Short-run and long-run policies for increasing bicycle transportation for daily commuter trips

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Long-run and short-run policies to increase the share of bicycle transportation for commuting to and from work are discussed. Analyses of data collected in the Philadelphia metropolitan area show that two general approaches can be taken to promote bicycle transportation. One is a set of policies geared to making bicycling safer and more convenient, essentially short-run ‘pro-bike’ policies. The other set is aimed at reducing the convenience of automobile commuting. This is an ‘anti-auto’ policy which can only be implemented in the long run. Since much of the sample had no choice but to commute by automobile, the impact of this constraint on the policy options is examined. In the long run it is assumed that commuters will have the choice of at least two modes by adjusting the distance between home and work locations. Specific proposals are discussed to implement some of the policies considered.

Keywords: bicycles, mode choice, transportation policy

Increasing the level of bicycle transportation is often considered as a means of decreasing the level of automobile commuting. Encouraging people to commute by bicycle is one of the solutions discussed to reduce traffic congestion, energy dependency and environmental problems, which have been associated with existing urban transportation systems. The purpose of this paper is to analyze the potential policies which will be necessary to facilitate increased bicycle commuting, both in the short run and in the long run.

The analyses presented will examine policies for achieving a larger share of bicycle commuters in the mix of urban transportation modes. The primary focus is on the importance of improving the safety and convenience of bicycling as a means of increasing bicycle commuting. Reducing the convenience of automobile commuting is also examined as a measure for increasing the usage of alternative modes, particularly bicycling. Safety concerns have often been cited as a principal reason for the low level of bicycle transportation for utilitarian trips, but urban forms and roads that are designed exclusively for the convenience of automobiles have had an impact on modal choice also.

It will be shown that two sets of potential policy actions can be taken. One involves policies that proactively encourage bicycling, such as improving convenience and safety by providing bicycle lanes or wide road shoulders, while the other involves policies designed to discourage the use of single-occupant automobiles. The latter tend to be long-term policies aimed at changing urban forms to reduce sprawling land use patterns.

Policy changes can have a major impact on the share of bicycles used for urban transportation. Pucher (1988) has shown how different policies in western European countries have resulted in a lower level of automobile usage. These policies include substantially larger taxes on gasoline and subsidies to mass transit. These types of policies (while not originally intended as such) probably more accurately reflect the social costs of automobile transportation than in the USA. The result is a lower level of automobile transportation and increased usage
of transit, walking and bicycling. Some European countries, such as The Netherlands and Denmark, have very high proportions of total trips made by bicycle, demonstrating that it is possible for modern developed countries to reduce motor-vehicle use. It has been official policy in these countries to build safe and convenient bicycle lanes and to discourage automobile traffic in cities. In contrast, Hanson (1992) concludes that automobile usage in the USA is heavily subsidized. This paper shows what actions will be necessary to increase the share of bicycle usage in modern US cities and suburbs; with obvious lessons for other nations considering alternatives to building automobile dependent cities.

This paper will be structured as follows. The first section will outline the two key hypotheses examined: the relation between perceptions of bicycling risk and modal choice and how perceptions of the convenience of alternative modes affects choice. This will be followed by a description of the survey and modeling methodologies and the definition of choice sets used in the analysis. The results are presented in three sections, first a discussion of the impact of convenience on modal choice, followed by an analysis of risk factors in bicycle transportation. Short-term and long-term effects are then compared using aggregate choice elasticities. The results of these analyses are subsequently related to the most effective policies for simultaneously increasing bicycle usage and decreasing automobile usage. It will be shown that a short-term policy of providing safe and convenient bicycle lanes and a long-term policy of reducing the convenience of automobile commuting are amongst the best ways of promoting increases in bicycle commuting and reductions in automobile usage (Noland, 1992).

Formulation of hypotheses

It has been hypothesized that one of the reasons people do not use bicycles more often is that they think it is too risky. Concerns about the safety of bicycling have not previously been addressed in other research as a determinant of modal choice. Surveys have indicated that safety concerns are a major disincentive to increased bicycle commuting. An Environmental Protection Agency study (US EPA, 1979) reviewed surveys that indicated concerns about accidents deterred people from using bicycles. A survey of travel within the City of Philadelphia found that 53% of the respondents would require exclusive bicycle paths as a necessary condition for bicycling to work (Philadelphia City Planning Commission, 1990). This is essentially a proxy for concern about the risk of bicycling (which is generally attributable to automobile–bicycle accidents).

It is also hypothesized that the convenience of alternative modes is related to various land use factors, such as population density. Newman and Kenworthy (1989) estimated that sparsely populated areas of less than 30 people/hec tare make non-motorized transport not feasible. Land uses have been separated, with residences, employment and retail activity in separate zones creating an imbalance between housing and jobs (Cervero, 1989). Access between the zones is made most convenient for automobile users, due partly to distance, and also due to the physical separation created by large suburban roads. The risk of crossing these roads can deter both bicyclists and pedestrians.

Previous research has examined attributes which determine whether people will use bicycles for transportation including Lott et al. (1977) and Robinson (1981). The former study found that shorter travel distances and younger people are more likely to travel by bicycle. Robinson (1981) did not find safety to be a significant issue in people’s choice of mode. One of the motivating factors in the current study was that no previous research on bicycle transportation has explicitly analyzed the many risk factors associated with bicycle commuting.

The primary hypotheses examined in this paper are how perceptions of the risk of bicycling and the perceived convenience of alternative modes influences the decision to commute by bicycle. This is stated formally in the following hypotheses:

1. Individual perceptions of the convenience of alternative modes influence the choice of mode selected for commuting.
2. Individual perceptions of the risk of bicycling influence the decision to commute by bicycle.

The modeling methodology utilized also elicited information related to perceptions of the costs and comfort of alternative modes, but the primary discussion will focus on the above two hypotheses related to perceptions of risk and convenience.

Rejecting or failing to reject these hypotheses can have important policy implications if decision makers wish to encourage bicycle transportation as a means of solving urban transportation and environmental problems. For example, designing roads which are safe for bicyclists rather than maximizing motor-vehicle traffic capacity may be necessary. Road design can be an integral element in policies to slow motor vehicle traffic, thus making it safer for bicycles and simultaneously reducing the convenience of the automobile. These policy initiatives will be discussed more fully in the final section of this paper.

Survey methodology and measurement of risk factors

Data for this study were collected using a mail survey conducted in the Pennsylvania counties of the Philadelphia metropolitan area. Prior to sending out the mail survey, two focus groups were conducted and a small pre-test was mailed to verify and refine the survey questions. The focus groups contained primarily bicyclists and addressed issues of concern to bicyclists regarding both risk factors and other impediments to bicycle commuting. The pre-test was sent to 50 bicyclists and a random sample of 50 Philadelphia residents. This was used primarily to verify that questions would be understood by the respondents.
During June and July of 1991, a 12 page survey was sent to 1000 bicyclists (based on lists supplied by local bicycle clubs) and to 500 randomly selected people from a purchased list (referred to as the "bicyclist" sample and the "general" sample, respectively). The survey was conducted using techniques recommended by Dillman (1978). This enabled a good response rate of over 35% of the general sample and over 64% of the bicyclist sample to be achieved.

The survey collected information regarding each respondent's daily commute trip. This included the transportation mode chosen (automobile, transit, bicycle or walking), the length of the trip, the perceived cost of the trip and various other attributes associated with the commute trip.

Risk perceptions were elicited by using two different methods. One question elicited two scores from the respondents. These were the likelihood of having an accident, and given that an accident had taken place, the expected severity of the accident. Since risk is a measure of the expected outcome of an event, this implies that the probability of the event occurring should be multiplied by the outcome of the event. On the basis of this model, the scores (ranked from 1–7) were multiplied together to achieve a risk coefficient. The square root of this coefficient was then taken to re-scale the risk coefficient between 1 and 7 (the greater value indicating a greater perception of risk). This question is presented in Figure 1. Respondents were asked to consider their risk over a five year time frame. This was arbitrarily selected as a large enough time frame to allow people to adequately think about the risks involved with each transportation mode.

Table 1 shows the relative values for the perceived risk measure, by mode chosen for commuting. In all cases, bicycling is considered the riskiest mode, even by people who choose to commute by bicycle. This corresponds with studies which have attempted to assess the relative risks of various modes (US EPA, 1979; Mitchell, 1978; Holdgate, 1981). Transit is perceived to be relatively safe, which corresponds to aggregate safety statistics in the USA (National Safety Council, 1992). Automobile and walking risk fall somewhere in between, with walking generally considered safer (except by people who choose to commute by automobile). This is because of the relative travel distances involved; when the measure is scaled by travel distance (not shown) automobiles are perceived to be relatively riskier (Noland, forthcoming).

Risk perceptions were measured rather than attempting to assess objective measures of the risk of bicycling. This was done for several reasons. First, to properly assess individual responses to risky situations it is necessary to determine individual perceptions of risk (Slovic et al., 1982). These can vary for many reasons ranging from individual attitudes about risk taking, to the specific characteristics of each individual’s commute. For example, those traveling longer distances had a higher mean risk perception score than those traveling shorter distances. This indicates that individuals were assessing their personal exposure to risk in their risk perception scores since lengthier commutes would, on average, result in greater exposure to risky situations.

Another reason for using perceptions of risk is that no data exist to adequately measure objective risk scores for each individual and their specific commuting route. Different roads may have different rates of bicycle accidents, but given the low level of bicycle transportation, data at such a disaggregate level is meaningless (in addition, it is not recorded in a manner that is retrievable for analysis).

Survey respondents also ranked a list of potential risk factors facing bicycle commuters (see Figure 2). The question asked for a risk score to be selected for each risk factor presented based on the respondent's own feelings about each situation. These risk factors ranged from a score for "extremely risky" to "extremely safe" (lower values indicated higher risk scores). Respondents were asked to answer only for the specific route they would encounter if they were to (or already do) commute by bicycle.

Convenience levels for each mode were also elicited from the survey. A scale from 1 to 7 was used, ranging from "very inconvenient" to "very convenient". This

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2This included one postcard reminder one week after the initial mailing, a three-week follow-up which included a second copy of the questionnaire, and a one dollar incentive for the general sample.
3This is defined as an exogenous sampling procedure by Ben-Akiva and Lerman (1985). The significance of the coefficients is not affected by this sampling procedure. Elasticities and sample enumeration forecasts are adjusted based on relative population and sample ratios. This is discussed further below.
4Respondents were also asked about multi-mode transit trips. However, the sample included only one person who rode a bicycle to a train station.
5This can result in different responses having the same risk score. For example, one person may select (1) 'Almost certain not to have an accident' and (6) 'Permanently disabling injuries'. Another may choose (3) 'Somewhat unlikely' and (2) 'Minor scratches and bruises'. Both would result in the same risk score equal to 6. The former has a large perceived severity of the accident but thinks that it is extremely unlikely, while the latter feels accidents are not too unlikely but that they would have relatively minor consequences. This is the intention of this variable, to weight perceived severity of accidents by their perceived probability of occurrence.
6Alternative formulations for combining these two measures were also tested: for example, scaling the severity measure to weight fatalities with a much higher measure than no injuries. These alternative transformations did not provide any different results. Therefore, the simple multiplicative transformation is presented for simplicity. For more detail, see Noland (forthcoming).
7Slovic et al. (1978) have shown that people respond to lifetime estimates of the risk of driving a car more readily than to the risk involved with a single trip.
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The following ratings were given for the likelihood of being in an accident during the next five years if one were to commute to and from work. This was solicited for the following four transportation modes: automobile, bicycle, transit and walking.

The question was phrased as follows:

Please rate how likely YOU think it is for you to be in an accident during the next five years, if you used each of the following forms of transportation for commuting to and from work or school?

1 = Almost certain not to have an accident
2 = Very unlikely
3 = Somewhat unlikely
4 = 50% chance of having an accident
5 = Somewhat likely
6 = Very likely
7 = Almost certain to have an accident

The following ratings were given for the severity of an accident if it were to occur.

The question was phrased as follows:

Now consider the severity of an accident if it were to occur. Please rate how seriously injured YOU think you would be if you were to be in an accident with each of the following forms of transportation?

1 = No injuries whatsoever
2 = Minor scrapes and bruises
3 = Injuries requiring medical attention but no hospital stay
4 = Injuries requiring short hospital stay of a few days
5 = Injuries requiring lengthy hospital stay of several months with fall recovery
6 = Permanently disabling injuries (paralysis or coma)
7 = Fatal injuries

Figure 1 Survey question on risk perceptions of alternative modes

measured the perceived convenience of each mode for the commute trip of each survey respondent. As with the case of measuring risk perceptions, individual convenience perceptions are the relevant variable to include in the model. Each individual will assess the relative convenience of his or her commute for alternative modes based on the factors they consider important. As was expected, population density and travel distance are correlated with the perceived convenience of various transportation modes. The validity of the scale is supported by this result; i.e., those with longer commutes found the automobile to be more convenient and those with shorter commutes found walking and bicycling to be more convenient.

Multinomial choice analysis methodology

Consumer demand theory states that individual’s will seek to maximize the utility of their actions. For modal choice decisions, this implies that a commuter will select that transportation mode that maximizes his or her utility for the journey to and from work. Multinomial logit (MNL) models provide a method for modeling discrete choice problems and determining the significance of attributes in a hypothesized utility function. In this case, the choice of commute mode is the dependent variable (which is discrete) while the attributes which may influence choice are the independent variables.

MNL models are based on a Random Utility Model. Ben-Akiva and Lerman (1985) and Train (1986) provide a thorough presentation of these models and their applications to transportation. This model states that choice probabilities are equal to the probability that the utility of an alternative is equal to or greater than the utilities of all other alternatives in the given choice set. The utilities are assumed to be random variables. Some of the underlying sources of randomness include attributes that are unobserved by the researcher, unobserved taste variations amongst individuals, measurement error, and the substitution of instrumental variables to represent actual attributes.

MNL models are estimated using maximum likeli-

| Table 1 Mean values of perceived risk measures by mode chosen |
|---------------------------------|----------------|---------------|---------------|---------------|
|                                | Mode chosen   | Bicycle       | Walking       | Transit       |
| Perceived risk of bicycling    | 3.62          | 4.34          | 3.88          | 4.07          |
| Perceived risk of automobiles  | 2.98          | 2.85          | 3.11          | 3.28          |
| Perceived risk of walking      | 2.44          | 3.13          | 2.30          | 2.71          |
| Perceived risk of transit      | 2.30          | 2.46          | 2.11          | 2.21          |
For the specific route you would use (if you commuted by bicycle), please indicate how safe or risky you feel each situation listed below is, using the scale shown.

<table>
<thead>
<tr>
<th>1 = Extremely risky</th>
<th>4 = Moderately safe</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 = Very risky</td>
<td>5 = Very safe</td>
</tr>
<tr>
<td>3 = Moderately risky</td>
<td>6 = Extremely safe</td>
</tr>
</tbody>
</table>

Rainy weather
Snowy weather
Snow or ice on the road
Pot holes or debris on the road surface
Riding on a road with no shoulders
Riding at night when using a light
Riding at night with no lights
The presence of bad drivers on the road
Heavy car traffic
Riding on a road with high posted speed limits
Not stopping at a stop sign on a bicycle
Not stopping at a traffic light on a bicycle
Riding on the wrong side of the street, facing traffic
Riding at the same speed as traffic (20-25 mph) in the middle of the road

Figure 2 Survey question on bicycle risk factors

hood estimation procedures (see Ben-Akiva and Lerman (1985) for a full explanation of possible estimation procedures). Estimates for attribute coefficients and corresponding t-statistics are generated by the model. In this study the results are interpreted based on the statistical significance of the attributes and their aggregate elasticities.

Specification of logit models of multinomial choice requires construction of utility models for each alternative (e.g. each mode of transportation). Two types of parameters can be estimated in these models. In those cases where each alternative has the same measurable attribute, a generic parameter can be estimated. As an example, consider the travel time attribute. This variable is observed for each mode. If a coefficient were generically estimated, then its value would show the significance of travel time between the various modes. If one particular mode always has the shortest travel time, then a negative sign on this coefficient would indicate that the impact of shorter travel time increases the probability of selecting that mode.

The other option is when an attribute has a different coefficient for different modes. They can then be specified for each alternative, and are known as alternative specific coefficients. For example, the convenience of modes may be perceived differently for each mode, therefore one may wish to estimate separate convenience coefficients for each mode. This implies that the convenience coefficient has a different value in the respective utility functions for each mode. If the coefficient were generic across modes, then it would be the same in each mode's utility function.

Another example of an alternative specific coefficient is when it is included in the utility function of only one mode. For example, assume that perceptions of risk are found only to be important as an attribute in the bicycle utility function. By including this attribute as specific to just the bicycle mode, one is assuming that it is equal to zero for all other modes (i.e. is equal to zero in the utility functions of the other modes)

Elasticities can be evaluated from the coefficients estimated from a logit model. These allow one to measure how an individual's choice probability will change due to a change in an attribute for that alternative. Since these are point elasticities, they only apply to small changes in attribute values. A direct elasticity, defined for alternative, $i$, individual, $n$, and attribute, $k$, for attribute coefficient $\beta_k$ is:

$$E^{p(i)}_{x_{nk}} = [1 - p_n(i)x_{nk}]x_{nk}\beta_k$$

(1)

The value of the attribute is equal to $x_{nk}$.

Cross-elasticities may also be defined as:

$$E^{p(i)}_{x_{nk}} = -p_n(i)x_{nk}\beta_k, \text{ for } j \neq i$$

(2)

A cross elasticity measures the change in an alternative's choice probability for an individual given a change in the attribute of another alternative. Logit cross elasticities are uniform across all alternatives $i$ other than $i = j$. These formulas can be expressed as:

$$E^{p(i)}_{x_{nk}} = [\delta_{ij} - p_n(i)x_{nk}]x_{nk}\beta_k$$

(3)

where $\delta_{ij} = 0$ for a cross-elasticity and 1 for a direct elasticity.

The elasticities defined above are disaggregate elasticities that measure change in probabilistic choice at the individual level. Aggregate elasticities can be defined that measure how the expected share of a group of individual's change their choice of mode. These are calculated as the weighted average of the individual level elasticities:
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\[
P_{ij}^* = \frac{\sum_{j=1}^{N_j} P_i(j) P_j^*}{\sum_{j=1}^{N_j} P_i(j)}
\]  

This weighted average uses the choice probabilities, \(P_i(j)\), as weights. The summation is over the sample from \(n = 1\) to \(N_j\).

The sampling strategy included two different subsamples, the general random sample and the bicycle club sample. This type of sampling strategy is defined in Ben-Akiva and Lerman (1985) as exogenous sampling. The sample is segmented on an attribute, in this case membership in a bicycling organization. Coefficients of exogenous samples are estimated using the same methods as simple random samples.

Calculation of aggregate elasticities based on an exogenous sample requires a different weighting of the individual elasticities. The average probability weights must be adjusted to account for the proportion of each exogenous sample in the general population. For example, assume one sample is drawn exogenously based on income levels, and represents 10% of the general population. Then their individual elasticities, when aggregated, must be weighted by this amount (i.e., the sub-sample proportion in the general population). The following equation can be used to calculate aggregate elasticities for exogenous samples:

\[
P_{ij}^* = \frac{\sum_{j=1}^{N_j} \left( \frac{N_j}{N} \right) \frac{1}{N_i} \sum_{m=1}^{N_m} P_i(j) P_j^*}{\sum_{j=1}^{N_j} \left( \frac{N_j}{N} \right) \frac{1}{N_i} \sum_{m=1}^{N_m} P_i(j)}
\]

\(N_j\) is equal to the population total in each exogenous group, \(N\) is equal to the total population size, and \(N_{ij}\) is equal to the size of the sample in group \(j\). This means that the ratio \(N_{ij}/N_j\) is equal to the proportion of the population in each group. A rough estimate of 0.025% is assumed to represent the proportion population of the bicycle club sample.

Weights for population income distributions were also included to help correct for the undercounting of lower income individuals in the sample.

The hypotheses discussed above will be evaluated based on the theoretical significance of the perceived risk and perceived convenience attributes in the MNL model.

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\(^8\)See Ben-Akiva and Lerman (1985) p 113 for a complete derivation of this formula.

\(^9\)See Ben-Akiva and Lerman (1985) pp 206–207 for a derivation of this conclusion.

\(^10\)As a more specific illustration of this, assume two samples are drawn exogenously. Sample 1 has 500 people and represents an income group which is 10% of the general population. Sample 2 has 300 people and represents the remaining income groups which comprise 90% of the general population. The weighting for each individual elasticity in sample 1 would be 1/500 x 1/10 (0.0002). For sample 2 it would be 1/300 x 9/10 (0.003). Note that these weights sum to 1 when aggregated (0.0002 x 500 + 0.003 x 300 = 1).

\(^11\)Based on approximately 10,000 cyclists in clubs in the five county area divided by total population (1990 census for total population is 3,728,000).

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**Availability of modes in individual choice sets**

It is assumed that each individual faces a given choice of transport modes in their choice set. Several assumptions were made in defining these choice sets. The choice set for each individual was defined based on the commute distance and whether they stated that transit was an available option. Those with a commute distance of less than 2 miles (3.22 km) were assumed to have the choice of walking, while those with commute distances of less than 6 miles (9.66 km) were assumed to have the choice of bicycling. Some respondents who actually bicycled to work had a longer commute distance and therefore had bicycles included in their choice set. Not owning a bicycle did not exclude bicycles from an individual’s choice set, due to the relatively low acquisition costs of purchasing a bicycle. Automobile and transit choice was based upon respondents stating that these modes were available as options. Table 2 shows the number of respondents with a choice of each mode and the number choosing each mode.

Some of those included as having a choice of using a bicycle (or other non-auto mode) may have virtually no practical option of using a non-auto mode. For example, they may find it necessary to transport children to school with an automobile, they may have large items to transport to and from work, or they may wear work clothes that they find unsuitable for bicycling. These are not reasons for excluding these people from having a choice of using a bicycle; however, they would presumably find a bicycle more inconvenient than using an automobile. This can be confirmed by analyzing the average level of convenience for those who indicated the following reasons for not bicycling to work: 'Arrive at work/school all sweaty' and 'Need to carry things'. The first question implies that they may be uncomfortable using a bicycle with work clothes on. The perceived convenience of using a bicycle was 3.17 and 3.40 for those who answered that these were reasons for not using a bicycle. Those who did not indicate these were reasons had a perceived bicycling convenience score of 4.83 and 4.29 respectively, therefore, those who indicated that the above two items deterred them from using a bicycle found bicycles to be significantly less convenient for their commute.

Many of the respondents to the survey indicated that they had no choice of transportation mode for their daily commute trip. Either they needed their car for work or there were no other feasible options available to them.

**Table 2 Number of respondents with choice of modes**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Number of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobile</td>
<td>316</td>
</tr>
<tr>
<td>Bicycle</td>
<td>215</td>
</tr>
<tr>
<td>Transit</td>
<td>261</td>
</tr>
<tr>
<td>Walk</td>
<td>72</td>
</tr>
<tr>
<td>Actual choice</td>
<td>181</td>
</tr>
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<td>---------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Have choice</td>
<td>316</td>
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<tr>
<td>Choose mode</td>
<td>181</td>
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72
Generally they lived too far from work to walk or bicycle, and there was no transit available (especially for suburb to suburb commuting trips). It was not examined why people indicated that they needed their car for work, but the high number of respondents indicating this (20% of the sample) probably means that people were not just considering work-related errands which required them to have a car at work. Cervero (1989) has shown that non-job related trips made during lunch breaks are a common reason for requiring an automobile at work. It is probable that many people responded affirmatively to the survey question because of non-job related reasons for ‘needing’ a car at work. In any case, these people, by definition implied that they do not have a choice of mode, and are excluded from the choice analysis.\textsuperscript{13}

Long-term changes in the availability of modes is one of the key elements in evaluating long-term policy options. This is based primarily on reductions in travel distances and changes in spatial location. The long-term elasticities discussed further below assume that individuals are no longer constrained by a lack of choice, but now have a choice of at least two modes for their daily commute trips.

Convenience of alternative modes

The hypothesis that individual perceptions about the convenience of alternative modes is important in determining the choice of commute mode is now analyzed. Increasing the convenience of bicycling should increase its level of usage, while making automobile commuting less convenient, should decrease the number of people who commute by automobile. In addition, it is important to analyze how perceptions of the convenience of alternative modes can be translated into measurable parameters, such as population densities and parking availability.

The relative convenience of each mode seems to be related to different factors. For bicycling and walking, there is a mild correlation with the reported travel time (\(0.303\) and \(-0.372\) respectively). Increases in travel time reduce the perception of the convenience of these modes. The convenience of transit and automobiles does not show any correlation with travel times. However, for automobiles there is a strong negative correlation with population and employment densities (both at home or work locations). For the other modes, this correlation is generally positive, as is shown in Table 3. The implication is that those who live and work in suburban areas find the automobile more convenient, while the opposite is true for other modes. Note that transit convenience has the highest positive correlation with population and employment densities at the work location (i.e. the central business district).

The convenience of parking at work plays a role in the perceived convenience of bicycling. Those respondents with safe bicycle parking available have a statistically significant higher mean perception of bicycling convenience than those without parking available (4.176 versus 3.270). The availability of automobile parking was not analyzed, although suburban areas generally have abundant free parking while Center City Philadelphia has relatively expensive parking (although for many employees this may be subsidized).

In analyzing the impact of perceived convenience on modal choice, it was found that the travel time and population density variables (the later included as specific to the automobile mode) were not significant when included in an MNL model along with the perceived convenience variable.\textsuperscript{14} Travel time and the population density variables are significant in the expected direction, when perceived convenience is excluded from the model. Increased travel time has a negative coefficient and increased density reduces the likelihood of commuting by car (which implies that transit and the non-motorized modes would have a positive coefficient). When only the perceived convenience variable is included in the model, it is found to be highly significant. Calculation of the \(\beta^2\) statistic, which can be used to compare models based on the same data, indicated that the model containing the perceived convenience variable was superior (Ben-Akiva and Lerman, 1985). The perceived convenience variable probably contains more information than travel times and population densities, and more importantly, measures each individual’s concept of what convenience is.\textsuperscript{15}

The convenience of modes is determined differently for different modes (e.g. population densities have different impacts on each mode). This would imply that the convenience coefficient in the utility function for each mode should be different. An alternative-specific formulation of the MNL model was tested and is presented in Table 4, column A. A chi-square test indicated that the generic hypothesis should be rejected in favor of this alternative specific formulation.

\begin{table}
\centering
\begin{tabular}{lrrrr}
\hline
 & \text{Bicycle} & \text{Auto-} & \text{Transit} & \text{Walking} \\
\hline
\text{Population density at home} & 0.216 & -0.369 & 0.288 & 0.381 \\
\text{Employment density at home} & 0.136 & -0.332 & 0.150 & 0.473 \\
\text{Population density at work} & 0.112 & -0.408 & 0.368 & 0.208 \\
\text{Employment density at work} & -0.042 & -0.372 & 0.565 & 0.142 \\
\hline
\end{tabular}
\caption{Correlation of convenience and density measures}
\end{table}

\textsuperscript{13}This is due to multi-collinearity of the variables.

\textsuperscript{14}This is an area ripe for future research possibilities. Namely how do people perceive the convenience of alternative modes and what is the importance of policy variables such as parking availability, travel speeds, reliability and access times.

\textsuperscript{15}It is possible that some of these people would be encouraged to commute by bicycle if there were incentives for both commuting by bike and using bicycles for lunch-break trips. For example, reimbursing employees for business related use of their bicycles as is now done for business use of personal automobiles. These type of incentives were not specifically examined in this study but could be considered in future research.
## Table 4 Multinomial logit models

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>choice of mode</th>
<th>Number of records = 354</th>
<th>Number of carers = 510</th>
<th>Coefficient estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Automobile constant</td>
<td>9.17479</td>
<td>6.34570</td>
<td>9.20973</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.715)</td>
<td>(3.619)</td>
<td>(3.858)</td>
<td></td>
</tr>
<tr>
<td>Transit constant</td>
<td>2.80956</td>
<td>4.79831</td>
<td>4.68539</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.138)</td>
<td>(2.800)</td>
<td>(1.826)</td>
<td></td>
</tr>
<tr>
<td>Walk constant</td>
<td>3.79397</td>
<td>5.25058</td>
<td>4.75222</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.376)</td>
<td>(3.155)</td>
<td>(1.707)</td>
<td></td>
</tr>
<tr>
<td>Perceived cost (generic)</td>
<td>-0.0102561</td>
<td>-0.056897</td>
<td>-4.954</td>
<td></td>
</tr>
<tr>
<td>Perceived cost (specific to bicycles)</td>
<td>0.056603</td>
<td>0.056897</td>
<td>(-2.660)</td>
<td></td>
</tr>
<tr>
<td>Perceived cost (specific to automobiles)</td>
<td>-0.914536 E-2</td>
<td>-0.960898 E-2</td>
<td>(-4.240)</td>
<td></td>
</tr>
<tr>
<td>Perceived cost (specific to transit)</td>
<td>-0.103597 E-2</td>
<td>-0.196081 E-2</td>
<td>(-0.275)</td>
<td></td>
</tr>
<tr>
<td>Perceived convenience (specific to bicycles)</td>
<td>0.789901</td>
<td>0.739999</td>
<td>(4.036)</td>
<td></td>
</tr>
<tr>
<td>Perceived convenience (specific to automobiles)</td>
<td>-0.450554</td>
<td>0.513972</td>
<td>(3.530)</td>
<td></td>
</tr>
<tr>
<td>Perceived convenience (specific to transit)</td>
<td>1.10086</td>
<td>1.07796</td>
<td>(3.090)</td>
<td></td>
</tr>
<tr>
<td>Perceived convenience (specific to walking)</td>
<td>1.06142</td>
<td>1.16112</td>
<td>(3.595)</td>
<td></td>
</tr>
<tr>
<td>Travel time (generic)</td>
<td>-0.0273681</td>
<td>-0.022609</td>
<td>(-1.971)</td>
<td></td>
</tr>
<tr>
<td>Perceived risk (generic)</td>
<td>-0.517487</td>
<td>-0.254609</td>
<td>(-1.971)</td>
<td></td>
</tr>
<tr>
<td>Perceived risk (specific to automobiles)</td>
<td>0.318492</td>
<td>(1.623)</td>
<td>(2.275)</td>
<td></td>
</tr>
<tr>
<td>Perceived risk (specific to bicycles, transit, walking)</td>
<td>0.0163297</td>
<td>(1.028)</td>
<td>(3.297)</td>
<td></td>
</tr>
<tr>
<td>Weather related risk component (specific to bicycling)</td>
<td>0.387418</td>
<td>0.255991</td>
<td>(2.786)</td>
<td></td>
</tr>
<tr>
<td>Lack of shoulders risk factor (specific to bicycling)</td>
<td>0.318492</td>
<td>0.255991</td>
<td>(2.786)</td>
<td></td>
</tr>
<tr>
<td>Perceived comfort (generic)</td>
<td>0.375255</td>
<td>0.50750</td>
<td>0.255991</td>
<td></td>
</tr>
<tr>
<td>Number of motor vehicles owned (specific to automobiles)</td>
<td>0.816504</td>
<td>0.403629</td>
<td>0.755729</td>
<td></td>
</tr>
<tr>
<td>Bicycle parking available (specific to bicycles)</td>
<td>1.31281</td>
<td>1.60176</td>
<td>1.31255</td>
<td></td>
</tr>
<tr>
<td>Bicycling competency (specific to bicycles)</td>
<td>0.049639</td>
<td>0.496250</td>
<td>0.503497</td>
<td></td>
</tr>
<tr>
<td>Sex (m =1, specific to bicycling &amp; transit)</td>
<td>1.44694</td>
<td>1.29487</td>
<td>1.23205</td>
<td></td>
</tr>
<tr>
<td>Income (specific to automobile)</td>
<td>-0.147293 E-4</td>
<td>-0.962855 E-5</td>
<td>-0.150045 E-4</td>
<td></td>
</tr>
<tr>
<td>Hours of exercise per week (specific to bicycling and walking)</td>
<td>0.0694505</td>
<td>0.0738392</td>
<td>0.0732675</td>
<td></td>
</tr>
<tr>
<td>$L(\beta)$</td>
<td>-127.73</td>
<td>-171.55</td>
<td>-125.34</td>
<td></td>
</tr>
<tr>
<td>$\delta^2$</td>
<td>0.5202</td>
<td>0.3665</td>
<td>0.5280</td>
<td></td>
</tr>
</tbody>
</table>

T-stats are in parentheses.

All the convenience coefficients have a high level of significance. However, the coefficients for transit and walking are higher than for automobiles and bicycles. Therefore, convenience seems to be more important for transit and walking. Automobile convenience has the lowest coefficient value, while bicycling convenience is slightly higher (0.4506 versus 0.7599 respectively). Therefore, it seems that while convenience is significant for all the modes, it is most important for transit and walking, and less important for automobiles and bicycling. This may reflect the fact that bicycling and automobiles give the best door-to-door level of convenience (walking does also but is obviously much more sensitive to travel distances, which may overwhelm this effect). Transit convenience is probably sensitive to the time required to wait for the mode, transferring between vehicles, and the time required to get to the mode's access point.
The high levels of significance of the convenience coefficients may exhibit an upward bias. This could be due to the fact that people justify their choice of mode by assuming it is the most convenient. The perceived convenience variable may be endogenous to the choice of mode. Small (1992) indicates that this may cause problems in using the model for predictive purposes. However, in terms of indicating the factors which aid in choosing modes, perceptions of attributes are the relevant decision parameter.

The individual preferences revealed by the convenience coefficients indicates that policies aimed at reducing automobile commuting convenience or increasing bicycling convenience should be effective at increasing the level of bicycle commuting. These policies should focus on reducing the relative travel time for bicycle commuters and increasing travel times for automobile commuters. Various policy options and the long-term nature of these policies will be discussed further below.

Analyses of bicycling risk measures

The survey conducted for this research found that a large percentage of respondents reported that safety related concerns were a major reason for not commuting by bicycle. About 50% of the total sample surveyed reported that they considered bicycle commuting 'too dangerous' and over 60% said there was 'too much car traffic' (which is one of the primary sources of risk).

Mean values for the perceived risk measure (based on the survey questions in Figure 1) for each mode, are presented in Table 1 by mode chosen for commuting. As can be seen, regardless of the mode actually used, the bicycle is perceived as the riskiest mode for commuting. All respondents perceived the automobile to be the second most risky mode for commuting, followed by walking. Transit was considered the least risky commute mode.

The difference in perceived risk between the various modes and the commute mode chosen is also interesting to observe. For example, automobile commuters perceive a larger difference between the risk of bicycling (4.34) and the risk of using an automobile (2.85), compared to differences between other modes. This suggests that risk may play a role in their decision not to commute by bicycle.15

The model shown in Table 4, column A, however, does not show the perception of risk attribute to be significant in the choice of the bicycle mode. The perception of risk variable was entered as alternatively-specific to the automobile mode and as identical for the three other modes. Bicycling, walking and transit do not have a significant perceived risk coefficient (T=−1.028), although the sign is in the expected direction. However, the perceived risk of using an automobile is significant in explaining the choice of the automobile mode.17

This formulation indicates that perceptions of bicycling risk do not seem to play a significant role in the decision to commute by bicycle. Another formulation of the model did give a significant result for a generic perceived risk variable (i.e. riskier modes such as bicycling and automobiles are less likely to be used). This is shown in Table 4, column B. This model included travel time as a variable instead of the perceived convenience variable and had a lower value for \( \beta \). Perceived risk and travel time are correlated due to the increased risk exposure for those with longer commutes; therefore, this model may exhibit a greater degree of multi-collinearity.

From a policy perspective it is informative to examine more specific measures of risk. The road-related risk factors (see Figure 2) were included in the model to determine if various unique road-related risks influence the choice of bicycling. The only road-related risk factor that showed statistical significance in the expected direction is for those who rate riding on a road with no shoulders as risky. Lower values on the risk factor score indicate greater risk, therefore a positive coefficient reflects a higher level of risk reducing the likelihood of commuting by bicycle. The greater the risk level of the 'lack of shoulders' on the road risk factor, the less likely a bicycle will be chosen for commuting. Table 4, column C shows the results for this model. This has an important policy implication, since this indicates that widening shoulder lanes and/or putting in dedicated bicycle lanes would have an impact on modal choice.

Three of the road-related risk factors, 'potholes or road debris', the 'presence of bad drivers', and 'heavy car traffic', show no significance. High posted speed limits have a significance level above 95%, but with an unexpected negative sign (these results are not shown in the model in Table 4, column C). This is difficult to explain, since it indicates that those people who think riding on roads with faster traffic is more risky, are more likely to commute by bicycle. Perhaps those who do commute by bicycle merely recognize the risk of high speed traffic more than those who commute by other modes. It may also be that bicyclists simply do not use roads with high speed traffic and thus are not indicating that this is a risk factor on their commute route.

A weather related risk component, which combines the first three factors from the question in Figure 2, is included in Table 4, column C, and was found not to be highly significant.18 This indicates that the risk associated with weather conditions does not have a major influence on the choice of mode.

The analysis of perceptions of risk and the risk factors

15This implies that making automobile commuting more dangerous will decrease usage of the mode. Obviously this would probably not be considered a viable public policy. This effect is examined in more detail in Noland (forthcoming).

16This variable was derived from a principal components analysis of the questions in Figure 2. For more detail see Noland (1992).
seems to show that the decision to use a bicycle for commuting does have some relationship to risk factors. While the overall perceived risk variable has a very low level of significance, the factor related to the lack of shoulders on the road is significant. The implications of these issues on policies for increasing bicycle usage will be discussed below. Obviously a 'pro-bike' policy of risk reduction would involve widening road shoulders or providing bicycle lanes.

Other significant variables
As can be seen by the results in Table 4, most of the other variables included in the model have a high level of significance in explaining modal choice. While not the primary focus of this paper, these are briefly discussed in this section. The cost coefficients show that the dollar cost of automobiles is significant. The higher the perceived cost, the less likely people will select the mode. The sign of the transit cost coefficient has the expected direction, but is not significant. The bicycle cost coefficient has a high level of significance, but the direction of the sign indicates that those who perceive the dollar cost of bicycling to be higher are more likely to commute by bicycle. This may indicate that those who purchase more expensive bicycles, which require more expensive maintenance, are more likely to use a bicycle for commuting. This could also reflect an awareness of the dollar costs of commuting by bicycle amongst people who have never used the mode for commuting. Alternatively, this could indicate that those who commute by bicycle are more willing to purchase more expensive bicycles.

As the perceived comfort of the mode increases, it is more likely to be used. The automobile mode has the highest mean value for this variable; therefore, the influence of this attribute tends to favor the automobile mode.

Other variables that are important include the availability of bicycle parking which is positively significant. The number of motor vehicles owned increases the likelihood of using an automobile. Increased bicycling competency has a positive coefficient with a 90% level of significance. This variable was included to control for any differences between the bicycle club and the general sample. While this variable was not highly significant, it does indicate that those people in the bicycle club sample (who, on average, rated a higher bicycling competency score) were more likely to commute by bicycle. Note also that gender (specified as specific to bicycles and transit) is highly significant in predicting choice.19 Males are more likely to use bicycles and transit than females.

These results are generally comparable to other models of mode choice; although none have used so many bicycle-specific variables. For example, the cost of

modes and number of motor-vehicles owned are commonly found to be significant in the choice of commute mode. Higher income is usually found to favor automobile usage, but this was not the case in the above models. The results in all three models show a low level of significance for income and an unexpected direction for the sign.

Long-run and short-run elasticities
In the short run, many people do not have a choice of modes. The primary reason for this, as discussed previously, is the unavailability of transit for some home to work trips and travel distances that exceed feasible distances for bicycling or walking.

Those people classified as having no choice of modes may, in the long-run, change the spatial relationship of where they live relative to their work location such that they have a choice of modes. Long-run policy measures to encourage mixed-use developments may reduce the perceived need to have a car at work (e.g. if a more balanced mix of retail and office space is established in suburban work locations, then going to a restaurant for lunch does not require a car). In addition, more densely populated areas may allow more extensive transit service to be established, or may give people the choice of walking or bicycling to work, if they are now close enough to their work location. The average commute distance for the sub-sample having a choice of modes is significantly shorter (8.64 miles, 13.91 km) than for those with no choice of mode (13.98 miles, 22.51 km), who are overwhelmingly captive to the automobile.

Table 5 shows the predicted shares of each mode for the model in Table 4, column C. The first column shows the modal split estimated for a population with a choice of modes. When those respondents with no choice of commute modes are included, this substantially increased the proportion commuting by automobile, while reducing the share using the other modes.20 The actual modal splits are also shown. 21 As can be seen, the model substantially over predicts the level of bicycling in the region. 22

The aggregate elasticities calculated using only those people who have a choice of mode represent long-run elasticities. In other words, this assumes a world where

19 Chi-squared tests indicated that there was no statistical difference between these two modes for the gender variable. Therefore the model was calibrated with this alternative-specific formulation.

20 The modal shares for the estimation including those with no choice of modes was calculated by setting the choice probability for those respondents equal to one, weighting the respondent by the appropriate population weight, and then summing over the sample.

21 These are for 1980 data and include the entire nine-county region rather than just the Pennsylvania counties. Information was supplied by the Delaware Valley Regional Planning Commission.

22 The value reported may actually represent a substantial undercount of total bicycle commuting in the region. The percentage reported represents a count of about 7000 bicycle commuters in the entire region. Recent estimates have shown that about 20000 bicyclists commute to the University of Pennsylvania campus (mainly students). If one considers only other University campuses in a region ranging from Princepston in Mercer County to Swarthmore in Delaware County, the 7000 bicycle commuter figure seems low (and may not have included students as commuters).
people have arranged their home to work trip such that they have a choice of at least two modes. Short-run elasticities can be calculated by including those with no current choice of mode in the elasticity equation (5), thus representing the current pattern of mode availability. This is done by setting $P_j(i)=1$ for those individuals with no choice of mode.

The short-run versus long-run elasticity definition is based on the availability of a choice of modes. This assumes that those people who have located their home to work trips such that they have no choice of mode have utility functions similar to those who currently have a choice of modes. This assumption may not hold in reality, especially if these people have made their decision to be captive to the automobile based on some unmeasured preference for commuting by automobile. It is likely that many people who do have a choice of modes may also exhibit an unmeasured preference for automobiles, much of which may be captured by the perceived convenience variable. In any case, those people with no choice of modes are normally excluded from modal choice models and this technique provides a means for including them.

Aggregate elasticities show the percentage change in the share of a given mode for an incremental change in a specific attribute. The percentage changes in the predicted share can be considered as an indicator of the effectiveness of alternative policies. Long-run and short-run aggregate direct elasticities are presented in Table 6 and aggregate cross elasticities are presented in Table 7. The major difference between the elasticities calculated for those with a choice of modes, and those with no choice of mode, is in the sensitivity to the choice of selecting an automobile. The automobile elasticities are smaller in the short-run since a larger percentage of automobile commuters cannot be induced to switch away from the automobile due to the lack of choice in their specific commute situation. For example, the elasticity for the convenience of automobile commuting in the long-run is 0.311 versus only 0.0858 in the short-run.

The bicycle aggregate elasticities do not show any difference between the short- and the long-run. This is since virtually all those commuting by bicycle have a choice of another mode. These results imply that it is possible to achieve some increase in the share of commuters using bicycles with short-run policies. However, most of these will not be diverted from the automobile mode.24

24The logit model, by definition, implies that when one mode has an increase in its share, then all alternative modes have an equal percentage decrease in their shares. However, given the lack of choice constraint for many of the automobile commuters, a proportionally lower percentage of automobile commuters will shift to bicycle usage (compared to those shifting from transit and walking).

The relatively large elasticity for increasing the convenience of bicycle commuting (3.208) indicates that this may be one of the more effective policy options, for example, by shortening commute distances. Unfortunately, this is a long-term policy involving changes in land use patterns. Building bicycle lanes to reduce risk, while having a lower elasticity value (0.496), can be a relatively effective policy, as is increasing the level of safe bicycle parking (0.838).

Looking at the aggregate cross-elasticities, that is the change in the share using bicycles when an automobile attribute is changed, shows that decreasing the convenience of automobiles has the largest elasticity value (−0.562). However, this again is a long-term policy option. Examination of the short-run impact of policies...
Increasing bicycle transportation for commute trips: R B Noland and H Kunreuther

bike' policies on automobile usage shows little impact on changing the share of automobile commuters. Reducing the risk of not having bike lanes has a negligible elasticity (-0.00674). The long-run elasticities, while larger, are still rather small.

These elasticities indicate the difficulty of reducing automobile usage in the short-run. While short-run policies that promote bicycle usage can have a beneficial impact, they do not significantly reduce automobile usage. Only those longer term policies, which allow a greater choice of modes, can significantly reduce automobile usage.

Another technique for evaluating the impact of various policy options is sample enumeration (Ben-Akiva and Lerman, 1985). This technique consists of changing relevant policy variables and examining the impact on modal shares. While the elasticity measures allow comparison for marginal changes in policies, sample enumeration allows larger more realistic values to be examined.

Two policy options are examined using sample enumeration. First, assume that a network of bicycle lanes is constructed such that no commuter is exposed to any risk due to the lack of a bicycle lane. Presumably all respondents would then not face the risk of riding on a road with no shoulders. This would be equivalent to the value for 'extremely safe' (6) in the question in Figure 2. Substituting this value into the data and calculating new modal shares, shows that bicycle usage would increase by 75.4% in the long-run and by 196% in the short-run. Table 8 shows these results. Note that automobile usage decreases more in the long run than in the short run, as is to be expected.

The second policy option is to decrease the perceived convenience of automobile commuting. The perceived convenience scale (measured from 1 to 7) for automobiles had a mean value of 6.56 for those commuting by automobile. Those commuting by bicycle had a mean perceived convenience of automobile commuting of 4.82. If one assumes that a more attractive urban density for bicycle commuting resulted in a similar mean perception of the convenience of automobile commuting of 4.82, then this value can be used in a sample enumeration.

These results are shown in Table 9. Again, notice that in the short run, the share of automobile commuting shows a very small decrease (2.6%). In the long run this policy option reduces the share commuting by automobiles more than the 'pro-bike' policy of building a network of bicycle lanes. However, the level of bicycle commuting only increases by 19%, since there are larger increases in the share using transit than when the 'pro-bike' policy is followed. Increased transit usage is a major outcome of any policy that succeeds in making automobile commuting less convenient.

Table 8 Sample enumeration with 'lack of shoulders' risk factor = 6

<table>
<thead>
<tr>
<th>Mode</th>
<th>Modal share with choice (long-run)</th>
<th>Percentage change</th>
<th>Modal share with no choice (short-run)</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>22.2</td>
<td>753.5</td>
<td>7.7</td>
<td>162.2</td>
</tr>
<tr>
<td>Car</td>
<td>60.0</td>
<td>-30.4</td>
<td>84.7</td>
<td>-16</td>
</tr>
<tr>
<td>Transit</td>
<td>12.9</td>
<td>65.4</td>
<td>1.9</td>
<td>-26.9</td>
</tr>
<tr>
<td>Walking</td>
<td>4.8</td>
<td>41.2</td>
<td></td>
<td>-44.1</td>
</tr>
</tbody>
</table>

Table 9 Sample enumeration with convenience of automobile = 4.82

<table>
<thead>
<tr>
<th>Mode</th>
<th>Modal share with choice (long-run)</th>
<th>Percentage change</th>
<th>Modal share with no choice (short-run)</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>8.8</td>
<td>238.5</td>
<td>3.1</td>
<td>192</td>
</tr>
<tr>
<td>Car</td>
<td>58.1</td>
<td>-32.6</td>
<td>84.0</td>
<td>-26</td>
</tr>
<tr>
<td>Transit</td>
<td>23.8</td>
<td>205.1</td>
<td>9.5</td>
<td>218</td>
</tr>
<tr>
<td>Walking</td>
<td>9.3</td>
<td>173.5</td>
<td>3.4</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Conclusions and policy implications

The major results of this study imply that two courses of action are possible to both increase the level of bicycle commuting while simultaneously reducing automobile commuting. One course is to pro-actively encourage increased bicycle usage by providing an infrastructure that increases the convenience of bicycle transportation. The second alternative is politically more difficult to implement, but would involve decreasing the relative convenience of automobile commuting and providing urban forms that allow people to have a choice of modes.

The former strategy can be implemented by providing convenient bicycle lanes on city and suburban streets. This can generally be accomplished merely by enlarging the roadway shoulder and ensuring that a safe and efficient network of bicycle routes is maintained. Bicycle parking facilities at places of employment are also necessary to enhance the convenience of the mode.

Increasing the convenience of bicycle commuting can also be used as a method of decreasing the convenience of automobile commuting. For example, on-street bicycle lanes can replace on-street parking. Traffic signals can be timed to reflect the average speeds of bicycles rather than automobiles. This would also tend to slow automobile traffic, which would create a safer environment for bicyclists.

A more radical approach is to actually prohibit automobile traffic or severely restrict access and speed in various zones. Such 'traffic-calming' schemes have been used successfully in Europe to protect residential areas (Tolley, 1992). However, a more comprehensive approach is necessary to discourage automobile traffic from larger zones without merely diverting it to surrounding areas. Such 'environmental traffic zones' would use the physical design of road facilities to force slower speeds. This would essentially decrease the convenience of using automobiles while making bicycle

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*Both changes in modal shares are calculated from column 2 of Table 5, the current prediction with no choice of mode.*
usage (and walking) safer, more convenient, and more pleasant.

A longer term strategy for reducing the convenience of automobile commuting would require changing the tendency for new residential developments to have low population and employment densities. More intensive, centralized development (or redevelopment) of land would allow people to choose to live close to their place of employment. Transit usage would also increase if long-term policies to reduce automobile dependency are implemented.

This research has focused primarily on perceptions of risk and convenience in the determination of modal choice and the impact of limited choice sets. Some unanswered questions need to be addressed by future research which more carefully analyzes how perceptions of modal convenience are formed. For example, specific characteristics of road design can have an impact on both the risk and convenience of bicycling. Large multiline streets, with large traffic capacity for automobiles can act as barriers to non-motorized transportation, due to the risk of crossing the street, and the inconvenience of finding a safe crossing point. In addition, understanding why people choose to live and work in patterns that do not allow a choice of modes needs to be better understood.

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