RELATIONSHIPS BETWEEN MODE CHOICE AND INDEPENDENCE FOR THE JOURNEY TO SCHOOL

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ABSTRACT

The study of children's travel behavior is complicated by the reliance of children on adult chaperones. This reliance is stronger for motorized travel than for non-motorized travel because most children cannot legally operate motor vehicles. It is unclear, however, whether children's reliance on private cars for the journey to school is a cause or a result of their reliance on household adults to accompany them on these trips. We seek to determine (1) which individual, household, and trip characteristics are associated with households' choice of mode (car, bike, or walk) and choice of independence (accompanied by a household adult, accompanied by another person, or unaccompanied), and (2) whether the choice of mode depends upon the choice of independence or vice versa. To address the first question, we estimate two multinomial logistic regression models: one predicting choice of mode and the other predicting choice of independence. To address the second question, we estimate three multinomial logistic regression models predicting mode and independence simultaneously: the first modeling all combinations of mode and independence as independent alternatives, the second nesting alternatives with nests defined by mode, and the third nesting alternatives into nests defined by independence. We find that variables related to household structure are important predictors of independence and variables related to resource availability are important predictors of mode. Moreover, while our results suggest that choice of mode is not independent from choice of independence, we find weak evidence that the choice of mode is entirely dependent upon the choice of independence.

Keywords: children, active travel, mode choice, independent mobility

INTRODUCTION

A primary benefit of non-motorized travel for children is the ability to travel independently from adults. However, both independent travel and non-motorized travel by children have declined in recent decades across multiple countries (*1*). Characteristics of the physical, cultural, or policy environment may require children's trips to take place by car. Even in contexts where efforts have been made to encourage active travel, explicit requirements or cultural norms requiring children to be accompanied by adults may circumvent those efforts if the choice of mode for children's travel depends on whether a child is able to travel independently.

The purpose of this paper is to examine the relationship between choice of mode and choice of independence (whether a child travels alone, with a parent, or with others). We focus our analysis on the journey to school because this is a trip that is constrained in terms of whether and when it will take place, and it takes place at a time of day that frequently corresponds with non-discretionary work trips by adult household members. We find that household structure (the presence of siblings and a non-working mother) is associated with the independence of the journey to school and resource availability (income and vehicle access) is associated with mode choice. Trip distance, age, gender, and density are associated with both. Moreover, we find better support for the conclusion that the choice of mode depends upon the choice of independence for the journey to school than than for the conclusion that the choice of independence depends on the choice of mode or that the two choices are independent of one another.

In the following section, we summarize existing literature on independent and active travel to school. This is followed by a description of the dataset and modeling approach we used to address the questions of which individual, household, and trip characteristics are associated with the choice of mode and the choice of independence, and whether the choice of independence can be better described as a cause or a result of the the choice of mode. We present the results of our analysis and discuss the their implications, both for future research and for policies and strategies aimed at reducing car-dependence for the journey to school.

BACKGROUND

Substantial research has been published on the correlates with, causes of, and barriers to active travel to school. Reviews of this literature include McMillan (*2*), Davison et al. (*3*), Sirard and Slater (*4*), Stewart (*5*), Rothman et al. (*6*), and Aranda-Balboa et al. (*7*).

Distance is the stongest predictor of mode choice for the trip to school. Studies seeking to identify a threshold distance beyond which the likelihood of walking to school decreases substantially have found that distance to be 0.71 miles (1.14 kilometers) for primary school children in California (*8*), 0.78 miles (1.25 kilometers) for seven- to eleven-year-old children in urban areas of Spain (*9*), and 0.88 to 1.89 miles (1.42 to 3.05 kilometers) for ten- to fourteen-year-old children in Norfolk, United Kingdom (with distances increasing with age) (*10*).

McMillan (*2*) has proposed a framework for explaining the mode choice for children's journey to school in terms of the built environment, mediated by household resources and real and perceived safety and moderated by parental attitudes, sociodemographics, and social norms. Subsequent literature reviews have generally confirmed the greater importance of sociodemographics and parental attitudes and perceptions, relative to built environment characteristics (and controlling for trip distance) (*3–7*).

McDonald (*11, 12*) has found important relationships between active travel to school and the genders of both a school child and their parents. Girls are less likely to travel to school by active modes than boys are, and most of this difference is from a gender gap in cycling (*11*). Moreover, the work status of a child's mother, but not their father, is an significant predictor of a child's mode of travel to school (*12*).

Formal efforts in increase active travel to school, especially in the United States context, are classified as Safe Routes to School (SRTS) programs. As research has confirmed the importantace of sociocultural factors relative to built environment factors, SRTS programs have shifted their focus accordingly. When they were first introduced to in the mid-1990s, SRTS programs generally emphasized improvements to pedestrian and cycling infrastructure, but have since expanded to include non-infrastructure strategies, with efforts typically characterized in terms of four elements, described as the four 'E's: Education (e.g., teaching drivers to yield to pedestrians and cyclists); Encouragement (e.g., Walk to School Day events); Enforcement (e.g., the use of police officers and community volunteers to enforce traffic laws); and Engineering (e.g., sidewalk and crosswalk improvements) (*13*). In recent years, the Safe Routes Partnership, a non-profit organization that promotes and supports SRTS programs in the United States, has added two additional 'E's (Equity and Evaluation) to create their "Six 'E's" framework (*14*). In June 2020, in response to nationwide protests against police violence, the Safe Routes Partnership revised their "Six 'E's" framework to replace Enforcement with Engagement, where engagement represents community engagement (*14*).

Much of the research on active commuting by children is situated in the public health literature and frames the importance of active transportation in terms of its potential physical activity benefits. This emphasis on the health benefits of active travel to school is underscored by Jing et al.'s (*15*) finding that the Journal of Transport and Health is the the journal that has published most frequently on active travel to school. Literature reviews specifically addressing the relationship between active travel to school and health benefits associated with physical activity include Lubans et al. (*16*) and Davison et al. (*3*). These reviews have found some consensus that walking and cycling to school is associated with increased physical activity and greater physical fitness, and more mixed results relating active travel to school to obesity and body-mass index.

Fewer studies have framed active travel to school in terms of benefits and risks that extend beyond children's physical activity. Wilson, Wilson, and Krizek (*17*) discusses the environmental impact of school choice policies that increase student commute distances and car-reliance. Bierbaum et al. (*18*) discuss the equity implications of school choice policies where access to better schools is conditional on access to private, motorized transportation.

A review by Schoeppe et al. (*19*) takes a broader scope than the literature reviews discussed above by including studies of travel by all trip purposes rather than focusing exclusively on school trips and by examining the effects of both active travel and independent mobility. They focus on physical activity benefits and find that both active travel and independent mobility are associated with greater physical activity in children.

Fewer studies directly address the relationship between active travel and independent mobility, although the presence of a relationship is quite intuitive, at least in one direction: Children cannot operate motor vehicles, so travel by car must be accompanied rather than independent. However, travel by active modes can be either independent or accompanied. Walking school buses, in which schools or parent organizations organize groups of children to walk to school together accompanied by an adult volunteer, offer an approach to decoupling active travel from independent travel (or at least from travel that is independent from a parent) (*20–24*).

Yarlagadda and Srinivasan (*25*) apply a multinomial logistic regression to simultaneously predict mode and independence for the journey to school by children younger than eighteen year old, modeling the choice as being among nine independent alternatives: Bike, car (as a driver, since older children in the sample may be licensed drivers), school bus, transit, walking (with separate alternatives for walking along or walking with the child's mother), and car (as a passenger, with separate alternatives for riding with the child's mother, father, or a non-household member). Notably, walking to school with the child's father was not included in the model because it was very rare in the study sample. They find that the work status of a child's mother and the work status of a child's father are both significantly related to the likelihood that the respective parent will drive their child to school, but with effects in opposite directions. Mother with inflexible work schedules are more likely to drive their children to school than mothers who are not workers or have flexible work schedules. Fathers with inflexible work schedules are less likely to drive their children to school than fathers who are not workers or have inflexible work schedules.

This study takes a similar approach to that of Yarlagadda and Srinivasan (*25*) by applying a multinomial logistics regression to simultaneously predict the mode and independence of the journey to school. We depart from their approach by applying a nested model structure to test whether the choice of mode depends upon the choice of independence or vice versa.

DATA AND METHODS

We draw on data from the 2017 National Household Travel Survey (NHTS) for this analysis. Respondents to the NHTS complete a 24-hour travel diary on an assigned travel day. The 2017 survey data includes 923,572 trips by 219,194 individuals across 117,222 households.

For our analysis, we selected survey-day trips to school by survey respondents between the ages of 8 and 13 years old, excluding trips that are longer than 1.25 miles (2 kilometers). Trips involving multiple stages (for example, a walk to a school bus, followed by a school bus trips to school) were classified as a single trip and assigned to the mode associated with the longest segment of the trip. This yields an initial sample of 2,165 trips by 2,165 children across 1,758 households. Of those, only ten trips took place by transit, two took place by motorcycle or moped, and eleven took place by unspecified modes. These 23 trips were removed from the sample, and these modes were assumed not to be available to the rest of the sample. Twenty percent of students in the initial sample used a school bus for the trip to school and/or the trip home from school. We removed these students from our sample and assumed that the remaining students were not eligible for school bus service. We assumed that the choice to travel by foot, bike, or car was available to all students. This may overestimate the availability of bike and car travel, but the survey did not include information on bicycle ownership and data on car ownership did not seem to be a reliable indicator of car availability, since many students in zero-vehicle households did commute to school by car.

We also classified each trip in our sample into into one of three categories of independence:

- Alone: Unaccompanied trips
- With parent: Trips accompanied by a parent (defined as any household adult)
- With others: Trips accompanied by others, which could include:
  - Siblings (defined as any household children),
  - Non-household children, or
  - Non-household adults

We removed trips from our initial sample if survey respondents indicated that a child had driven to school alone (15 trips), or if there were missing values for household income or for the

TABLE 1: Mode of travel by independence for journey to school

	With parent*	With others	Alone	Total
Car	999	65	0	1 064
Walk	172	153	155	480
Bike	24	23	67	114
Total	1 195	241	222	1 658

* All household adults are classified as parents.

population density of both the trip origin and destination. This resulted in a final sample of 1,658 trips by 1,658 children.

Table 1 shows the number of trips in each cross-category of mode and independence.

We estimated a set of multinomial logistic regression models predicting travel mode and independence for survey-day trips to school. The independent variables we included in our model are listed in Table 2 along with basic descriptive statistics.

Using the data described above, we estimated a series of multinomial logistic regression models using Biogeme (*26*):

- A model predicting the mode of each trip
- A model predicting the independence of each trip
- A set of models predicting the combined mode and independence of each trip

Since children cannot operate legally operate motor vehicles (and thus cannot travel alone by car) the choice of independence is closely related to the choice of mode. We estimated a set of three models predicting mode and independence simultaneously. These models predicted whether a child would travel to school by any of the following eight combinations of mode and independence:

- By car with a parent
- By car with others (not a parent)
- walking alone
- walking with a parent
- walking with others
- cycling alone
- cycling with a parent
- cycling with others

One model is unnested, as illustrated in Figure 1, suggesting that the choices of independence and mode are independent of one another. A second model nests alternatives within modes, as illustrated in Figure 2, representing the case where decision of whether a child travels independently depends on the choice of mode. A third model nests alternatives with in categories of independence, as shown in Figure 3, representing the case where mode choice depends on the decision of whether a child will travel independently. Biogeme estimates a logit scaling parameter (μ) for each nest. For consistency with utility theory, these values must be greater than one. An alternative parameter to represent the scaling of nests in a nested logit model is the nesting coefficient (λ), which must be between zero and one for consistency with utility theory. λ is equal to $1/\mu$, and values of μ that are greater than one will thus yield values of λ that are between zero and one.

TABLE 2: Independent variables included in regression models

Variable	Mean or proportion (unweighted)	Standard deviation (unweighted)
Household characteristics		
Household income[1]	\$97 603	\$70 048
Number of vehicles per driver	1.1	0.5
Presence of a non-working father[2]	11%	NA[6]
Presence of a non-working mother[3]	35%	NA
Individual characteristics		
Age	10.2	1.6
Female	48%	NA
Has a younger sibling[4]	48%	NA
Has an older sibling	46%	NA
Trip characteristics		
Trip distance (kilometers)	1.1	0.5
Population density (People per square km)[5]	2 483	2 257

Notes:
1. The NHTS records household income in one of eleven income categories. We converted this to a continuous variable by assigning each household an income at the midpoint of its respective category. For the highest income category (greater than \$200,000 USD per year), we assumed an income of \$250,000 USD per year.
2. All male household adults are classified as fathers.
3. All female household adults are classified as mothers.
4. All household children are classified as siblings.
5. The publicly-available NHTS dataset does not provide the locations of trip ends, but it does give the population density of the census block group at each trip's origin and destination.
6. NA = "Not applicable".

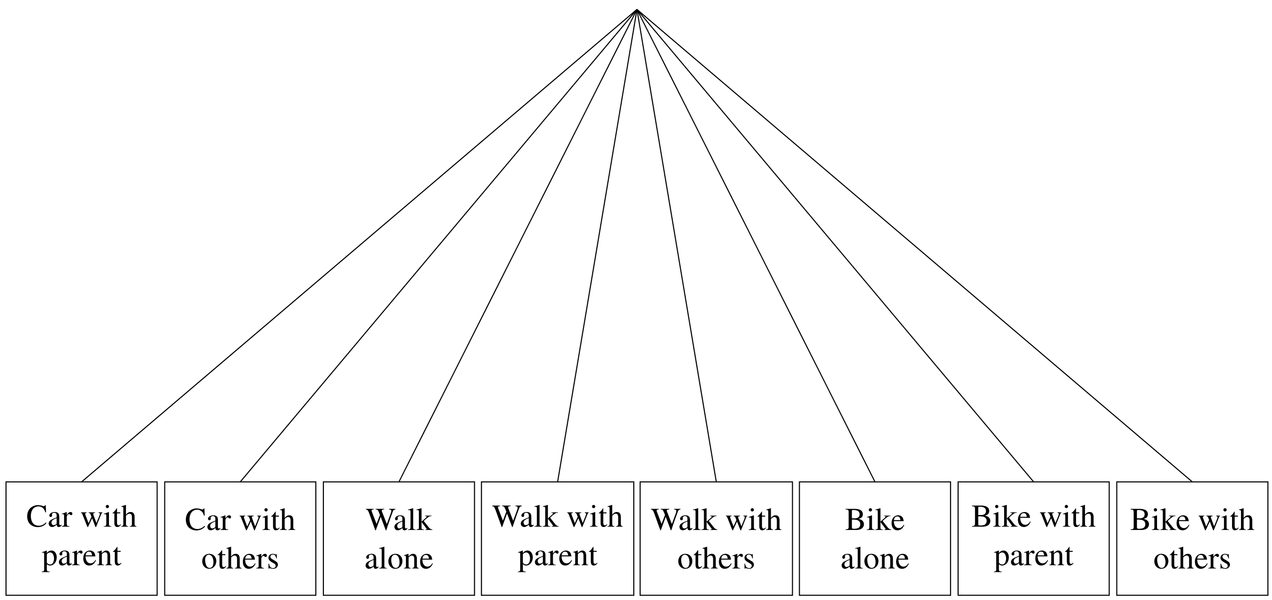

FIGURE 1: Choice structure for non-nested model

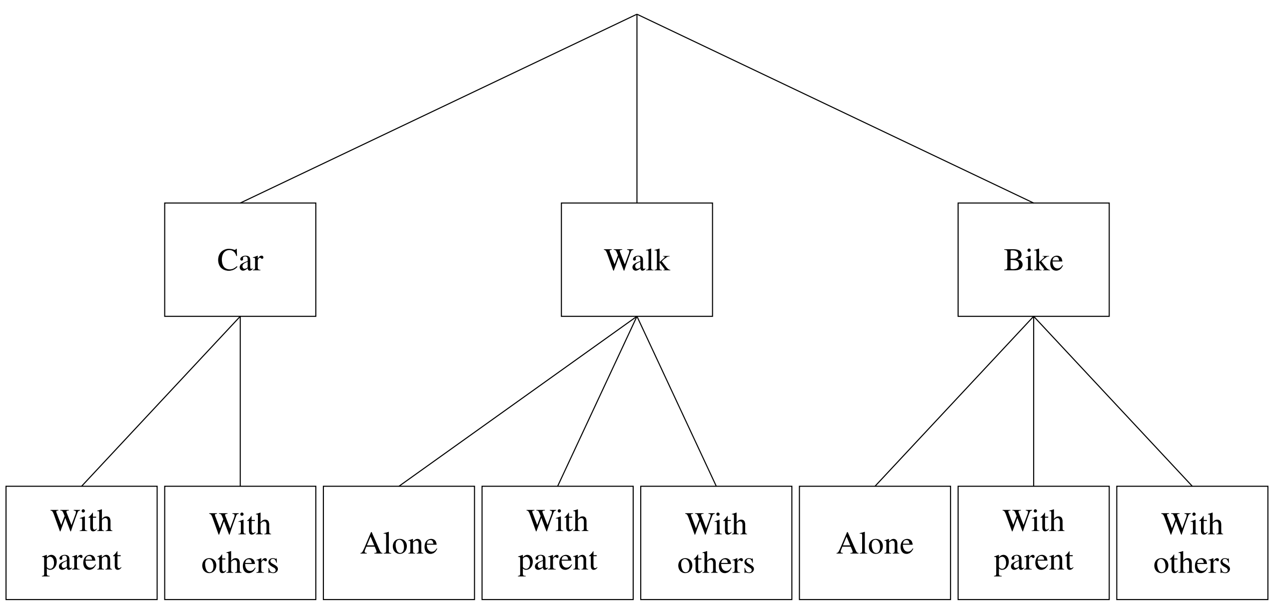

FIGURE 2: Choice structure for model with mode-based nests

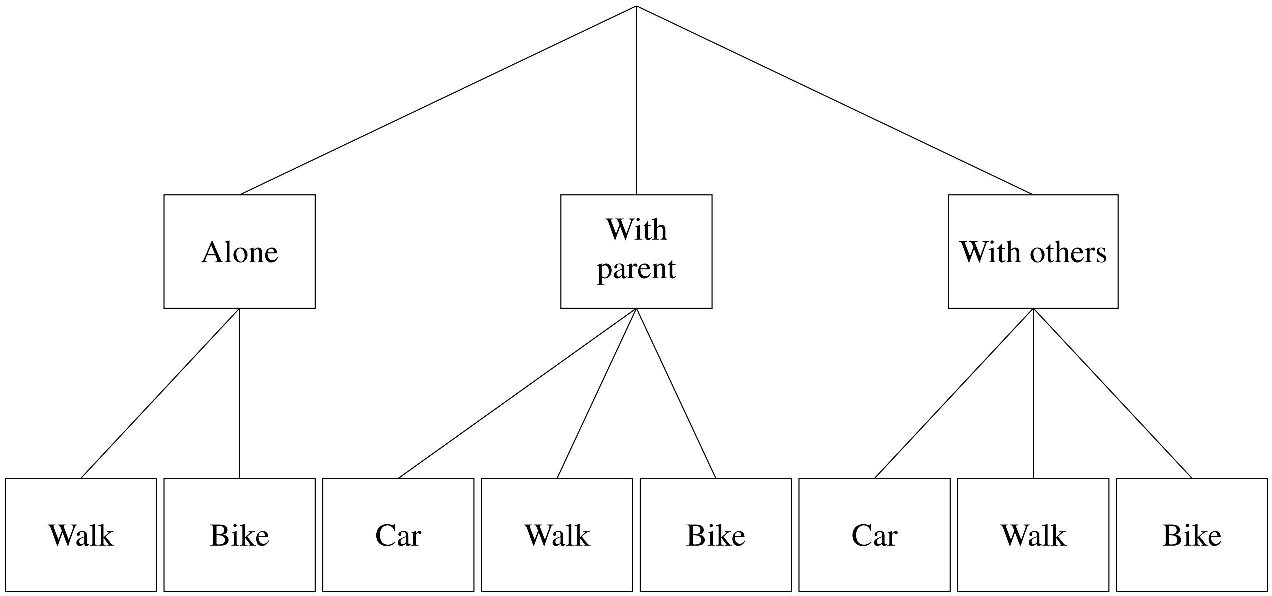

FIGURE 3: Choice structure for model with mode-based nests

RESULTS

Table 3 shows the results of the multinomial logistic regression model predicting mode choice for the trip to school, and Table 4 shows the results of the model predicting independence. Coefficients are not directly interpretable since the likelihood of a given alternative depends on the relative utilities of all alternatives.

To aid in the interpretation of model results, Figure 4 illustrates the results of the model predicting mode choice, showing the variation in the probability of each mode with each significant independent variable, holding all other variables constant at their respective means. Each variable in Figure 4 is varied within the range that is present in the data, with the exception of vehicles per driver. The maximum value for the number of vehicles per driver in our sample is 12, but 98 percent of our sample came from households with two or fewer vehicles per driver, so we truncated the scale in the figure to better illustrate this more typical range. The darkest gray color in 4 represents the probability of travel by car; the lighter gray represents the probability of travel by bike, and the lightest gray represents the probability of walking. Consistent with findings by (*11*). girls are more likely than boys to travel by car, and this difference is mainly driven by a difference in the propensity to bike. The likelihood of traveling by car or by walking decreases slightly with income, as the likelihood of cycling increases. This may be a result of better, safer, bike infrastructure in more affluent areas. The likelihood of travel by bike is somewhat consistent across the range of population densities, and higher densities are associated with a shift from driving to walking. Travel by car and bike both become more common with increasing trip distances. Travel by car becomes more likely and walking and cycling become less likely as the number of household vehicles per driver increases. Older children are more likely to walk to school and less likely to travel by car.

Figure 5 similarly illustrates the model predicting independence. The purple color in 4 represents the probability of travel with a parent; the orange represents the probability of travel with others, and the green represents the probability of traveling alone. Differences in mode choice associated with differences in density, though statistically significant, are quite minor. The likelihood of traveling with a parent increases substantially with trip distance and decreases substantially with age. Girls are less likely to travel alone than boys are, and the presence of a non-working mother in the household is associated with a greater likelihood that a child will travel with their parent. Children with older siblings and those with younger siblings are more likely to travel with a someone other than a parent than children without siblings are. For children with an older sibling, travel with a non-parent primarily replaces travel with a parent. For children with a younger sibling, travel with a non-parent primarily replaces travel alone.

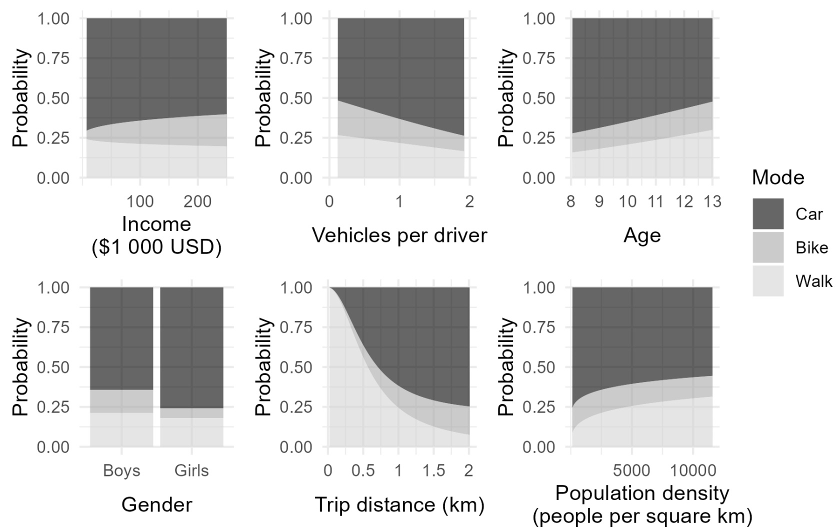

FIGURE 4: Modeled relationships between mode and significant independent variables. Other variables held at sample mean.

TABLE 3: Results of multinomial regression model predicting mode choice

Log likelihood: -1153.93 (22 parameters)					
Likelihood ratio test (for null model): χ^2 = 1335 ($p < 0.001$)					
Variable	Alternative (relative to car)	Coefficient estimate	Standard Error	p-value	
Intercept	Bike	-4.39	1.23	< 0.001	***
	Walk	-5.07	0.76	< 0.001	***
Household characteristics					
log(household income)	Bike	0.42	0.14	0.003	**
	Walk	-0.01	0.07	0.849	
Vehicles per driver	Bike	-0.65	0.31	0.037	*
	Walk	-0.46	0.17	0.008	**
Non-working father	Bike	-0.55	0.37	0.143	
	Walk	0.21	0.19	0.270	
Non-working mother	Bike	0.05	0.22	0.835	
	Walk	-0.06	0.14	0.681	
Individual characteristics					
Age	Bike	0.14	0.06	0.017	*
	Walk	0.19	0.04	< 0.001	***
Female	Bike	-1.04	0.22	< 0.001	***
	Walk	-0.33	0.13	0.009	**
Has younger sibling	Bike	-0.39	0.22	0.082	
	Walk	0.15	0.14	0.267	
Has older sibling	Bike	-0.12	0.22	0.581	
	Walk	0.22	0.14	0.116	
Trip characteristics					
log(trip distance	Bike	0.09	0.22	0.688	
	Walk	-1.97	0.18	< 0.001	***
log(density)	Bike	0.03	0.08	0.741	
	Walk	0.35	0.06	< 0.001	***
* = 95-percent confidence, ** = 99-percent confidence, *** = 99.9-percent confidence					

TABLE 4: Results of multinomial regression model predicting independence

Log likelihood: -1161.975 (22 parameters)
Likelihood ratio test (for null model): χ^2 = 1319 ($p < 0.001$)

Variable	Alternative (relative to with parent)	Coefficient estimate	Standard Error	p-value	
Intercept	With others	-4.79	0.81	< 0.001	***
	Alone	-6.93	0.92	< 0.001	***
Household characteristics					
log(household income)	With others	-0.05	0.09	0.570	
	Alone	0.02	0.09	0.838	
Vehicles per driver	With others	-0.10	0.15	0.525	
	Alone	> -0.01	0.13	0.994	
Non-working father	With others	-0.10	0.24	0.674	
	Alone	-0.17	0.27	0.519	
Non-working mother	With others	-0.59	0.17	< 0.001	***
	Alone	-0.44	0.17	0.015	*
Individual characteristics					
Age	With others	0.25	0.05	< 0.001	***
	Alone	0.53	0.05	< 0.001	***
Female	With others	-0.39	0.16	0.008	**
	Alone	-0.75	0.15	< 0.001	***
Has younger sibling	With others	0.36	0.16	0.021	*
	Alone	-0.72	0.17	< 0.001	***
Has older sibling	With others	0.52	0.15	0.001	***
	Alone	< 0.01	0.17	0.976	
Trip characteristics					
log(trip distance	With others	-0.81	0.13	< 0.001	***
	Alone	-1.08	0.15	< 0.001	***
log(density)	With others	0.11	0.06	0.049	*
	Alone	0.03	0.06	0.661	

* = 95-percent confidence, ** = 99-percent confidence, *** = 99.9-percent confidence

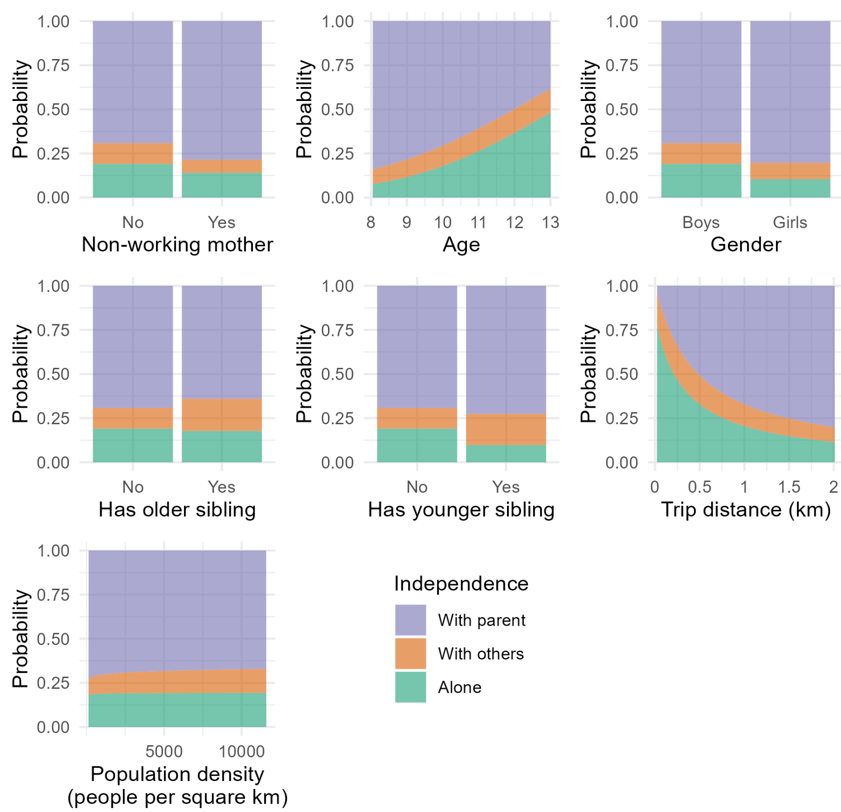

FIGURE 5: Modeled relationships between independent travel and significant independent variables. Other variables are held at sample mean.

We also estimated three models that predict independence and mode simultaneously: one without nests, one using mode-based nests, and one using independence-based nests. The nested logit models estimate a scale parameter for each nest, and each of these must be greater than or equal to one in a valid model. The model with mode-based nests failed to produce a scale parameter greater than one for the car nest, and is thus not valid. All scale parameters in the the model with independence-based nests are greater than or equal to one, but they are not significantly different from one. A likelihood ratio test comparing the model with mode-based nests to the unnested model produced a chi-squared value of 10.6 and a p-value of 0.005. A likelihood ratio test comparing the model with independence-based nests to the unnested model produced a chi-squared value of 17.4 and a p-value of 0.001. Taken together these, these results indicating that the model with independence-based nests offers a better fit than the non-nested model or the model with mode-based nests. Thus, the model with independence-based nests is the preferred model. However, since the nest scale parameters are not significantly different from one, the evidence that mode choice for the journey to school depends on a households' choice of independence is fairly weak: the structure of the combined choice of mode and independence is likely more complicated than that represented in Figure 3. Table 5 summarizes the results of the model with independence-based nests.

Figure 6 illustrates the model predicting mode choice and independence simultaneously, showing the variation in probabilities for each significant independent variable, holding all other

TABLE 5: Results of nested logit model predicting independence and mode

Log likelihood: -1886.333 (80 parameters)					
Likelihood ratio test (for null model): χ^2 = 3123 ($p < 0.001$)					
Variable	Alternative (Base: car with parent)	Coefficient estimate	Standard Error	p-value	
Intercept	Car with others	-4.62	0.96	< 0.001	***
	Bike alone	-6.88	0.95	< 0.001	***
	Bike with others	-4.83	0.90	< 0.001	***
	Walk alone	-6.96	0.95	< 0.001	***
	Walk with others	-4.88	0.97	< 0.001	***
Household characteristics					
Non-working mother	Car with others	-0.53	0.18	0.003	**
	Bike alone	-0.37	0.19	0.047	*
	Walk alone	-0.37	0.19	0.047	*
	Walk with others	-0.53	0.17	0.002	**
Individual characteristics					
Age	Car with others	0.22	0.06	< 0.001	***
	Bike alone	0.50	0.05	< 0.001	***
	Bike with others	0.23	0.05	< 0.001	***
	Walk alone	0.51	0.06	< 0.001	***
	Walk with others	0.23	0.05	< 0.001	***
Female	Car with others	-0.41	0.15	0.006	**
	Bike alone	-0.80	0.17	< 0.001	***
	Bike with others	-0.40	0.15	0.009	**
	Walk alone	-0.77	0.17	< 0.001	***
	Walk with others	-0.42	0.16	< 0.008	**
Has younger sibling	Car with others	0.37	0.18	0.035	*
	Bike alone	-0.69	0.18	< 0.001	***
	Walk alone	-0.69	0.18	< 0.001	***
	Walk with others	0.41	0.18	0.024	*
Has older sibling	Car with others	0.50	0.17	0.003	**
	Bike with others	0.49	0.18	0.006	**
	Walk with others	0.52	0.16	0.0001	**
Trip characteristics					
log(trip distance)	Car with others	-1.08	0.34	0.002	**
	Bike alone	-1.38	0.25	< 0.001	***
	Bike with others	-1.10	0.29	< 0.001	***
	Walk alone	-1.46	0.26	< 0.001	***
	Walk with others	-1.20	0.31	< 0.001	***
log(density)	Bike with others	0.16	0.07	0.031	*
	Walk with others	0.18	0.09	0.044	*
Scale parameters	With parent	1.29	1.00	0.195	
	With others	43.6	31.3	0.164	
	Alone	22.1	86	0.797	
Note: Non-significant coefficients are included in the model, but not shown in the table. * = 95-percent confidence, ** = 99-percent confidence, *** = 99.9-percent confidence					

variables constant at their respective means. As in Figure 4, the darkest shade of each color represents travel by car, the lighter shade represents travel by bike, and teh lightest shade represent walking. As in Figure 5, shades of purple represent travel with a parent, shades of orange represent travel with others, and shades of green represent travel alone.

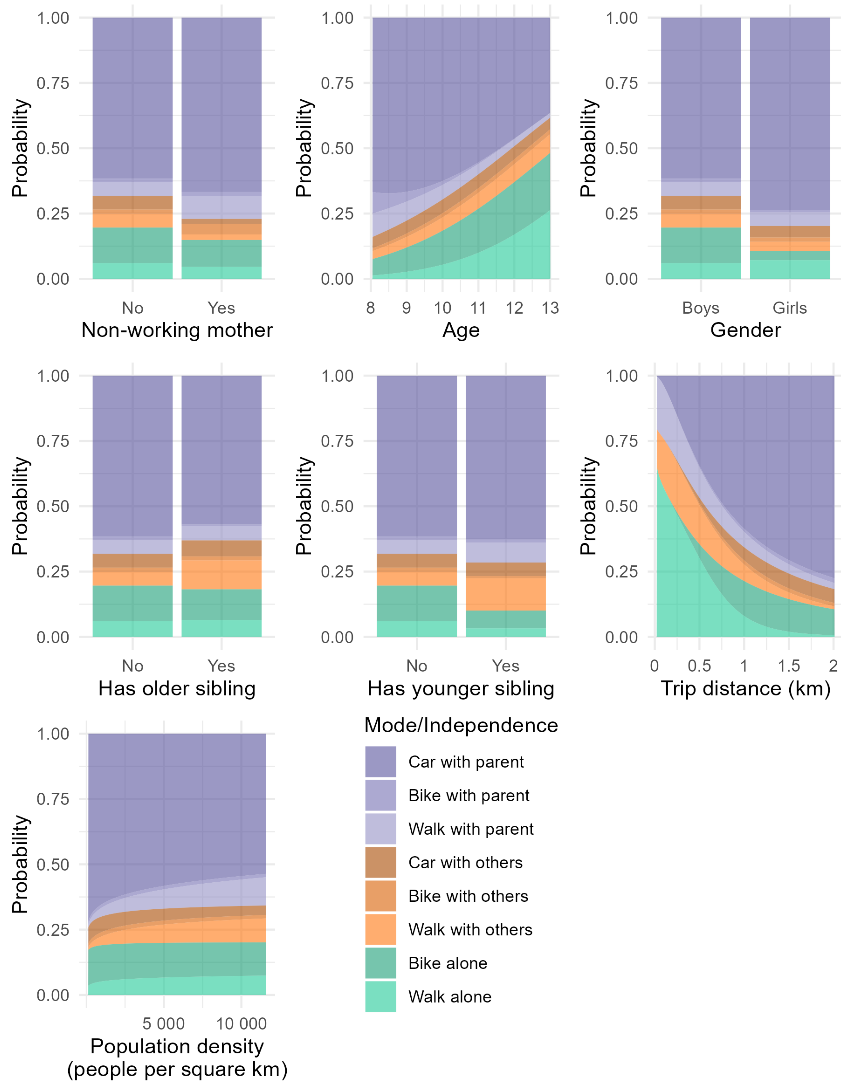

FIGURE 6: Modeled relationships between independent travel and significant independent variables

As expected, a longer distance increases the probability that a child is being driven to school by a parent compared to all other alternatives. A higher density increases the probability of using active modes, but only when the child is traveling with others. In general, a non-working mother in the household and lower age of the child traveling to school increase the probability of the child being transported in a car by a parent. Girls are less often transported by others and even less often travel alone. If the child has younger siblings, they more often travel with others adults than their own parents and they less often travel alone. Similarly, if they have older siblings, they more often travel with others, but no effect is found for when they travel alone.

The scale parameters should be interpreted with caution, since they are not significantly different from one, but based on their magnitudes alone, all indicate higher substitution across trips within the "with parents" nest, the "with others" nest and the "alone" nest respectively. The within-nest substitution is highest for "with others" trips" followed by "Alone" and "With parent". The substitution effects is to a high extent seen in figure 6 for age, distance and density. The overall probability of the child using an alternative in the "with others" nest is fairly stable for changing values of these variables while the within substitution is high, especially for trip distance and population density. Clearly, household composition variables are driving the substitution from this nest. The overall probability for the alternatives in the "alone" nest are more affected by all variables, except if the have older siblings. A clear within-nest substitution is present especially for gender, trip distance and age.

DISCUSSION

In general, household structure (the presence of siblings and a non-working mother) is associated with the independence of the journey to school and resource availability (income and vehicle access) is associated with mode choice. Trip distance, age, gender, and density are associated with both.

This analysis tested three alternative model structures to simultaneously predict the mode and independence of the journey to school: One corresponding to a case where the choice of independence is independent from the choice of mode; one corresponding to a case where the choice of mode depends on the choice of independents; and one corresponding to a case where choice of independence depends on the choice of mode. Of these three alternatives, the best-performing model structure was the one corresponding to the case where choice of mode depends upon choice of independence.

Given the failure of either nested model to produce scale parameters that are significantly different from one, the relationship between choice of mode and choice of independence is likely to be more complicated than can be represented by either nested model presented here. There may be bidirectional interdependence between choice of mode and choice of independence, where the choice of mode influences the choice of independence *and* the choice if independence influences the choice of mode. A cross-nested logit model would allow for the definition of independence-based nests and mode-based nests in the same model, with an estimated parameter to describe the degree to which each combination of mode and independence belongs to each of multiple nests. This approach would require many more model parameters to be estimated and would thus require a larger sample and/or a smaller number of explanatory variables to converge to a meaningful result.

The finding that household structure is an important predictor of independence raises the question of whether the relationship between independence and mode choice and between both of these outcomes and other explanatory variables might differ among various household types. For example, households with multiple working adults might have an entirely difference decision-making structure than those with single parents or a non-working parent. A latent-class model would allow us to determine whether multiple classes of households exist with distinct relationships between individual and household characteristics and the choice of mode and independence, and to determine which household-level variables predict membership in each of these classes.

The significance of a child's sex and the the presence in the home of a non-working mother (but not a non-working father) are consistent with findings by McDonald (*11, 12*) and are suggestive of a gendered bias in who bears the burden of physical and social environments that limit independent mobility. Further research on the relationships between independent mobility and gender gaps in opportunities for both children and their parents is needed.

Finally, our sample includes a low share of bicycle trips, which is typical of children's travel to school in the United States. This results in very low sample sizes in our cross-categories of mode and independence. It would be worthwhile to repeat this analysis in with data from a context in which rates of children's cycling are much higher, such as in the Netherlands or Denmark. These countries also have difference cultural norms and policies that affect the gendered division of household labor, so a comparative analysis would also add useful nuance to our findings related to parental and child gender.

CONCLUSION

This study is primarily motivated by the question of whether the choice of independence for a child's journey to school depends on the choice of mode or whether the choice of mode depends on the choice of independence. We further sought to determine which individual, household, and trip characteristics best explain the choice of mode and the choice of independence. We find that the choice of mode depends on the choice of independence, that variables related to resource availability are important predictors of mode, and that variables related to household structure are important predictors of independence.

More complex modeling techniques and additional data would allow a more nuanced understanding of these relationships, but the findings presented here have important implications for for policies and strategies intended to increase the use of active modes for the journey to school. Many schools have policies in place to discourage or restrict students from arriving at or leaving school independently. The safety benefits of adult supervision on the the journey to and from school should be carefully weighed against the risks associated with car-dependency such as the reduced physical activity and increased vehicle traffic in the immediate vicinity of school sites. Education- and encouragement-based activities associated with Safe Routes to School programming should focus not only on encouraging walking and cycling, but on also encouraging parents to consider when their child may be ready to travel to school independently or in groups with other children. Walking school buses may represent a promising strategy by allowing children to walk to school in cases where parents do not believe their children are ready to walk alone, but are unable to walk with them.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: C.T. Voulgaris, A.F. Jensen; data assembly: C.T. Voulgaris; analysis and interpretation of results: C.T. Voulgaris, A.F. Jensen, G.S. Macfarlane; draft manuscript preparation: C.T. Voulgaris, A.F. Jensen, G.S. Macfarlane. All authors reviewed the results and approved the final version of the manuscript.

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