y_{ct}} - (1-\pi_b)\frac{\partial U_{bt}}{\partial y_{bt}}\right] \gtrless 0$$

The sign of (5) depends on the marginal utilities of income and the probabilities of arriving on time. Since individuals are assumed to be risk averse, it follows that the marginal utility of income is higher (in either event) for the more costly mode. Assuming, for the moment that car transportation is more expensive and that it is more reliable, i.e., $\pi_c > \pi_b$, the first term in (5) would be positive. However, since the probability of late arrival is greater when riding the bus the second term could be negative unless the marginal utility of income when driving is sufficiently greater than the marginal utility of income when taking the bus to offset the differences in probabilities of late arrival. The intuition here is that if one is to arrive late and hence incur a penalty on net daily income, then every dollar of income is worth more so that it may be preferable to use the cheaper alternative. The sign of the second term is indeterminate in the absence of more restrictive assumptions, however, since it is discounted by the fraction $(1 - \partial\alpha/\partial Y)$, its magnitude may be lesser than that of the first term. Hence, if car transportation carries less risk of arriving late, the effect of increases in income would be likely to cause the choice of driving to prevail.

It is interesting to note that if the individual is risk neutral, then changes in income would bias the choice towards the mode that yields the highest expected level of net income. This occurs because the individual is concerned with maximizing the expected value of income, without regard to risk. To see this, recall that a risk neutral individual's preferences do not exhibit diminishing marginal utility of income, assuming constant marginal utility of income and rearranging terms (5) becomes:

$$(6)\quad \frac{\partial R}{\partial Y} = \frac{\partial U}{\partial y}\frac{\partial \alpha}{\partial Y}[\pi_c - \pi_b] \gtrless 0$$

where $\partial U/\partial y$ is the constant level of the marginal utility of income. The sign of (6) depends on whether driving or riding a bus has a higher probability of arriving on time. This does not hold for risk averse individuals because they are concerned with the cost of the downside risk of late arrival.

The effects of the remaining exogenous variables are more straightforward. We examine these now, beginning with the effect of an increase in the probability of timely arrival for either mode. Differentiating (4) with respect to π_c yields

$$(7)\quad \frac{\partial R}{\partial \pi_c} = U_{co} - U_{ct} > 0$$

Which implies that automobile transportation is more likely to be chosen as it becomes more reliable relative to taking the bus. Similarly, differentiating (4) with respect to π_b yields

$$(8)\quad \frac{\partial R}{\partial \pi_b} = U_{bt} - U_{bo} < 0$$

Thus, when one transportation mode becomes more reliable relative to its alternatives it is more likely to be chosen. These results have useful implications for urban transportation policies discussed in the next section.

The effects of changes in the costs of transportation are also straightforward. If the marginal cost of a roundtrip by car increases this mode becomes less likely to be chosen, since

$$(9)\quad \frac{\partial R}{\partial M_c} = -\pi_c \frac{\partial U_{co}}{\partial y_{co}} - (1-\pi_c)\frac{\partial U_{ct}}{\partial y_{ct}} < 0$$

Similarly, an increase in the marginal cost of a roundtrip by bus makes this mode less likely to be chosen:

$$(10)\quad \frac{\partial R}{\partial M_b} = \pi_b \frac{\partial U_{bo}}{\partial y_{bo}} + (1-\pi_b)\frac{\partial U_{bt}}{\partial y_{bt}} > 0$$

It is also possible to employ this framework to consider the effect of other further removed exogenous influences on the choice of transportation mode. For example suppose that the penalty for late arrival, α, is a function of the level of gross daily income and of some exogenous parameter, θ, i.e., let

$$(11)\quad \alpha = \alpha(\theta; Y)$$

Such that a larger value of this parameter implies a larger penalty for late arrival. The parameter θ may vary across different types of employment. For example a professional with the same income as a non-professional might have a higher penalty on daily gross income because being late may cause the loss of a client (or patient) which affects future income as well. An increase in the penalty α increases the likelihood that the more reliable transportation mode is chosen. This is established by differentiating (4) with respect to θ which after rearranging terms yields:

$$(12)\quad \frac{\partial R}{\partial \theta} = \left[-(1-\pi_c)\frac{\partial U_{ct}}{\partial y_{ct}} + (1-\pi_b)\frac{\partial U_{bt}}{\partial y_{bt}} \right] \frac{\partial \alpha}{\partial \theta} \gtrless 0$$

If, as was assumed earlier, automobile transportation is more reliable and expensive, then the sign of (12) is positive.

The conclusions described in (5) - (12) can be used to evaluate the effectiveness of public transportation policies, as well as search for new policy strategies. This issue is addressed in the next section.

IV. Predictions and Policy Implications

Previous empirical analyses have concluded that the demand for a mode of transportation is generally own and cross price inelastic. According to the framework in this paper this phenomena occurs as a result of differences in the time lengths of trips (which directly impacts leisure time) and differences between the probabilities of late arrival between the two modes. It is also possible that individuals anticipate the effect of relative price changes on their environment. If offsetting changes in the environment result from price changes then individuals may not react in the manner described in the previous section. We begin by considering algebraically how this might occur and later demonstrate this via simulation analysis.

Comparative Statics

According to (9) and (10) an increase in the cost of using a particular mode reduces the likelihood that it will be used, so that by default the other mode may be preferred. Thus, if the cost of using the bus, M_b, increases commuters may switch modes. If a large number of them do so, then bus travel is likely to become more difficult which could reduce the probability of arriving on time. The opposite would occur if the cost of using a car, M_c, increases. This feedback can be modelled here by assuming that the probabilities of on time arrival are functions of the marginal costs of transportation. Hence, we now assume that

$$(13)\quad \pi_c = \pi_c(M_c, M_b)$$

and

$$(14)\quad \pi_b = \pi_b(M_c, M_b)$$

Such that $\partial\pi_c/\partial M_c > 0$, $\partial\pi_c/\partial M_b < 0$, $\partial\pi_b/\partial M_c > 0$, $\partial\pi_b/\partial M_b > 0$.

If (13) and (14) hold, then the impacts of changes in the marginal prices described in (9) and (10) become

$$(15)\quad \frac{\partial R}{\partial M_c} = -\pi_c\frac{\partial U_{co}}{\partial y_{co}} - (1-\pi_c)\frac{\partial U_{ct}}{\partial y_{ct}} + \frac{\partial \pi_c}{\partial M_c}[U_{co}-U_{ct}] + \frac{\partial \pi_b}{\partial M_c}[U_{bt}-U_{bo}] \gtrless 0$$

$$(16)\quad \frac{\partial R}{\partial M_b} = \pi_b\frac{\partial U_{bo}}{\partial y_{bo}} + (1-\pi_b)\frac{\partial U_{bt}}{\partial y_{bt}} + \frac{\partial \pi_c}{\partial M_b}[U_{co}-U_{ct}] + \frac{\partial \pi_b}{\partial M_b}[U_{bt}-U_{bo}] \gtrless 0$$

While the signs of (9) and (10) have a determinate impact, (15) and (16) do not. To see this, consider (15); the first two terms are the same as in (9) hence their sum is negative. The third term is positive since utility is higher when an individual is not late. By the same token, the fourth term is negative.

Depending on the strength of the feedback effects, changes in relative marginal prices may have an initial impact but over time this could deteriorate and eventually show up as a statistically insignificant effect. Empirically this would emerge as own cross price inelasticities of demand. Thus urban transportation policies based on price changes may, due to reliability perceptions and expectational effects, be ineffective.

Other policies such as those involving incentives for car pooling can also be ineffective since they tend to relieve traffic congestion which in turn raises the probability of on time arrival and possibly the amount of leisure time non-pooling car drivers can achieve. From the comparative static results in the previous section this indicates that the propensity to drive actually increases. This propensity also applies to bus riders who may be induced to switch to a car pool. Thus, policies designed to encourage car pooling may not achieve the desired objective. To examine the effect of the feedback on potential policies we turn to a simulation analysis.

Simulation Results

In simulating the model we employed the following parametric values: there are 1000 commuters, with daily gross incomes uniformly distributed between \$60 and \$280, who can take their car at a marginal roundtrip cost of \$5 or the bus for \$1.80. Arriving late costs a commuter 10% (that is, $\alpha = 0.1$) of that day's daily income. These individuals allow a maximum of 30 minutes for either segment of the trip. The minimum time for a one way car trip is assumed to be 10 minutes with groups of 25 cars (one person per car) at any point on the single route available. These groups move through the queue every half minute. Buses have a capacity of 65 passengers and run every 5 minutes. Each bus and car lot can be delayed by a time factor uniformly distributed between 0 and 5 minutes. This time factor reflects possible random delays due to accidents, inclement weather, etc., and is independently drawn for each lot. Excluding the random time factor, this set of parameters allows the entire population to commute by car and arrive on time, but only the first 260 bus riders can arrive on time. The public transportation system thus has a 26% relative capacity.

The simulation flows as follows: the individuals evaluate the expected transportation time, the probability of arriving late, and the cost for each mode. They choose the mode that gives them the highest expected utility. To this end we assumed that all individuals have identical utility functions of the form

$$(17)\ U(y,N) = 10^{-3}y^{0.5} + 10^{-5}N^{0.5} + 10^{-6}yN$$

Once the individuals make their choice they enter the car or bus queue and are randomly assigned to lots. The time length of a trip thus depends on which lot the individual is assigned to and the random time factor for that lot. As larger numbers of individuals select a mode, i.e., as a mode becomes more congested, the expected length of the trip and the probability of late arrival for that mode also increase since an individual's chances of being assigned to an early lot diminish. Individuals are assumed to return in the same order they arrived, with equal travel time for the evening trip. Once the "day" is over the proportions of car and bus passengers that arrived late and the average time of roundtrips is computed and the commuters use this data to update their expectations for the next day. This procedure is repeated for 150 days, at which point the simulation stops.

The results of this experiment were averaged for the last twenty days of the simulation (in order to remove the effect of minor fluctuations around the steady state) and are presented in Table 1 below. In this table we list the proportions of commuters that selected car and bus by income level, the overall proportions, and the proportions that arrived on time (these include the proportion that arrived in less than 30 minutes) and tardy. In the first scenario (the base scenario for comparisons) only the commuters in the lowest income group selected the bus, representing 25% of that income bracket and 13% of the overall population.[2] On average the 87% of the population that took the car arrived on time 98% of the time, the bus riders arrived on time 90% of the time.

(Table 1 about here.)

The simulation analysis focuses on three effects: changes in the relative costs of transportation, changes in the socio-economic characteristics of the population, and changes in the transportation network. The second scenario involved increasing the marginal roundtrip cost by car, M_c, by 50%. The third scenario involved decreasing the marginal roundtrip cost by bus by 100%. The results are summarized in the second and third pairs of columns in Table 1. Both experiments involve lowering the relative cost of bus transportation, however, in either case the response was proportionally less than the change in cost. This occurs primarily because a small increase in bus ridership involves a larger decrease in the probability of on time arrival.

The next experiment involved increasing the penalty for late arrival from 10% to 25% of gross daily income. As illustrated in the fourth scenario, this experiment indicated virtually no change in mode choices. Thus, areas with individuals who are greatly impacted if they arrive late are not more likely to select a car.

The last two scenarios examine the impact of changes in the capacity of the two modes. Doubling the number of buses within any time interval elicited a large response from the commuters. However, notice that in the base scenario 130 commuters chose the bus when its

[2] The effect of income on selecting a car is a result of our assumption of a strictly concave utility function. If we had selected a quasi-strictly concave function over the income range then the effect of income would not have been monotonic.

capacity was at most 260 passengers within a half hour. In this case the capacity is at most 520 passengers within a half hour and 270 commuters selected the bus. The proportional excess capacity remained the same. Similar results are obtained if car traffic is slowed down to the rate of one lot every minute (as opposed to every half minute). In that case more lower income commuters select the bus than in the base case so that the probability of on time arrival on either mode is lower.

Policy Implications

From the above analysis we draw the following conclusions: (1) lowering the cost of bus transportation will increase ridership if the capacity is simultaneously increased and if commuters are aware of this; (2) areas with greater concentrations of higher income types (and of commuters who are more significantly affected by a late arrival) are not affected by increased capacity - to increase ridership other factors (not examined here) may be more important. In a few words the impact of capacity at critical times of the day has a greater impact on mode choice via the effect on uncertainty than other variables such as relative costs, time length of trip, and income.

Policies that decrease the probability of on time arrival when taking a car have a marked negative impact on the propensity to select this mode. Such policies could take the form of restricting cars to certain lanes on congested routes during peak hours, or restricting automobile from the best routes during peak hours, and/or making parking difficult in the major employment locations. While such policies do encourage use of public transportation, they are not efficient because no commuter is made better off: those who chose to drive their car before these policies were made effective arrive later, those who previously elected to ride the bus arrive later, and switching modes is ineffective.

By running more buses, providing routes and lanes dedicated only to buses, and expanding public transportation networks, all commuters can be made better off and bus ridership is likely to increase. To achieve the desired result, however, the expectations feedback effect must be overcome, that is the effect of these changes on a commute must be made well known. Even more effective, however, would be to combine increased capacity with policies designed to make commuting by car less desirable.

V. Expanding the Framework

The contribution of this paper is twofold: First, we have incorporated developments in microeconomic analysis into a model of the choice of a transportation mode. Although it appears that it is the utility maximization hypothesis that drives our analysis, in actuality our approach may be better characterized as a full price model. The full price (or cost) of transportation includes not only the direct expenditures but the opportunity cost of time (measured by the relative preferences for income and leisure, and the levels of these which each mode allows one to achieve) and a risk premium (measured by the probability of late arrival for each mode). Second, by doing so we are able to explain a host of empirical results, particularly the generally insensitivity of modal choice to relative costs. Policies are designed to alter equilibria to other more desirable states (at least according to the policymaker's preference ordering). In order to provide the basis for practical policy analysis, it was necessary to describe the supply side more fully in order to characterize an equilibrium. For this purpose we simulated the model to establish policies that can make commuters better off while simultaneously achieving the objective of increased bus ridership.

It is also conceivable that the set of attributes in our full price approach could be expanded. Our approach includes the opportunity cost of time and risk of late arrival. However, there exist other attributes of transportation modes that need to be accounted for. For example, bus route systems that require riders to make connections that expose them to inclement weather or other undesirable situations (such as waiting in a high crime area) raise the propensity to drive. The presence of numerous speed traps along main thoroughfares would have the opposite effect. Thus, an interesting extension of our framework involves incorporating a more complete set of modal attributes.

The importance of modal attributes and the full price nature of the choice model described here suggest that a hedonic analysis of transportation costs would provide useful information into the nature of mode choices. A hedonic analysis would reveal the value commuters place on the individual attributes of modes thereby providing a basis for making pricing and taxing decisions that can be used in designing transportation system policies.

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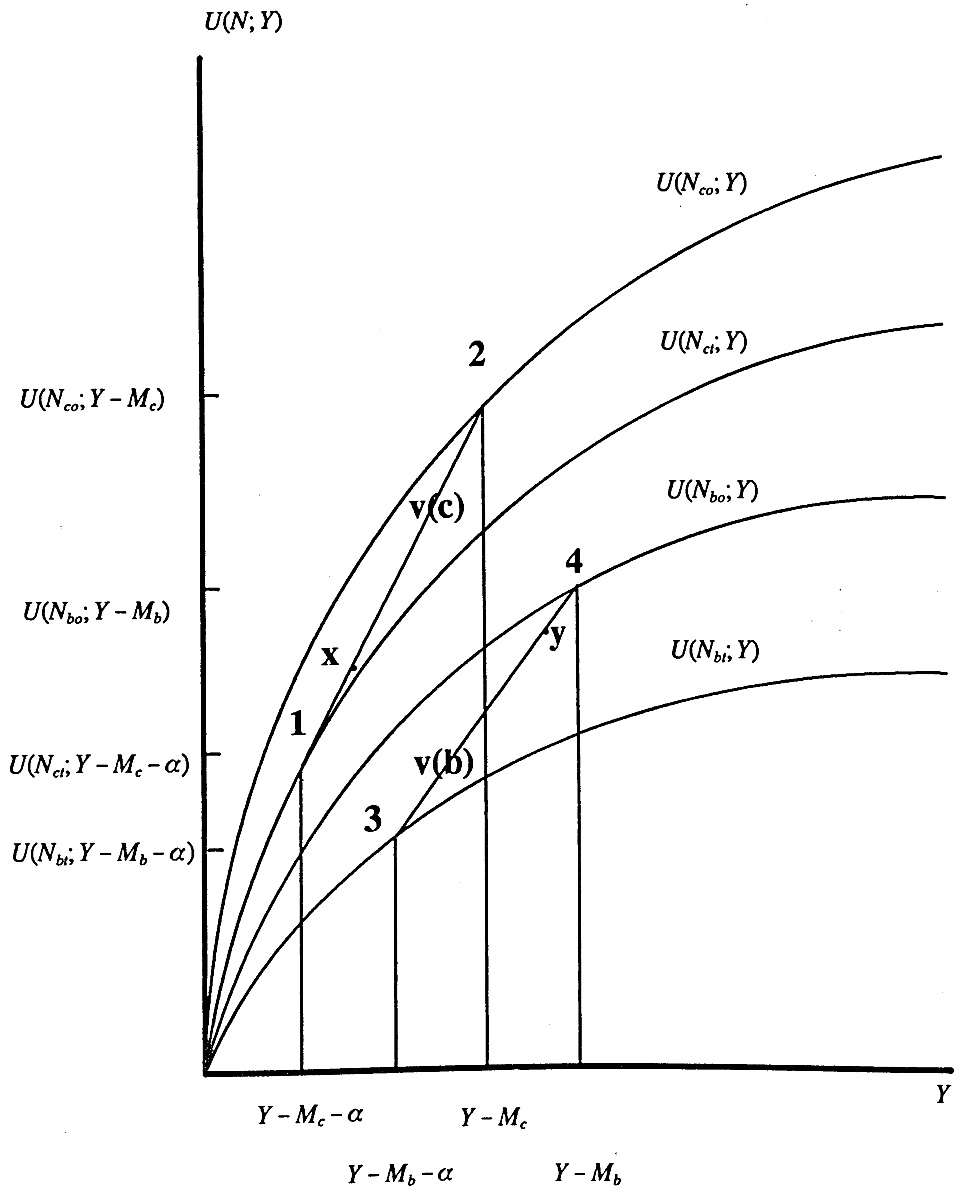
Figure 1. Graphical Representation of the Decision Framework



Note: $N_{ci} > N_{bi}, i = 0, t$

TABLE 1

Simulation Results Averaged Over The Last Twenty Days*

Scenario:	1		2		3		4		5		6	
Income	**%Car**	**%Bus**	**%Car**	**%Bus**	**%Car**	**%Bus**	**%Car**	**%Bus**	**%Car**	**%Bus**	**%Car**	**%Bus**
60-115	75	25	66	34	40	60	69	31	7	93	18	32
116-170	100	0	100	0	100	0	100	0	88	12	69	31
171-225	100	0	100	0	100	0	100	0	100	0	98	2
226-280	100	0	100	0	100	0	100	0	100	0	100	0
60-280	87	13	85	15	82	18	86	14	73	27	70	30
Arrival	**Car**	**Bus**	**Car**	**Bus**	**Car**	**Bus**	**Car**	**Bus**	**Car**	**Bus**	**Car**	**Bus**
On Time	98	90	99	82	99	83	97	93	100	99	66	65
Tardy	2	10	1	18	1	17	3	7	0	1	34	35

* In percentage terms.