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An explanation of the relationship between adults' work trip mode and children's school trip mode through the Heckman approach

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ABSTRACT

Most studies on children's travel hypothesize that the characteristics of children, households, schools, and neighborhoods exogenously affect their travel mode to school. This study makes an additional assumption that children's mode to school and household adults' travel mode to work are interrelated because of a lifestyle choice made by parents and caregivers. With this assumption, Heckman probit models were used with data from the 2009 US National Household Travel Survey to predict household adults' travel mode to work and children's travel mode to school jointly. It found strong evidence that household adults' decision to drive to work significantly increases the probability of children being dropped off at school and decreases their likelihood of walking and bicycling, but not vice versa. As adults' mode choice is more fundamental in the household decision-making process, the study suggests that children's mode choice studies should not ignore how parents or caregivers travel to work.

1. Introduction

We often observe friends and neighbors dropping off children at school on their way to work and hear them say that it is more convenient than having to wait for the school bus. Yet studies on children's travel to school have paid little attention to the travel characteristics of household adults when predicting travel modes used by children for school trips. By using statistical models, this study examines how adults' travel to work influences children's travel mode to school.

Primarily due to the perceived health benefits from walking and bicycling, children's travel mode to school has recently received substantial attention in transportation research. Many studies have used statistical models to predict children's travel mode to school using characteristics of children, households, schools, and neighborhoods as exogenous, or externally determined, independent variables. As shown in the literature review in Section 2, there is growing recognition in recent literature that the characteristics of parents have an influence on how children travel to school. A number of studies on adults' travel mode choice also recognize that the presence of children in the household has an effect on how adults travel to work. Activity-based transportation models have often been founded on the assumption that certain activities are jointly performed by household adults and children. Studies on parents' escorting behavior show that dropping off and picking up children from school are two of the most common activities performed jointly by adults and children in a household. Together, these studies provide sufficient information to hypothesize that the travel patterns of children and adults in a household are interrelated.

In recent years, geographers have been increasingly favoring the 'new mobilities paradigm' as a mechanism to connect transportation with the social and natural sciences (Cresswell, 2010, 2011). This study is relevant in the context of this paradigm because it considers the interdependence of travel among household members. While conventional transportation research almost exclusively focuses on physical movement, the new mobilities paradigm focuses on a constellation of mobility involving physical movement, the shared meaning or experience of movement, and the embodiment of the practice of movement (Cresswell, 2010). Cresswell (2010) argues that, by focusing almost exclusively on physical movement, conventional transportation research often ignores the fact that how one person moves or travels affects how other persons move or travel. Interestingly, Cresswell (2010) makes the argument by suggesting that adults' school runs affect how children travel to school.

This study hypothesizes that the interrelation between children's travel mode to school and adults' mode to work are interrelated because of households' lifestyle choices. According to Van Acker et al. (2010), long-term decisions made by households and individuals are lifestyle choices within which short-term choices such as daily trips are made. Weber (1978) defined lifestyle as a status that a group of individuals seeks to achieve and share.

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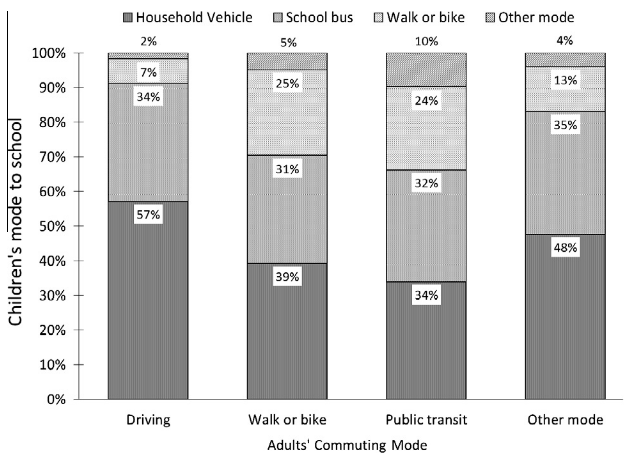

Fig. 1. Modes used by children to go to school by work-trip modes of household adults. *Source*: Prepared from pooled data for households with school-going children aged 5–15 in the 2009 National Household Travel Survey (USDOT, 2011).

Although the concept is easily understood, the reasons that drive individuals to select a lifestyle cannot be easily discerned, let alone quantified.

A classic example of a lifestyle choice is an individual's decision to be a homemaker. When a person decides to be a homemaker, while others with similar characteristics decide to participate in the wage-labor market, the reasons for that person's decision not to participate in the labor force cannot be observed in labor-market data. It is in this context that the Heckman model was born (Heckman, 1974, 1976, 1979). The premise of the Heckman model is that, because of the unobservable reasons prompting some individuals not to participate in the labor force, the observed labor market outcomes are biased due to self-selection. In addition to allowing for the correction of this bias, the Heckman model enables one to determine the effect of the selection bias on an outcome measure.

This paper uses the Heckman model to examine the interrelationship between workers' travel mode to work and children's mode to school. While a logit or probit model can be used to predict the travel mode of a child by taking adults' mode as an exogenous independent variable, or vice versa, the Heckman model involves joint prediction of the travel modes of the two groups through a system of two equations. By doing so, the model accounts for the effect of self-selection by the first group on the mode choice of the second group. Thus, compared to logit or probit models, the Heckman model has the advantage of adding an element of causality in the prediction of travel modes.

From the lifestyle choice perspective, it makes more intuitive sense to hypothesize that adults' decisions about travel mode to work are more fundamental in the household decision process than children's travel mode to school. To test this hypothesis, Heckman probit models were first used to examine the effects of adults using different travel modes to work on children's travel mode to school. To examine if the factors that influence children's mode to school also influence adults' travel mode to work, additional modeling efforts were undertaken. While children and adults from the same household may have similarities in their mode-use patterns because of the similarities in characteristics of households and the places where they live, when these characteristics are controlled for, the Heckman model can demonstrate if there is an additional effect of self-selection by one group on the modes used by the other group.

To demonstrate that the travel modes of adults and children may be interrelated, the cross classification of children's mode to school is shown against household adults' travel mode to work in Fig. 1 by using pooled data from the 2009 US National Household Travel Survey, or NHTS (USDOT, 2011). Since in many households one adult walks to work or takes public transit while another adult drives to work, it is possible for a non-driving adult worker to have children in the household who are driven to school. It is for this reason that for each type of commuting mode of adults (see Fig. 1), a proportion of children are driven to school. However, despite the dilution of the data because of pooling, Fig. 1 still shows that the proportion of household children being driven to school is substantially higher for adults who drive to work (57%) compared to adults who walk or bicycle to work (39%) or take public transit (34%). Furthermore, the figure shows that the proportion of household children who walk or bicycle to school is only 7% for adults who commute to work by automobile, whereas the proportion is 25% for adults who walk or bicycle to work, and 24% for adults who use public transit.

Data from the 2009 NHTS were used for the statistical models in this paper because they provide by far the largest and most recent travel survey data representative of the country. In contrast to past surveys, the 2009 edition provides special data on children's travel to school and parents' concerns about children's travel to school. For modeling purposes, data from the NHTS person file and trip file were combined. Household adults were pooled for school-going children aged 5–15. Therefore, the analysis includes only those households that had school-going children aged 5–15. All working adults in those households were included in the analysis to ensure that, in addition to parents, potential caregivers were also taken into consideration.

The remainder of this paper is divided into four sections. Section 2 provides a review of past studies on children's travel to school and adults' travel to work by focusing on the types of models used for predicting travel modes and variables included in the models. Section 3 conceptually describes the Heckman model and provides examples of empirical studies in other fields by focusing on the use of the model to predict discrete outcomes. Section 4 describes the data used for analysis and presents the results from the statistical models. Before presenting results from the Heckman model, results are presented from multinomial logit (MNL) and probit models on children's mode choice so that these results can be compared with the Heckman model results. Although Heckman models were used to examine the effects of several modes used by adults on children's mode and, conversely, to test the effect of modes used by children on adults' mode, due to space limitations detailed results are presented only from the models that examine children's mode-use patterns when adults drive to work. However, summary statistics are presented for different mode combinations for comparison. Section 5 presents a summary of the findings and implications for future research.

2. Studies on mode choice of adults and children

Mode-choice studies of adults and children typically use statistical models often broadly referred to as discrete choice models, where the likelihood of using a travel mode is predicted by treating modes as a binary variable (e.g., car versus other modes) or a categorical variable (e.g., car versus rail versus bus). These types of models, elaborately described in Ben-Akiva and Lerman (1985) and Train (1986), are based on the utility theory.

Over the past four decades, a large number of empirical mode-choice studies have been conducted pertaining to adults' travel, mostly in the context of work trips but sometimes also in the context of non-work trips. Many of these used binary logit models to compare between two modes (Cervero, 1996; Cervero and Kockelman, 1997; Cervero and Radisch, 1996), whereas others used MNL models to compare among several modes (Train, 1980;

Asensio, 2002; Cervero, 2002; Bhat and Sardesai, 2006; Hensher and Rose, 2007; Pinjari et al., 2007). In other mode-choice studies for adults, nested logit models have been used to examine choices within another set of choices (O'Fallon et al., 2004; Zhang, 2004; Hensher and Rose, 2007).

To predict the mode choice of adults, researchers historically have considered a variety of independent variables, including travel distance, time, and/or monetary cost (Train, 1980; Cervero, 1996, 2002; Hensher and Rose, 2007), characteristics of specific modes (Train, 1980; Cervero, 2002; Schwanen and Mokhtarian, 2005; Hensher and Rose, 2007; Pinjari et al., 2007), household characteristics such as income, number of workers in the household, presence of children in the household, and vehicle ownership (Train, 1980; Cervero, 1996; Srinivasan and Ferreira, 2002; Schwanen and Mokhtarian, 2005), personal characteristics such as gender and occupation (Schwanen and Mokhtarian, 2005; Hensher and Rose, 2007), individuals' perception of travel (Schwanen and Mokhtarian, 2005), and place characteristics (Cervero, 1996, 2002; Pinjari et al., 2007). While the mode choice of adults has been studied thoroughly over several decades, children's mode-use patterns attracted the attention of researchers primarily during the previous decade. Since the primary focus of the models in a majority of these studies is to compare walking or bicycling with all other modes, these studies have predominantly used binary logit models for prediction purposes. Examples of such studies include McDonald (2007a, 2007b, 2008a), McMillan et al. (2006), Timperio et al. (2006), McMillan (2007), Rodríguez and Vogt (2009), Zhu and Lee (2009), and McDonald et al. (2011). Studies that compared the likelihood of children using several modes have generally used MNL models. Examples include McDonald (2008b), Müller et al. (2008), Yarlagadda and Srinivasan (2008), Marshall et al. (2010), and Wilson et al. (2010). In some instances, researchers have used other models, including nested logit (Jensen, 2008), MNL probit (Sidharthan et al., 2011), and covariance heterogeneity (Ulfarsson and Shankar, 2008).

The number and characteristics of the independent variables used for modeling children's mode to school varies from study to study. Yet these variables pertain to a few broad categories: spatial or locational characteristics of places, distance to school, demographic and socio-economic characteristics of children and households, school characteristics, and perceptions of adults about children's travel. In a review of studies on school travel, Stewart (2011) noted a large number of studies worldwide that showed children's likelihood of using non-motorized modes decreasing with greater distance to school. In addition to distance, empirical studies on children's travel mode to school have included the age of child, gender, race or ethnicity, household income, household vehicle ownership, the number of children in a household, parents' work schedule, and parents' education (McDonald, 2007a, 2007b, 2008a, 2008c; McMillan, 2007; McDonald et al., 2011). Other areas addressed include parents' concerns about children's travel to school, dwelling type of parents, single-parent status and homemaker status of parents, immigrant status of parents, characteristics of areas, and school type (Kerr et al., 2006; McDonald, 2007a, 2007b, 2008a, 2008b; McMillan, 2007; Marshall et al., 2010; Wilson et al., 2010; McDonald et al., 2011).

Although many studies on children's school trips do not address the connection between activities by adult household members and children, a few studies have explicitly considered this relationship. For example, McDonald's (2008b) binary logit model on children's travel mode included mother's and father's work trip time as independent variables, Yarlagadda and Srinivasan (2008) considered the influence of parents' employment and work flexibility on children's mode use, Copperman and Bhat (2007) studied travel activity sharing between children and household adults, whereas Vovsha and Petersen (2005), Schlossberg et al. (2006), Wen et al. (2008), and Yoon et al. (2011) studied parents' escorting of school children. All these studies recognize that travel and non-travel activities of children and adults in households are often interrelated. Many other studies, especially studies on activity based travel, recognize this interrelationship (Gliebe and Koppelman, 2002;Yagi and Mohammadian, 2008; Timmermans and Zhang, 2009; Maat and Timmermans, 2009). Yet other studies have recognized that the presence of children affects household adults' travel patterns (Cervero and Kockelman, 1997; Dieleman et al., 2002; Srinivasan and Ferreira, 2002; O'Fallon et al., 2004; Schwanen and Mokhtarian, 2005; Giuliano and Dargay, 2006).

Despite the recognition among many researchers that travel decisions of household members are interrelated, children's mode-choice studies by far have refrained from using models that jointly predict the travel modes used by adults and children in a household. One reason for the scarcity of studies that use this approach may be that, until a few years ago, popular software programs did not include an option to predict discrete variables jointly. However, advances in popular statistical programs such as SAS and STATA have made it easier to make joint predictions of discrete dependent variables such as travel modes.

3. The Heckman model and its application in empirical studies

The Heckman selection model includes two equations: selection and outcome. Using notations in Greene (2012), the selection equation and the outcome equation can be described as follows:

$$\text{Selection equation}: z_i^* = \boldsymbol{w}_i\gamma + u_i, z_i = 1 \text{ if } z_i^* > 0 \text{ and } 0 \text{ otherwise}$$
$$\text{Prob}(z_i = 1|\boldsymbol{w}_i) = \boldsymbol{\Phi}(\boldsymbol{w}_i'\gamma) \text{ and}$$
$$\text{Prob}(z_i = 0|\boldsymbol{w}_i) = 1 - \boldsymbol{\Phi}(\boldsymbol{w}_i'\gamma)$$

$$\text{Outcome equation}: \ y_i = \boldsymbol{x}_i\beta + \epsilon_i \text{ if } z_i^* > 0$$

where $\boldsymbol{w}_i$ is a vector of independent variables determining selection into a sample, $\boldsymbol{x}_i$ is a vector of independent variables determining an outcome, and $z_i^* > 0$ indicating that some observations of y_i are missing or censored because of selection. The error terms of the two equations, u_i and ϵ_i, are normally distributed and the correlation between the two is ρ. Mathematically,

$$u_i \sim N(0, 1)$$

$$\epsilon_i \sim N(0, \sigma^2)$$

$$\text{corr. } (u_i, \epsilon_i) = \rho$$

The selection and the outcome components of the Heckman model can include identical independent variables, but the selection component must include at least one variable that is not included in the outcome component. An example of the Heckman model is the estimation of wages by the outcome equation, where y_i is observed only for those who elect to be in the labor force, but not for those who choose to be out of the labor force. This problem is often referred to as a selection bias, sample-selection bias, or self-selection bias. When the bias exists, the estimation of the β coefficients of the outcome equation by the ordinary least squares method would be inefficient and the standard errors would be downward biased (Heckman, 1979). Whether and how self-selection affects the outcome equation is given by ρ, the correlation coefficient of the residuals in the selection and the outcome equations. In the Heckman model, which corrects for selection bias, a statistically significant ρ indicates that selection bias affects the estimates of β coefficients and their standard errors in the outcome equation. A positive sign for ρ indicates that selection affects the outcome positively and a negative sign indicates that selection affects the outcome negatively. For example, when persons in the labor force are coded 1 and persons not in the labor force are coded 0 in the selection equation of a model on wages, a significant and positive ρ would indicate that self-selection into the labor force has a significant positive effect on estimated wages.

During the past decades, many studies in various disciplines have used the Heckman model with a continuous outcome variable (y_i). Transportation studies that used this method to estimate a continuous outcome, such as travel distance and time, include Cooke and Ross (1999), Deka (2002), and Vance and Iovanna (2007). While many studies used the Heckman model to deal with missing data due to sample selection, other studies have used it to compare between groups on the basis of the significance of ρ; that is, to examine how the selection into one group affects the dependent variable of the outcome equation. For example, Briggs (2004) used the method to compare SAT scores of coached and un-coached students, Maury (2006) used it to compare profits of two different types of firms, Vance and Iovanna (2007) compared trip distance for car users and car non-users, and Leslie and Ghomrawi (2008) compared the effects of two different types of drugs on treatment duration.

In more recent years, a number of studies in diverse disciplines have used the Heckman model to examine the effect of selection on a dichotomous outcome variable. For example, Bratti et al. (2004) examined whether the employment outcome of students was related to participation in a survey, Bärnighausen et al. (2011) examined the likelihood of HIV status reporting on the basis of type of interview, Drope and Hansen (2009) examined if participation in industry associations had an effect on the likelihood of lobbying, Finney and Yoon (2011) examined the relationship between municipalities' decision to develop a web site to conduct financial transactions through the internet, and Heise (2010) examined if the participation in alternative dispute resolution programs had an effect on the likelihood of an appeal settling prior to a judicial decision. Other authors have used the method to study consumers' willingness to pay (Petrolia et al., 2010), the effects of regional trade agreements (Vicard, 2012), social capital (Cornwell and Cornwell, 2008), oncological evaluation (Davidoff et al., 2009), anti-depressant treatment (Tiwari et al., 2008), and attitudes toward general practitioners (Clerc et al., 2011). Despite these and many other studies in diverse fields, the use of the Heckman model to predict dichotomous outcome variables has been rare in transportation.

4. Data and analysis

4.1. Data

All empirical analysis in this paper is conducted with data from the 2009 US National Household Travel Survey (NHTS) (USDOT, 2011). This is by far the largest travel survey in the country, providing household, personal, and travel characteristics for 308,901 individuals belonging to 150,147 households nationwide. The dataset contains information on 1,167,321 trips made by persons of all ages for various purposes, including school trips by children and work trips by adults. In addition to the sheer size of the dataset and its national representation, the 2009 NHTS has the added benefit of including a number of questions on children's school trips and parents' perceptions about children's travel to school.

The data used for the analysis were mostly retrieved from the NHTS person file, but complemented by data from the trip file. The dataset was restricted to those households that had at least one school-going child aged 5–15 and whose travel mode to school was reported. This age group was specifically selected to conform to the NHTS age range pertinent to the federal Safe Routes to School (SRTS) program. For each of the selected children, the household adult workers were pooled. To exclude adults who might be college students but also make occasional work trips, persons aged 18–24 were eliminated and restricted to ages 25–64. Since non-parent household adults can also drop off children at school, all working adults in a household were included in the dataset. Finally, adult workers who mentioned using a personal vehicle to travel to work, but who were identified as a vehicle passenger in their commute trip in the trip file, were considered to have used other modes instead of being a driver when distributing workers by trip mode for commuting. It was assumed that these adults would have little or no influence in dropping off children at school.

In the pooled dataset used for modeling purposes, 47% of male children are driven to school compared to 53% of female children, 37% of male children take the school bus compared to 36% of female children, 13% of male children walk or bicycle to school compared to 9% of female children, and 3% of male children use some other mode compared to 2% of female children. Among the adult workers in their household, 91% of men drive to work compared to 92% of females, 4% of men use public transit compared to 5% of females, 3% of men walk or bicycle to work compared to 2% of females, and 2% of men use some other mode compared to 1% of females.

4.2. Selection of variables and their expected influence on travel mode

As indicated in the literature review, a wide range of variables pertaining to children, parents, households, schools, neighborhoods, and perceptions have been used by researchers to predict the travel mode of children. Similarly, a range of variables pertaining to transportation systems, individuals, households, and places have been used as exogenous variables to predict the travel modes of adults for work and non-work trips. The independent variables for the models on children's and workers' mode choice in this paper were selected on the basis of past empirical studies.

Distance to school is a critical variable for the model on children's trips to school, and is expected to decrease the likelihood of using non-motorized modes. Based on prior studies, younger children are more likely to be driven to school than older children and they are expected to walk less. Empirical studies also show that female children are less likely to walk or bicycle than male children. A variable on schools' restriction on walking alone has been included with the expectation that such policies would deter walking and bicycling among children. School type has been included with the expectation that public school students are less likely to be dropped off by household vehicles and they would be more likely to walk and bicycle than private school students because private schools, which are fewer in number, are likely to be more geographically dispersed than public schools.

A dummy variable on single parents was included with the expectation that children from single-parent households would be more likely to be dropped off at school, because working single parents are expected to have greater time constraints and concerns about children's safety. The number of children aged 5–15 was included as a variable with the expectation that having one or more school-age siblings would increase the likelihood of walking to school. A set of three variables on parents' safety concerns about children's travel to school were included, with the expectation that a greater concern would decrease the likelihood of walking and bicycling and increase the likelihood of using motorized modes. Although the NHTS provides a variable on parents' concern about distance to school, it was not included because actual distance has already been considered. A series of dummy variables representing household income has been included, with the expectation that children from higher income households would be more likely to be driven to school and less likely to take a school bus or walk.

Variables on dwelling type and dwelling tenure have been included to represent suburban living, with the expectation that children living in detached and owned homes would be less likely to walk or bicycle and more likely to use motorized modes. Race, ethnicity, and the foreign-born status of parents have been included, with the expectation that minority children would be less likely to be driven to school and more likely to use alternative modes. A set of dummy variables on metropolitan population size has been included, with the expectation that, due to a relatively urban environment in large metropolitan areas, children would walk more and use motorized modes less. Finally, a variable on household adults' travel mode to work has been included as an exogenous variable in the MNL and the probit models, with the expectation that children from households with workers driving to work would be more likely to be driven to school.

The selection of exogenous variables for the mode-choice models for workers' commute followed a similar logic as the children's mode-choice models. Like the children's models, it was expected that individual characteristics such as age and gender, household characteristics such as income and household size, dwelling characteristics such as dwelling type and tenure, and place characteristics such as metropolitan population size would influence workers' mode to work. A few additional variables were included in the commute models pertaining to the nature of work: namely, occupation, flex time, and part-time/full-time distinction. It was expected that manufacturing workers would drive to work more because of the location of manufacturing plants in areas with low transit service, and sales/service workers would drive more because of the need to use personal vehicles for work-related trips. Workers with flex time were expected to drive less because of lower time constraints, and full-time workers were expected to drive more because of greater time constraints.

A variable that has often been included in mode-choice models requires further discussion. While a number of studies on children's mode choice (e.g., McDonald, 2008a, 2008b; McMillan, 2007; McDonald et al., 2011) include a variable on number of household vehicles, other studies do not (e.g., Rodríguez and Vogt, 2009; Marshall et al., 2010; Wilson et al., 2010). Similarly, some studies on adults' mode choice include a variable on household vehicle ownership (e.g., Train, 1980; Cervero, 1996, 2002; Maat and Timmermans, 2009), but others do not (e.g., O'Fallon et al., 2004; Hensher and Rose, 2007). The assumption in including household vehicles as an exogenous variable in a mode-choice model is that households decide to own vehicles irrespective of how its members need to travel. Based on the number of vehicles available and other needs, members decide what mode to choose for a trip. However, it can be reasonably argued that households' decision to own vehicles is influenced by how the members need to travel and, therefore, household vehicles should not be considered exogenous in a mode-choice model. Based on this assumption, models presented in this paper exclude household vehicles as an exogenous variable. However, it should be noted that when a variable on number of vehicles per adult in household is included in the MNL, probit, and Heckman models on children's mode, the variable is significant, but the significance levels of the other variables remain unchanged. The conclusions in this paper, in fact, would be stronger when the variable is included but, since those results may be spurious, the models presented in this paper exclude the variable.

4.3. Probit and MNL models on children's mode to school

The results from an MNL model and three probit models on children's mode to school are presented in Tables 1 and 2, respectively. Table 1 shows the coefficients and other statistical test results for two modes, namely household vehicle and walking or bicycling, where school bus and other modes have been combined together as the referent category. In contrast, the probit models in Table 2 show coefficients and test results for three modes, namely household vehicle, walk or bicycle, and school bus. In these models the non-selected modes together constitute the referent category.

The results of the MNL and probit models are consistent with past studies. The direction of a few coefficients in the MNL model and the probit models is different only because the dependent variables have different referent categories. The MNL model and the probit model on walking or bicycling show that children's propensity to walk or bicycle to school decreases with distance to school. Both models also show that the propensity to use a household vehicle is the highest when the distance between home and school is between a half mile and 1 mile. Beyond 1 mile, trips are more likely to be made by school bus. Thus parents or caregivers are more likely to drop off children at school at a moderate distance and less likely to do so when schools are far away.

The MNL and probit models show that younger children (age 5–9) are less likely to walk or bicycle and more likely to be driven to school than older children (age 10–15). Similarly, the models show that male children are more likely to walk or bicycle and less likely to be driven to school than female children. Evidence is found from the models that schools' walk-alone restriction decreases the likelihood of walking or bicycling and increases the use of motorized modes. Public school students are more likely to walk, bicycle, or take a school bus and less likely to be driven to school than private school students. The models show evidence that children from single-parent households are more likely to be driven to school than children from other households, but the influence of single-parenthood on walking or bicycling is less clear. Evidence is found that having other school-age children in a household increases the propensity of walking or bicycling and decreases the likelihood of being driven to school.

Among the three variables on parents' perception of children's travel to school, the effect of a serious concern about traffic speed on children's mode is the least certain. The models show that a serious concern about crime is associated with a higher likelihood of being driven, a higher likelihood of walking or cycling, and lower likelihood of traveling by school bus. A plausible explanation for the positive association between serious concern about crime and a higher likelihood of walking and bicycling is that more children walk and bicycle in high-crime urban areas because of habituation despite parental concerns about crime. The models show that serious concern about traffic volume reduces the propensity to walk or bicycle and increases the propensity of school bus use.

The effect of household income on the likelihood of being driven to school and school bus use is clearer than its effect on walking or bicycling. As expected, the likelihood of being driven to school increases with household income, whereas the likelihood of using a school bus decreases with income. Children from the lowest-income households walk less, whereas children from the highest-income households walk more. Thus the trade-off between modes for high-income and low-income households appears to take place predominantly between private vehicles and school buses, with walking and bicycling being less relevant. At the lowest income level, children may walk or bicycle less because of busing, whereas at the highest income level children may walk or bicycle more because of greater awareness about their health benefits or better neighborhood quality.

The only consistent evidence regarding dwelling characteristics is that children living in single detached homes are more likely to be driven to school, and children living in owned homes are less likely to walk or bicycle to school. Together these variables seem to indicate that children in low-density neighborhoods are more likely to be driven to school than in areas with higher density. African-American children are less likely to be driven to school and

Table 1
Multinomial logit model on children's likelihood of going to school by household vehicle and walk or bike modes.

Variables	Household vehicle		Walk or bike	
	β	Std. Err.	β	Std. Err.
Intercept	2.483***	0.127	1.847***	0.238
Distance to school less than 1/4 mi. (1,0)	0.317***	0.099	2.221***	0.110
Distance to school 1/4–1/2 mi. (1,0)	0.217***	0.084	1.063***	0.104
Distance to school 1/2–1 mi. (1,0)[a]				
Distance to school 1–2 mi. (1,0)	−0.451***	0.057	−1.484***	0.100
Distance to school 2 mi. or more (1,0)	−1.022***	0.055	−4.480***	0.151
Child age between 5 and 9 (1,0)	0.194***	0.029	−0.801***	0.064
Male child (1,0)	−0.149***	0.028	0.153**	0.061
Walk alone restriction for all or part of K-8 grades (1,0)	−0.429***	0.049	−1.390***	0.086
Child attends public school (1,0)	−1.746***	0.054	−0.793***	0.136
Child belongs to single parent household (1,0)	0.159**	0.066	0.083	0.137
Number of children in age 5–15 in household	−0.215***	0.019	−0.069*	0.039
Parent seriously concerned about crime (1,0)	0.173***	0.045	0.439***	0.088
Parent seriously concerned about traffic volume (1,0)	−0.148***	0.040	−0.880***	0.102
Parent seriously concerned about traffic speed (1,0)	−0.046	0.040	0.119	0.102
Household income less than \$25,000 (1,0)	−0.568***	0.070	−0.517***	0.142
Household income \$25,000–\$50,000 (1,0)	−0.163***	0.046	0.008	0.100
Household income \$50,000–\$75,000 (1,0)[a]				
Household income \$75,000–\$100,000 (1,0)	0.060	0.043	−0.092	0.098
Household income \$100,000 or more (1,0)	0.149***	0.040	0.306***	0.091
Child lives in detached home (1,0)	0.238***	0.046	0.278***	0.097
Child lives in owned home (1,0)	−0.022	0.055	−0.586***	0.101
Child belongs to African American household (1,0)	−0.471***	0.062	−0.573***	0.134
Child belongs to Hispanic household (1,0)	0.305***	0.054	0.316***	0.100
Household has foreign-born adult (1,0)	−0.041	0.047	−0.220**	0.089
Not in metro or metro population less than 250,000 (1,0)[a]				
Metropolitan population between 250,000 and 1 mil. (1,0)	−0.027	0.041	0.236**	0.099
Metropolitan population between 1 and 3 mil. (1,0)	0.063	0.040	0.279***	0.095
Metropolitan population more than 3 mil. (1,0)	0.002	0.039	0.453***	0.086
Adult in household drives to work (1,0)	0.560***	0.066	−0.718***	0.103
N	26,054			
−2 Log likelihood	25,708			
Model χ^2	8875			
Prob > χ^2	0.0000			
Pseudo R^2	.347			

Note: Referent category for dependent variable is school bus and other modes.
[a] Referent category for independent variables.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

more likely to take a school bus, whereas Hispanic children are more likely to be driven to school and less likely to take a school bus. African-American children and those with foreign-born parents are less likely to walk or bicycle to school compared to other students. Children in large metropolitan areas walk or bicycle more often to school compared to rural, non-metropolitan, and small metropolitan areas. In contrast, school bus use is less common in large metropolitan areas, whereas metropolitan population size appears to have little effect on the use of household vehicles.

Finally, and most importantly, the MNL and the probit models show that when adults from a household drive to work, the propensity of children being driven to school increases and the propensity of children walking, bicycling, or taking the school bus decreases. It should be noted that in these models, the travel modes used by adults for work trips are assumed to be exogenously determined, whereas in the Heckman probit models in Section 4.4, adults' modes and children's modes are jointly determined.

4.4. Heckman probit models on children's mode to school

As indicated in Section 3, the Heckman probit model includes a selection equation and an outcome equation. For predicting children's mode to school conditional upon adults' mode, the binary dependent variable in the selection equation is a travel mode used by an adult, whereas the binary dependent variable in the outcome equation is a travel mode used by a child in the household. In both equations, the dependent variable is coded 1 when a mode is used and 0 when any other mode is used.

The results of the Heckman models on children's mode, conditional upon adults driving to work, are presented in Tables 3 and 4. The model results were obtained by the **heckprob** command in STATA as well as the **QLIM** procedure in SAS to ensure that the results are identical. The model in Table 3, predicting the likelihood of driving to work by adults, is the selection model from which the results of the outcome models on children's modes in Table 4 were obtained. Although children's modes were also predicted conditional upon adults taking public transit and walking or bicycling, the detailed results are not shown because of space limitations. Instead only the relevant summary statistics from these models are presented in Table 5.

The results of the selection model in Table 3 are consistent with expectations. The model shows that distance to work is positively associated with driving, workers from households with low income are less likely to drive, workers with the highest level of education are less likely to drive (presumably because of their concentration in large cities, where transit is more readily available), African-American workers are less likely to drive, workers living in detached and owned homes are more likely to drive, workers with a travel-related disability are less likely to drive, manufacturing

Table 2
Probit models on children's likelihood of going to school by household vehicle, walk or bike, or school bus.

Variables	Household vehicle		Walk or bike		School bus	
	β	Std. Err.	β	Std. Err.	β	Std. Err.
Intercept	0.865***	0.069	−0.503***	0.119	−2.097***	0.075
Distance to school less than 1/4 mi. (1,0)	−0.630***	0.040	1.145***	0.045	−0.531***	0.052
Distance to school 1/4–1/2 mi. (1,0)	−0.180***	0.040	0.510***	0.046	−0.220***	0.047
Distance to school 1/2–1 mi. (1,0)[a]						
Distance to school 1–2 mi. (1,0)	−0.082***	0.031	−0.593***	0.047	0.367***	0.034
Distance to school 2 mi. or more (1,0)	−0.264***	0.029	−1.703***	0.058	0.776***	0.032
Child age between 5 and 9 (1,0)	0.199***	0.017	−0.503***	0.033	−0.046***	0.018
Male child (1,0)	−0.103***	0.016	0.143***	0.031	0.078***	0.017
Walk alone restriction for all or part of K-8 grades (1,0)	−0.024	0.027	−0.587***	0.042	0.341***	0.029
Child attends public school (1,0)	−0.984***	0.028	0.368***	0.067	1.092***	0.031
Child belongs to single parent household (1,0)	0.089**	0.038	−0.010	0.068	−0.131***	0.040
Number of children in age 5–15 in household	−0.126***	0.011	0.041**	0.020	0.132***	0.011
Parent seriously concerned about crime (1,0)	0.067***	0.025	0.173***	0.044	−0.138***	0.027
Parent seriously concerned about traffic volume (1,0)	−0.020	0.023	−0.393***	0.051	0.132***	0.024
Parent seriously concerned about traffic speed (1,0)	−0.043*	0.024	0.036	0.052	0.024	0.024
Household income less than $25,000 (1,0)	−0.293***	0.040	−0.089	0.072	0.347***	0.042
Household income $25,000–$50,000 (1,0)	−0.104***	0.027	0.055	0.051	0.084***	0.028
Household income $50,000–$75,000 (1,0) [a]						
Household income $75,000–$100,000 (1,0)	0.041*	0.025	−0.082	0.050	−0.050*	0.026
Household income $100,000 or more (1,0)	0.061***	0.023	0.097**	0.046	−0.112***	0.024
Child lives in detached home (1,0)	0.128***	0.027	0.063	0.050	−0.116	0.028
Child lives in owned home (1,0)	0.053*	0.031	−0.308***	0.051	0.076	0.033
Child belongs to African American household (1,0)	−0.226***	0.036	−0.147**	0.070	0.228***	0.037
Child belongs to Hispanic household (1,0)	0.154***	0.030	0.075	0.049	−0.206***	0.032
Household has foreign-born adult (1,0)	−0.003	0.026	−0.100**	0.045	0.058**	0.028
Not in metro or metro population less than 250,000 (1,0) [a]						
Metropolitan population between 250,000 and 1 mil. (1,0)	−0.030	0.024	0.148***	0.050	0.003	0.025
Metropolitan population between 1 and 3 mil. (1,0)	0.020	0.023	0.138***	0.048	−0.060**	0.024
Metropolitan population more than 3 mil. (1,0)	−0.042*	0.022	0.238***	0.044	−0.057**	0.024
Adult in household drives to work (1,0)	0.458***	0.036	−0.590***	0.051	−0.098**	0.038
N	26,072		26,072		26,072	
Log likelihood	−16,556		−4141		−14,773	
Model χ^2	2634		6005		3885	
Prob > χ^2	0.0000		0.0000		0.0000	
Pseudo R^2	0.074		0.420		0.116	

[a] Referent category for independent variables.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

and sales/service workers are more likely to drive, and workers in large metropolitan areas are less likely to drive (once again, presumably because of the greater availability of public transit).

Similar to the selection model in Table 3 on the likelihood of adults driving to work, the outcome models on children's mode in Table 4 are consistent with expectations. Since the signs and the level of significance of the variables in the three models in Table 4 are almost identical to the probit models on children's mode choice in Table 2, they require no further discussion. However, to examine the effect of adults electing to drive, the sign of ρ and the χ^2 tests on ρ deserve attention. The χ^2 tests show that ρ is statistically significant at the 1% level in the children's household vehicle model, at the 5% level in the school bus model, and at the 10% level in the walk or bicycle model. The significant positive sign of ρ in the model on household vehicles for children indicates that the factors that influence adults' self-selection to drive to work increase the probability of children being driven to work. On the other hand, the negative signs of ρ in the walk or bicycle model and the school bus model indicate that the same forces decrease the probability of children walking, bicycling, or taking a school bus.

In addition to the outcome models in Table 4, children's modes were also predicted by the Heckman model conditional upon adults walking or bicycling and taking transit to work. These models showed expected results. The value of ρ and the χ^2 tests on ρ from these models are presented in Table 5.

The first column of Table 5 shows the modes used by adults in the selection equation and the subsequent columns show the value of ρ and χ^2 tests for the outcome models on children's mode. It is evident from the results that adults' decision to drive affects all modes used by children, whereas adults' decision to take public transit to work has no effect on children's modes. Interestingly, adults' decision to walk or bicycle is positively associated with children's propensity to walk or bicycle, but it has no effect on children using the two other modes. Together, these results indicate that household adults' choice of driving has a greater effect on children's travel mode to school than any other mode used by adults.

4.5. Does children's mode to school also affect adults' mode to work?

The MNL model in Table 1 and the probit models in Table 2 show that when adult workers travel to work by driving household vehicles, children are more likely to be driven to school and less likely to walk, bicycle, or take a school bus. Since these models treated adults' mode to work as exogenous, they showed only an association between the two. The Heckman models in Table 4 added an element of causality to this relationship by predicting adults' mode through the selection equation and making children's mode dependent on that selection.

Although it makes more intuitive sense to hypothesize that adults in a household choose a lifestyle within which children adapt and, therefore, children's mode is more likely to depend on

Table 3
Probit model on workers' likelihood of driving to work (the selection model).

Variables	β	Std. Err.
Intercept	0.299**	0.122
Distance to work less than 1 mi. (1,0)[a]		
Distance to work 1–5 mi. (1,0)	1.176***	0.051
Distance to work 5–10 mi. (1,0)	1.533***	0.055
Distance to work 10–15 mi. (1,0)	1.459***	0.057
Distance to work 15 miles or more (1,0)	1.287***	0.047
Full time worker (1,0)	0.035	0.047
Flex time allowed at work (1,0)	−0.118***	0.031
Male worker (1,0)	−0.387***	0.035
Worker lives in owned home (1,0)	0.347***	0.047
Worker lives in detached home (1,0)	0.265***	0.042
Number of children under 18 in household	0.030*	0.017
Number of adults in household	−0.012	0.023
Household income less than $25,000 (1,0)	−0.225***	0.065
Household income $25,000–$50,000 (1,0)	−0.027	0.051
Household income $50,000–$75,000 (1,0)[a]		
Household income $75,000–$100,000 (1,0)	0.034	0.048
Household income $100,000 or more (1,0)	−0.019	0.045
Worker has less than bachelor's degree (1,0)[a]		
Worker has bachelor's degree (1,0)	0.026	0.040
Worker has graduate or professional degree (1,0)	−0.183***	0.044
Professional, managerial or technical worker (1,0)[a]		
Manufacturing or construction worker (1,0)	0.096*	0.049
Administrative or clerical worker (1,0)	0.028	0.058
Sales or service worker (1,0)	0.085***	0.042
Worker has medical condition affecting travel (1,0)	−0.311***	0.099
Worker's age 25–29 years (1,0)	0.046	0.096
Worker's age 30–44 years (1,0)	0.119**	0.058
Worker's age 45–54 years (1,0)	0.025	0.058
Worker's age 55 years or above (1,0)[a]		
Worker is African American (1,0)	−0.227***	0.057
Worker is Hispanic (1,0)	0.097*	0.052
Worker is foreign born (1,0)	−0.051	0.044
Not in metro or metro population less than 250,000[a]		
Metropolitan population between 250,000 and 1 mil. (1,0)	0.064	0.050
Metropolitan population between 1 and 3 mil. (1,0)	−0.104**	0.044
Metropolitan population more than 3 mil. (1,0)	−0.456***	0.040
N	24,730	
Log likelihood	−4374	
Model χ^2	1808	
Prob > χ^2	0.0000	
Pseudo R^2	0.171	

[a] Referent category for independent variables.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

adults' mode than adults' mode on children's mode, to test if causality runs in both directions, the selection and outcome equations of the previously described Heckman model were switched to predict children's mode by the selection equation and adults' mode by the outcome equation. These models showed that children being driven to school has no effect on the likelihood of adults driving to work (ρ = 0.117, Prob > χ^2 = 0.143) or adults walking or bicycling to work (ρ = −0.200, Prob > χ^2 = 0.147). Similarly, children walking or bicycling to school has no effect on adults driving to work (ρ = −0.108, Prob > χ^2 = 0.148) or adults walking or bicycling to work (ρ = 0.171, Prob > χ^2 = 0.145). These results provide additional evidence supporting the hypothesis that adults' commuting mode selection affects children's travel modes and this relationship is mostly unidirectional.

5. Summary of findings

Like many past studies, this paper provided results from probit and multinomial logit models on children's travel mode to school by treating distance to school, children's characteristics, household characteristics, school characteristics, parents' perceptions, and place characteristics as exogenous. These results are consistent with past studies. In addition, the paper provided results from Heckman probit models to show the relationship between adults' mode to work and children's mode to school. The variables used in the Heckman models also showed consistency with past studies and the probit and MNL models. Together, these models provide evidence that distance to school, children's age and gender, school type, school policies on walking, household income, type of dwelling, size of metropolitan area, and certain parental perceptions influence children's travel mode to school.

For school officials, planners, and researchers concerned about walking and bicycling to school, the study provides some useful evidence. First, it shows that schools' walk-alone restriction reduces the likelihood of walking and bicycling by children. Second, public school students are more likely to walk than private school students. Third, like many other studies, it shows that the likelihood of walking and bicycling decreases with distance to school. However, when schools are more than a mile away, trips are more likely to be made by school bus instead of household vehicles. Fourth, parents' perceptions need to be studied more carefully in future research because a serious concern about traffic speed was found to have no effect on walking or bicycling, whereas children were found to walk and bicycle to school more when parents have a serious concern about crime.

The most significant contribution of this paper is its ability to demonstrate through a system of equations that children's travel mode to school is influenced by parents' travel mode to work. Because of the structure of the Heckman model, these results can be considered at least quasi-causal instead of being completely associative.

The effect of adults' mode on children's mode was clearly evident when household adults drove to work. The results indicate that, in lifestyle decisions, adults' travel mode to work is more fundamental than children's mode to school. It can be suggested from the observed dominance of adults' mode over children's mode in the household decision-making process that future studies should also consider the travel patterns of household adults when predicting children's mode to school so that the effects of other variables are not overestimated.

The evidence presented in this study can help to shape the overall transportation planning policies and practices of cities, counties, and states, as well as the efforts by state departments of transportation under the federal SRTS program and by the schools participating in the program. The study's conclusion that children are less likely to walk or bicycle when adults in the household drive to work indicates that policies and practices that affect driving to work also affect children's mode to school. Thus, free or subsidized parking at work, high capacity of roads relative to traffic volume, low employment density, and low gasoline tax can all be expected to decrease walking and bicycling to school by children, whereas developing land in a manner that promotes walking by adults to work could potentially increase walking and bicycling to school by children. The results suggest that promoting public transit options for commuting by adults may have no discernible impact on children's walking or bicycling to school.

The observed association between adults' travel mode to work and children's mode to school should also make those involved in promoting walking and bicycling under the SRTS program aware that improving walking and bicycling environments around schools cannot entirely determine whether children will walk or bicycle to school. While they may be important to a certain degree, ultimately how children travel to school also depends on how the adults in their households travel to work. Given the interconnection between adults' travel to work and household children's travel to school, it may be necessary to let parents play a significant role