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Investigating next generation's cycling ridership to promote sustainable mobility in different types of cities

Maria Kamargianni

UCL Energy Institute, The Bartlett, University College London, 14 Upper Woburn Place, WC1H 0NN, London, UK

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ABSTRACT

The aim of this paper is to develop a mode to school choice model to quantitatively evaluate the impact of various bicycle services and facilities on adolescents' mode choice behaviour. Stated preference (SP) scenarios specifically designed for this survey were used to elicit preferences for bicycle facilities and infrastructure, such as bike-lanes and bicycle parking places, and also for the availability of safety courses for school goers. The estimated mode choice model, which explicitly considers taste heterogeneity and panel effects, was tested with data collected in different types of cities (urban, rural and insular) of two different countries Greece and Cyprus, enabling comparisons in adolescents' travel behaviour across different geographical areas. The sample consisted of 9554 adolescent who yielded 20,432 SP responses for model estimation. Our results show that the prevalent factors affecting bicycle choice differ across different types of cities. Bad weather conditions affect the most the choice of bicycle in urban areas, while the most significant variable for rural areas is the percentage of cycleway coverage in the route between home and school. The availability of bicycle parking spaces at the schoolyard and the availability of school courses regarding how to walk and cycle with safety, also increased the bicycle utility in all five areas considered. Finally, three policy scenarios were tested to investigate modal split under various cycling policies.

1. Introduction

Half of the trips in urban areas of developed countries can be completed within a 20-min bike ride, while a quarter of the trips are within a 20-min walk (ATFA, 2009). At present, the vast majority of these short trips are done using motorized vehicles. However, trends are changing and the latest reports show that the "future belongs to walking and cycling" (Davis, Dutzik, & Baxandall, 2012; World Bank, 2008). They also show that the bicycle is the most common transport mode for the younger age groups, while statistics from European countries (EU Commission, 2015) show that young children walk the most, whereas somewhat older children (12–18 years of age) cycle the most.

Active transport is the missing piece in our transport system. Walking and bicycling can improve public transport by providing quick access to the destination. Given the availability of a safe and convenient infrastructure and the right built environment, more people would choose walking or bicycling for short trips. Savings in fuel costs, a smaller carbon footprint, and being a practical way to achieve recommended levels of physical activity, stand among the benefits that make active transport an attractive all-in-one package (ATFA, 2009). Due to the fact that transportation is a routine in which we all engage, active transport has great potential to increase our level of physical activity and help reverse current obesity trends, especially amongst children (Strong et al., 2005).

Although the advantages of cycling seem obvious, cycling needs encouragement in order to take place in urban environments - both in terms of promotion of cycling as a life style as well as in terms of providing appropriate physical conditions for cycling. If cycling facilities are provided at the right places and designed in an appropriate manner for each type of city (Flugel, Ramjerdi, Veisten, Killi, & Elvik, 2015; Krizek & Roland, 2005; Lachance-Bernard, Produit, Tominc, Niksic, & Golicnik Marusic, 2013; Tilahun, Levinson, & Krizek, 2007; Winters, Brauer, Setton, & Teschke, 2010; Winters, Davidson, Kao, & Teschke, 2011), people will more likely decide to use them on daily bases.

Against this background, the research on active commuting has expanded rapidly but the majority of studies refer to adults and elementary students by analysing data about their parents' activities leaving the adolescent age group's travel behaviour under-examined (Emond & Handy, 2012). Teenagers are a special age

E-mail address: m.kamargianni@ucl.ac.uk.

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group, and due to the rapid technological adaptation and the changes in socioeconomic characteristics of developed countries, their generation (Generation Y) exhibits completely different travel behaviour to that of Baby Boomers (Axhausen, 2013; Davis et al., 2012; Kamargianni, Ben-Akiva, & Polydoropoulou, 2014) and they consciously choose cycling as a lifestyle.

With these points in mind, the aim of this paper is to investigate the factors that affect the choice of cycling among the adolescent age group. By promoting cycling to school, there are both high possibilities to alleviate the morning traffic recorded around schools and also to develop the desired environmental friendly travel behaviour, which could be retained in their adulthood as well. For this purpose a stated preference (SP) survey was conducted in three Greek and two Cypriot cities, referring only to high-school students between 11 and 18 years old. A mode choice model was estimated for each city aiming to investigate the factors that affect the choice of cycling to school and the modal split under various policies. Furthermore, a comparison among the areas was conducted to investigate the differences or similarities among various built-environment schemes. The total sample consisted of 9554 adolescent students, who yielded 20,432 SP observations for model estimation.

The innovation of this research covers several topics. First of all, to our knowledge it is the first time that such a large-scale survey on travel behaviour, focussing only on teenagers (11–18 years old) and collecting SP data, has taken place. Secondly, the questionnaire used for collecting the data was designed specifically to investigate teenagers' perceptions of travel behaviour, by a multidisciplinary team of transport planers, psychologists and economists, with the aim of approaching the multi-dimensional nature of this transport problem in depth. Finally, data was collected from different types of cities in two countries, in order to compare travel behaviour among urban, rural and insular areas.

The remainder of the paper is structured as follows. Section 2 reviews the literature. The case study and the sample's descriptive statistics are presented in Section 3, while Section 4 presents the model estimation results and the model application. Section 5 concludes the paper by providing a summary of the findings, implications for policy and suggestions for further research.

2. Literature review

The increased dependence of households and individuals on private motorized transport modes has contributed to growing traffic congestion, air quality degradation (due to increased vehicle source emissions), and increased energy consumption (Litman & Laube, 2002; Saelens, Sallis, & Lawrence, 2003; Schipper, 2004; Schrank & Lomax, 2005). As a result, contemporary urban planners promote cycling as one of the most appropriate urban mobility alternatives as it is environmentally friendly, its facilities require less space and the activity itself has positive impacts on health (Sallis, Frank, Saelens, & Krafts, 2004).

Driven largely by this situation, research on bicycle related issues has expanded rapidly during the last few years. Thus, there is a substantial body of literature, which directly or indirectly investigates the effects of bicycle facilities availability and design attributes, on mode choice behaviour and bicyclist route preferences. These studies state the importance of providing adequate cycling facilities, such as bicycle paths and lanes, parking space availability, off-road and in-traffic facilities, and widely use SP data (Bhat, 2015; Dill & Carr, 2003; Garrard, Geoffrey, & Sing Kai, 2008; Kamargianni and Polydoropoulou, 2013b; Ortúzar, Iacobelli, & Valeze, 2000; Pucher & Buehler, 2008; Sener, Eluru, & Bhat, 2009).

The majority of these surveys investigate the improvements of cycling conditions using route choice experiments, while they mainly focus on the preferences of current cyclists (Wardman, Tight, & Page, 2007). For example, Stinson and Bhat (2003) used a web based SP survey to find out that respondents preferred bicycling on residential streets to non residential streets (due to the low traffic volumes on residential streets), while the most important variable in route preference was travel time. Taylor and Mahmassani (1996) also using SP data, showed that bike-lanes provided greater incentives to inexperienced cyclists (defined as those with a "stated low to moderate comfort levels riding in light traffic") as compared with more experienced cyclists; in fact, the latter group did not show a significant preference for bike-lanes over wide curb lanes. Abraham et al. (2004) also investigated cyclists' route preferences using an SP survey. Their model results showed that cyclists prefer off-street cycling facilities and low-traffic residential streets, whilst the authors claimed that this could have been due to an incorrect perception of safety on the part of respondents, and that education about the safety of off-road facilities could change their stated choices. Tilahun et al. (2007) investigated individual preferences for five different cycling environments finding out that respondents were willing to travel up to twenty min more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes associated with less dramatic improvements.

While there is significant work on cycling route choice experiments, mode choice studies which include bicycling as an alternative are limited; the vast majority of urban mode choice studies do not extend the choice set to include cycling. Indicatively, Ortúzar et al. (2000) studied the use of bicycles as an alternative mode of transport in Santiago using an SP experiment, where participants were called to choose between car and bicycle. Their mode choice model verified that trip length was a fundamental variable for choosing bicycle, and they indicated that there were sectors of the city where bikes could capture more than 10% of the trips, and that, on average, the use of bicycles could jump from its current 1.6% then to approximately 5.8%. Wardman et al. (2007) estimated a model combining revealed preference (RP) and SP data to forecast trends in urban commuting shares over time and to predict the impacts of different measures to encourage cycling. Of the en-route cycle facilities, a completely segregated cycle-way was forecast to have the greatest impact, but even the unfeasible scenario of universal provision of such facilities would only result in a 55% increase in cycling and a slight reduction in car commuting. Payments for cycling to work were found to be highly effective with a £2 daily payment almost doubling the level of cycling. The authors concluded that the most effective policy should combine improvements in en-route facilities, a daily payment to cycle to work and comprehensive trip end facilities, and this would also have a significant impact on car commuting.

Only recently, mode choice surveys have included the bicycle as an alternative. Dell'Olio, Ibeas, and Bordagaray, & Ortúzar (2014) estimated a mixed logit model with three transport alternatives (car, bus, bicycle) using data collected in a medium-sized Spanish city (Santander). Their results indicate that the most important variables among potential users were the cost and the climate, followed by the availability of infrastructure such as cycle paths and an extensive network of both public and private bicycle docking stations. Akar, Fischer, and Namgung (2013) investigated the gender differences in bicycle choice for commuters to the Ohio State University. Their results verified, once again, that people are sensitive to travel time particularly for non-motorized modes and that "feeling safe" is positively associated with bicycling choice.

However, the existing literature focuses mainly on adult's mode choice behaviour and no surveys using SP data and focussing on teenagers cycling behaviour to school have been identified. The investigation of this age group's mode choice and cycling behaviour

can have high significance. As they have not shaped their travel behaviour habits yet, the identification of the factors that affect their travel behaviour could provide significant insights for developing the desired patterns that encourage physical activity early in life and that may be carried on into adulthood, while they are likely to positively influence current and future health. Cycling is one such behaviour, and the journey to school provides an opportunity for increasing daily physical activity and potentially reducing dependence on the car for transporting children. This paper aims to investigate adolescents' mode choice behaviour, with a particular focus on cycling behaviour, using SP data. Further, the model estimation results will be used for policy analysis.

3. Survey

3.1. Questionnaire design

A questionnaire that takes into account the special needs of adolescents was specifically designed for the purposes of this survey (Kamargianni, 2014; Kamargianni and Polydoropoulou, 2013a). The questionnaire and SP experiments were designed using Sawtooth software and were made available both on-line and in paper format. The SP scenarios were designed and tested to ensure that all attributes of the alternatives were clear to teenagers. At this point, it is worthwhile to comment that even though the cost of travelling by car is not covered by teenagers but by their parents, this key variable was completely understood by the participants in our experiments. After numerous pilot designs, we settled on the scenarios presented in Table 1.

The scenarios have five alternative modes for the trip to school: Car, Powered Two Wheelers (PTW)/motorcycles, Bus, Walk and Bicycle. The number of alternatives shown to participants was adaptive to their mode availability (customized choice set); for example, if a teenager had no access to PTW, that alternative was not shown. The modal attributes were: travel time (specific to all modes), travel cost (specific to car, PTW and bus), parking place availability (specific to PTW and bike), walking time from home to bus stop (specific to bus), existence of cycle lanes/cycle ways (specific to bike), walkability/condition of sidewalks (specific to walk), availability of safety courses at school regarding cycling and walking (specific to walk and bicycle) and weather conditions. To avoid misperceptions and to ensure that the values of the latter three attributes were clear and understandable to all participants, we used pictures of actual wide and narrow sidewalks, cycle lanes and cycle ways, and weather conditions; these were presented followed by a short description before presenting the choice scenarios.

Scenarios were designed using near-orthogonality and ensuring attribute level balance (Johnson et al., 2013). The conditions for orthogonality were controlled through the incorporation of restrictions on implausible combinations (for example, the PTW travel cost could not be higher than the car travel cost). After selecting the attributes, attribute levels and incorporating the restrictions, we generated 600 different scenarios, where the order of the attributes was randomized. Each participant was presented with two SP scenarios in Cyprus and four SP scenarios in Greece. As participants had to fill in the questionnaire during their informatics lessons (35 min in Cyprus and 45 min in Greece), we did not have time to present more scenarios to the participants as advised by the literature (Louviere, Hensher, & Swait, 2000; Ortuzar & Willumsen, 2011).

3.2. Case study – data collection

Data collection took place in Greece from January to May 2013 and in Cyprus in February 2012. The research team, in cooperation with the Secondary Education Departments of each Greek area, worked together closely to define the sample of schools and grades (years) from each school that would be asked to participate in the survey, to obtain a representative sample of each area (Kamargianni & Polydoropoulou, 2014). In Cyprus, the Ministry of Education forwarded the electronic version of the questionnaire to all high schools in the country. During data collection in Greece, the researchers visited the schools to assist with any questions regarding the completion of the questionnaire. If the school gave the research team access to the informatics classroom, the online version was used; otherwise we used the paper questionnaire. Cypriot students filled-in the web-questionnaire during the

Table 1
SP design.

	Car (escorted by parents)	Motorcycle	Bus	Walk	Bicycle
Travel time (in minutes)	Actual travel time by car multiplied by ±10%,±30%	Actual travel time by PTW multiplied by ±10%,±30%	Actual travel time by bus multiplied by ±10%,±30%	Actual walking travel time multiplied by ±10%,±30%	Actual travel time by bicycle multiplied by ±10%,±30%
Travel cost (in Euro)	1, 1.5, 2, 2.5, 3, 3.5, 4, 5	1, 1.5, 2, 2.5, 3	0, 0.5, 1.0, 1.5, 2	–	–
Parking spaces at school yard	–	Available, Not available	–	–	Available, Not available
Walking time to the bus stop (in minutes)	–	–	2, 3, 5, 7, 10, 12	–	–
Bikepaths	–	–	–	–	Not available, Cycle-lanes available at the: - 1/3 of the route; - 2/3 of the route, - whole route, Cycle-ways available at the: - 1/3 of the route; - 2/3 of the route; - whole route
Walkability/Sidewalks	–	–	–	–	Wide sidewalks available at the: - 1/3 of the route; - 2/3 of the route, - whole route,
Safety school courses	–	–	–	Available, Not available	Available, Not available

informatics lesson with the supervision of their teachers, who had received extra guidance to assist with any questions regarding its completion.

The survey in Greece took place in three different geographical areas, while in Cyprus it was done in the whole country. Eight public high schools from the greater Athens area (urban area–1226 participants), six high schools in Alexandroupolis (rural town-875 participants) and eight high schools in Chios (insular area – 1023 participants) participated. The schools in the Athens area are in the Peristeri neighbourhood (from now on, we will refer to this area as Athens). The total sample in Cyprus consisted of 10,194 participants from its five main cities. However, for the purposes of this paper, we used only the sample from two cities (urban areas), Nicosia (3772 participants) and Limassol (2648 participants). We chose Nicosia, as it is the capital of Cyprus; although it has a bike-sharing system, only one cycle way, of 1.4 km, is available in the north-east border of the city. As this area is not residential and there are no schools, in general the cycle way cannot be used by students for their transport to school (the cycle lanes in Nicosia serve only two out of 28 high schools). We chose Limassol, as it is the only Cypriot city with cycle lanes; these mainly cover the coastal route of the city and some central roads. The characteristics of each city are briefly described in Table 2.

The characteristics of the participants from each area are presented in Table 3. The total sample consists of 9554 students of public high schools. The average age was 15.7 years and 52% were girls. The average number of trips in a typical school day is above 4.0 in all areas. The mode use patterns significantly differ between the two countries and across the urban, rural and insular areas. The most popular transport mode to school for Greek teenagers is walking, while for Cypriots is the private car (escorted by their parents). Also, significant heterogeneity is noticed in bicycle ownership rates. More than half of the Greek participants own a bike, while in Cyprus the figure is less than half. In the rural areas where cycle ways are available, 84% of participants owned a bike. The highest frequency of bicycle use was noted in Alexandroupolis; teenagers use their bikes an average of 6.8 times per week. The maximum cycling distance also varies across cities. The maximum cycling distance was recorded in urban areas (3.2 km).

4. Mode choice model

4.1. Model specification

We estimated mode choice models for each city; in Athens we had available 4904 observations, in Alexandroupolis 3500 observations; 4092 observations in Chios (GR), 7544 observations in Nicosia and 5296 SP observations in Limassol. The alternatives were:

1 Car (Athens: 24%, Alexandroupolis: 20%, Chios: 26%, Nicosia: 41%, Limassol: 41%)
2 PWT (Athens: 8%, Alexandroupolis: 12%, Chios: 21%, Nicosia: 6%, Limassol: 3%)
3 Bus (Athens: 25%, Alexandroupolis: 14%, Chios: 14%, Nicosia: 18%, Limassol: 14%)
4 Walk (Athens: 21%, Alexandroupolis: 22%, Chios: 19%, Nicosia: 15%, Limassol: 18%)
5 Bicycle (Athens: 28%, Alexandroupolis: 32%, Chios: 20%, Nicosia: 20%, Limassol: 24%)

There were two specification issues with the collected data. The first was that a simple logit may not be an appropriate model because of the potential correlation of the error terms of the car and PTW alternatives, and of the walk and bicycle alternatives. The second was that each teenager in Greece was presented with four experiments, while teenagers in Cyprus with two. Thus, the responses across experiments of the same individual are likely to be correlated. These issues can be addressed by incorporating error components in a logit mixture model for panel data (Walker, Ben-Akiva, & Bolduc, 2006).

In doing so the utility function associated with each alternative, was specified as:

$$U_{\text{int}} = \sum_{k=1}^{K} X_{\text{int}k}\beta_{kn} + \sigma_i\eta_n + \varepsilon_{\text{int}} \tag{1}$$

where i is the alternative, n is the individual, t denotes the choice experiment, X_{int} are vectors of the explanatory variables. The correlation among alternatives (nesting structure) and correlation across responses from an individual (panel effect) are captured by the error components η_n which are distributed *iid* Normal (0,1) across individuals n but remain constant within responses t from a given individual (see Train, 2003; Walker et al., 2006). The estimated parameters are the vectors β_{kn} and scalars σ_i.

The likelihood for the t responses of an individual i is given by:

$$P(i_t|X_n;\beta_k,\sigma_i) = \int \prod_{t=1}^{T} P(i_t|X_{nt},\eta_n;\beta_k,\sigma_i)f(\eta_n)d\eta_n \tag{2}$$

This is the product over the T responses of the logit probability of each individual response i_t conditional on the unknown η_n, $P(i_t|X_{nt},\eta_n;\beta_k,\sigma_i)$, and the product is integrated over the distribution of η_n. $f(\eta_n)$ is a multivariate normal with mean vector of zeros and covariance matrix equal to a identity matrix.

In our case the utilities of each alternative were specified as in equations (3)–(7). The utility of choice is a function of attributes of the alternatives. The deterministic utility contains the attributes of the experiments, the socioeconomic characteristics of the participants, as well as alternative specific constants for the alternatives Car, Bus, Walk and Bicycle.

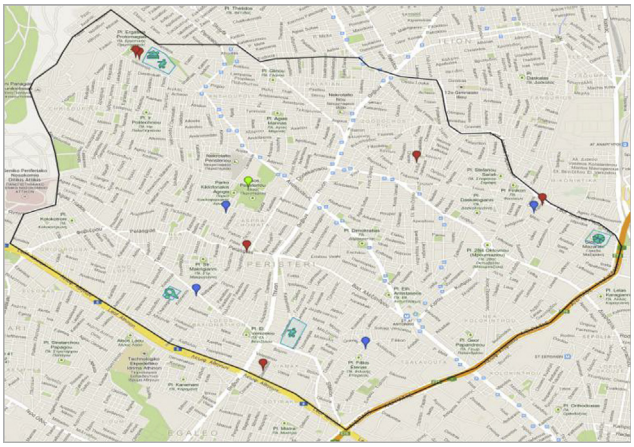
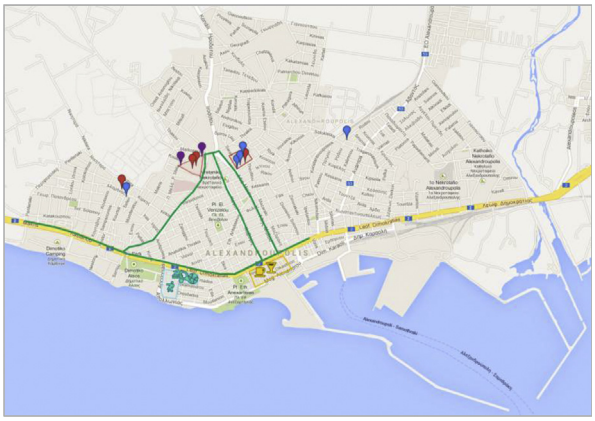
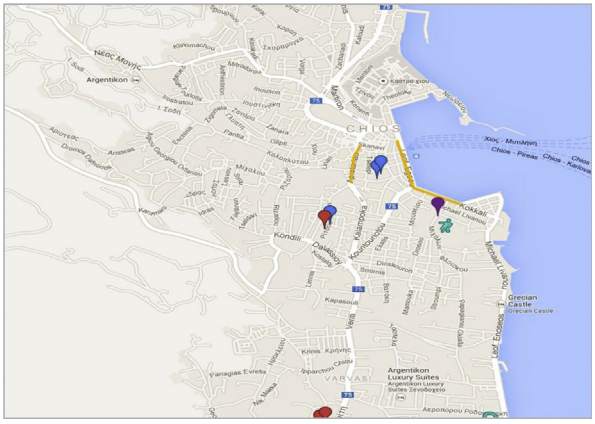
$$\begin{aligned} U_{nt}^{car} &= \beta_{\text{car}} + \beta_{ttcar}{*}TTCAR + (\beta_{tccar} + \beta_{pm1}{*}POCKMONEY){*}TCCAR \\ &\quad + \beta_{age1}{*}AGE1518 + \beta_{gen1}{*}FEMALE + \sigma^{priv}\eta_n^{priv} + \varepsilon_{nt}^{car} \end{aligned} \tag{3}$$

$$\begin{aligned} U_{nt}^{ptw} &= \beta_{ttptw}{*}TTPTW + (\beta_{tcptw} + \beta_{pm2}{*}POCKMONEY){*}TCPTW \\ &\quad + \beta_{pptw}{*}PPTW + \beta_{gen2}{*}FEMALE + \sigma^{priv}\eta_n^{priv} + \varepsilon_{nt}^{ptw} \end{aligned} \tag{4}$$

$$\begin{aligned} U_{nt}^{bus} &= \beta_{ttbus}{*}TTBUS + (\beta_{tcbus} + \beta_{pm3}{*}POCKMONEY){*}TCBUS \\ &\quad + (\beta_{wtbus} + \beta_{wbus}{*}WEATHER){*}WTBUS + \sigma^{bus}\eta_n^{bus} + \varepsilon_{nt}^{bus} \end{aligned} \tag{5}$$

$$\begin{aligned} U_{nt}^{walk} &= \beta_{walk} + \beta_{ttwalk}{*}TTWALK + \beta_{wsd}{*}SIDEWALKS \\ &\quad + (\beta_{w4} + \beta_{gen4}{*}FEMALE){*}WEATHER \\ &\quad + (\beta_{sc4} + \beta_{esc4}{*}ESAFEC){*}SAFEC + \beta_{age4}{*}AGE1518 \\ &\quad + \sigma^{act}\eta_n^{act} + \varepsilon_{nt}^{walk} \end{aligned} \tag{6}$$

Table 2
Characteristics of the sampled areas.

City – Greece	Characteristics
	Peristeri is located within the greater Athens area, 12 km southwest of Athens' city centre with a total population of 4,013,368. It is a heavily urbanized area with many buildings per km^2. There are narrow, highly congested streets, and parked cars everywhere obstructing road users' visibility. There are high schools in every neighbourhood (blue and red points on the map). Neither bicycle-sharing schemes, nor cycle lanes and cycle ways are available in the area. Population density: 13,928/km^2
	Alexandroupolis is a border coastal city with 72,959 residents surrounded by agricultural fields. The landscape consists of five-storey buildings, wide streets with low traffic levels and generally a low population density. In the city there are four main bicycle corridors depicted in green on the map linking the centre of the city with the high schools. All schools (blue and red points on the map) are situated in the southern part of the city. Population density: 96/km^2
City – Greece & Cyprus	**Characteristics**
	Chios is the fifth largest Greek island, situated in the Aegean Sea. Chios city has a population of 25,671 residents. It has the third highest car per capita ownership in Greece and the highest motorcycle ownership (Hel. Stat., 2011). Narrow streets and pavements, and parked cars that obstruct road users' visibility are a typical landscape. There are high schools in every neighbourhood. Neither bicycle-sharing schemes, nor cycle lanes and cycle ways are available in the area. Population density: 1042/km^2

(*continued on next page*)

Table 2 (*continued*)

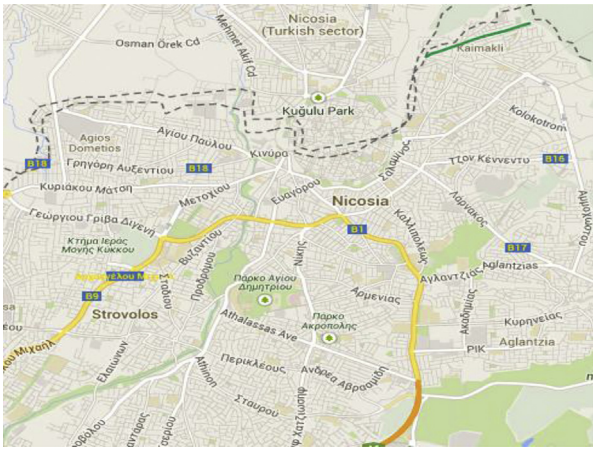
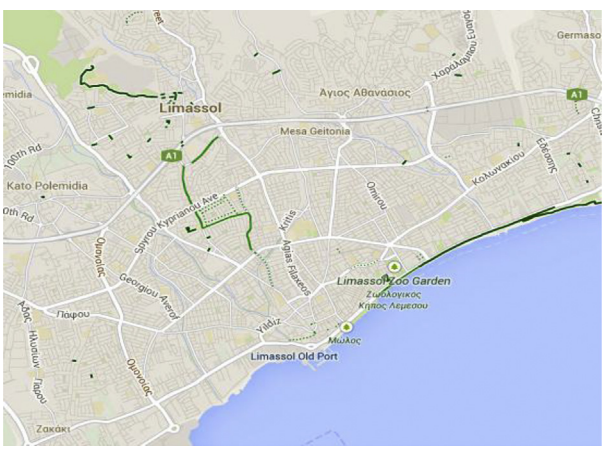
City – Greece	Characteristics
	Nicosia is the capital of Cyprus with a population of 310,355 residents. It is the last remaining divided capital in the world, with the southern and the northern portions divided by a Green Line. The city is ranked as the 5th richest in the world in per capita income terms. It is an urbanized area with many buildings per km^2. There are wide, congested streets, and a lot of parked cars obstructing road users' visibility. The green line on the South-East border of the city depicts the cycle way, while the municipality recently initiated a bike-sharing system at two central points. Population density: 2800/km^2.
	Limassol is the second largest city of Cyprus with a population of 235,000. The landscape consists of wide roads and pavements. It has an extensive bicycle-sharing system that is mainly used by tourists, as the bike-sharing points have been placed mainly at the coastal road and the touristic areas of the city. Since 2010 cycle lanes have also been constructed across the coastal road of the city and in some central roads, which are depicted with a green line on the map. Population density: 2900/km^2.

Table 3
Characteristics of the sample.

		Urban: Athens 1226 partic.	Rural: Alex/polis 875 partic.	Insular: Chios 1023 partic.	Urban: Nicosia 3772 partic.	Urban: Limassol 2648 partic.
Gender	Male	44%	52%	49%	45%	49%
	Female	56%	48%	51%	55%	51%
Age		16.4	15.0	15.6	15.8	15.3
Pocket money (Euro/day)		2.2	1.6	3.1	6.5	6.9
Own a bicycle		62%	84%	51%	41%	38%
Frequency of cycling (times per week)		2.1	6.8	3.3	1.1	0.8
Mode to school (mode used to go to school the day before participating in the survey)	Walk	36%	39%	34%	22%	16%
	Cycle	2%	21%	2%	2%	0%
	Public transport	30%	12%	20%	38%	33%
	Driver	3%	4%	13%	3%	1%
	Escorted by parents	29%	24%	31%	35%	50%
Maximum walking distance to school (in km)		1.3	2.5	1.6	2.1	2.0
Maximum cycling distance to school (in km)		1.9	3.2	1.8	1.4	1.6
Average number of trips (per school-day)		4.2	4.4	4.9	4.0	4.2
Household income (Euros/month)	Low (<€2000)	34%	40%	23%	22%	26%
	Medium (€2000–4000)	26%	29%	31%	29%	21%
	High (>€4000)	19%	17%	29%	27%	27%
	Not available	21%	14%	17%	22%	26%
Car ownership		2.3	1.7	1.8	3.6	3.8
Motorcycle ownership		0.9	0.7	1.4	0.9	0.6

$$U_{nt}^{bike} = \beta_{bike} + \beta_{ttbike}*TTBIKE + \beta_{psb}*PSBIKE + \beta_{bpb}*BIKELANE + \beta_{bwb}*BIKEWAY + (\beta_{wbike} + \beta_{gen5}*FEMALE)*WEATHER + \beta_{sc5}*SAFEC + \beta_{pm5}*POCKMONEY + \beta_{age5}*AGE1518 + \sigma^{act}\eta_n^{act} + \varepsilon_{nt}^{bike} \quad (7)$$

where *TTCAR* is travel time by car (min); *TCCAR* travel cost by car (Euro); *TTPTW* travel time by PTW (min); *TCPTW* travel cost by PTW (Euro); *PPTW* availability of PTW parking spaces at school (it takes the value 1 if there is parking place available, 0 otherwise); *TTBUS* travel time by bus (min); *TCBUS* travel cost by bus (Euro); *WTBUS* travel time from/to bus stop (min); *TTWALK* travel time on foot (min); *SIDEWALKS* existence of wide sidewalks across the route between home and school (continuous); *TTBIKE* travel time by bicycle (min); *PSBIKE* availability of bicycle parking spaces at school (it takes the value 1 if there is parking place available, 0 otherwise); *BIKELANE* existence of cycle lanes across the route between home and school (continuous); *BIKEWAY* existence of cycle ways across the route between home and school (continuous variable); *SAFEC* availability of school courses regarding walking and cycling with safety (t takes the value 1 if the course is available, 0 otherwise); *WEATHER* weather conditions (it takes the value 1 if it is a sunny day, 0 if it is a rainy day); *AGE1518* takes the value 1 if the participant is from 15 to 18 years of age, 0 otherwise; *FEMALE* takes the value 1 if the participant is female, 0 otherwise; *POCKMONEY* indicates the daily pocket money of the participants (continuous); σ^{priv} parameters that accounts for correlation between the private motorised modes (car and PTW) among observations from the same individuals in the data set; σ^{bus} parameter that captures the taste heterogeneity for bus and the panel effect among observations from the same individuals in the data set; σ^{act} parameters that account for correlation between active transport modes (walk and bike) among observations from the same individuals in the data set; $\eta_n^{priv}, \eta_n^{bus}, \eta_n^{act}$ are error components that capture the correlation among the alternatives (nesting structure) and the correlation across responses from the same individual (panel effect) and are distributed *iid* Normal (0,1) across individual *n*, but remain constant within responses *t*; $\varepsilon_{nt}^{car}, \varepsilon_{nt}^{ptw}, \varepsilon_{nt}^{bus}, \varepsilon_{nt}^{walk}, \varepsilon_{nt}^{bike}$ distribute *iid* Extreme Value across all individuals *n* and responses *t* and are independent from $\eta_n^{priv}, \eta_n^{bus}, \eta_n^{act}$.

Several variables and interaction terms among them were tested to obtain the final model. For example, we tested bicycle, and household car and PTW ownership. In the place of the variable pocket money in equations (3)–(5) and (7), we also tested the variable household income. Nevertheless, due to the fact that a significant percentage of the latter variable was missing, combined with the fact that teenagers did not usually know their exact household income, we preferred to use the variable pocket money (which is usually related with family income). We also tested alternative functional forms for variables such as age and pocket money, including a logarithmic effect, piecewise linear effects, and dummy variables for different ranges. Of these, the dummy variable specification for the specific range of age (15–18) and continuous pocket money worked out as the best specification.

Moreover, we carefully examined and filtered the sample, in order to put constraints on the options available to certain students. For example, students living at more than the maximum walking distance to school identified for each city (see Table 2) were not given the option of selecting walk. In the same way, teenagers that lived further away than the maximum cycling distance to school identified for each city (see Table 2) were not given the option of selecting cycling. The car option was available to all participants, as all households owned at least one car. The PTW alternative was available only to the teenagers that stated they had access to a PTW either as drivers or passengers.

The likelihood function for the aforementioned mode choice model is:

$$P(i_t|X_n;\delta) = \int \prod_{t=1}^{T} P(i_t|X_{nt}H;\delta) f(H) dH \quad (8)$$

where δ designates all the unknown parameters to be estimated ($\delta = \{\beta_k, \sigma^{priv}, \sigma^{ptw}, \sigma^{act}\}$), *H* designates all the η_n error components ($H = \{\eta_n^{priv}, \eta_n^{bus}, \eta_n^{act}\}$). The product over the *T* responses of the logit probability of each individual response i_t conditional on the unknown θ, $P(i_t|X_{nt},H;\delta)$, and the product is integrated over the distribution of *H*. Finally, $f(H)$ is a 3-dimensional multivariate normal with 3×1 mean vector of zeros and covariance matrix equal to a 3×3 identity matrix.

4.2. Model estimation results

This section presents and discusses the estimation results of the choice model. We first estimated a multinomial logit (MNL) model for each area, that served as base model. Due to the specification issues of the collected data that were discussed in the previous subsection, we incorporated to the MNL three error components, creating a mixed logit (MMNL) model. Both models were estimated using Pythonbiogeme, version 2.3 (Bierlaire & Fetiarson, 2009). The number of draws was set to 20,000. Due to space limitation, in Table 4 we present only the estimation results of the MMNL for all the cities in our sample.

As expected, the signs for the coefficients of travel time, travel cost and walking to the bus stop time are negative in all cases. These imply that increases in the values of these variables for an alternative mode reduce the utility of that mode and the probability that it will be chosen. Also, the taste heterogeneity parameters indicate that there is correlation between car and PTW (private motorized modes) and between walk and bicycle (active transport modes).

The model's estimation results indicate that there are significant differences among the three Greek geographical areas (urban, rural, insular areas), while the results for the two Cypriot cities are quite similar. Moreover the results of Nicosia and Limassol are quite similar to those of Athens, indicating that the mode choice behaviour in urban areas is affected by approximately the same factors in the same way. The results of the models for Alexandroupolis and Chios indicate that the mode to school choice behaviour of teenagers in rural and insular areas is different from those in urban areas.

For all areas, as teenagers' pocket money (Euros/day) increases, they are more likely to choose private motorized vehicles (car and PTW) for their transport to school. This variable is statistically significant for all models except Alexandroupolis' (rural area). This variable was also interacted with travel cost and the positive sign indicates that even if the travel cost increases, teenagers with higher pocket money still prefer private motorized vehicles. Pocket money was also interacted with the travel cost of bus, where the negative sign indicates that even if the cost of bus increases, teenagers with higher pocket money do not prefer the bus.

The availability of parking spaces for PTW at schools affect positively this choice, but it is statistically significant only in the model for Chios. Teenagers in this area widely use PTW for all their trips, thus they give particularly attention to this facility. In addition, females prefer being escorted by car, rather than walking and cycling to school, a fact that is consistent with other surveys (Larsen et al., 2009; Mota et al., 2007). The sign of the gender variable

Table 4
Model estimation results.

	Athens (urban)		Alexandroupolis (rural)		Chios (insular)		Nicosia (urban)		Limassol (urban)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
β_{car}	−1.62	−7.18	−1.29	−6.56	−1.03	−2.12	−0.92	−3.31	−1.31	−0.12
β_{bus}	−1.13	−2.94	−4.40	−11.22	−1.89	−3.53	−4.89	−10.14	−4.97	12.33
β_{walk}	−3.84	−5.99	1.66	−2.03	−5.76	−6.60	−3.09	−14.00	−2.78	−15.05
β_{bike}	−3.57	−4.96	1.29	3.17	−1.29	−5.37	−2.51	−13.17	−2.98	−13.60
Travel time – Car	−0.06	−11.58	−0.68	−6.56	−0.28	−5.96	−0.07	−15.96	−0.06	−15.07
Travel cost – Car	−0.21	−2.23	−0.11	−2.81	−0.26	−5.42	−0.26	−2.42	−0.26	−5.42
Age 15–18 years old – Car	−0.39	−1.86	−0.22	−0.68	−0.19	−0.84	−0.13	−2.41	−0.13	−0.84
Female – Car	0.59	3.41	1.11	5.58	2.25	8.62	0.66	3.62	0.82	4.23
Pocket money – Car	0.001	2.40	0.01	1.03	0.03	4.94	0.01	2.26	0.001	2.60
Travel time – PTW	−0.25	−13.31	−0.24	−11.53	−0.28	−16.95	−0.21	−16.81	−0.35	−15.85
Travel cost – PTW	−0.39	−3.66	−0.58	−4.90	−0.34	−3.24	−0.45	−3.24	−0.41	−3.59
Parking availability – PTW	0.10	1.78	0.21	1.56	0.31	3.21	0.08	1.21	0.12	1.18
Female – PTW	−0.26	−3.35	0.52	2.44	−1.61	−5.94	−0.20	−3.00	−0.28	−2.04
Pocket money – PTW	0.01	2.14	0.02	2.49	0.34	5.67	0.01	2.89	0.015	2.24
Travel time – Bus	−0.06	−10.05	−0.05	−10.69	−0.12	−7.99	−0.07	−9.68	−0.04	−10.01
Travel cost – Bus	−0.43	−3.23	−0.46	−2.40	−0.33	−5.77	−0.46	−3.77	−0.41	−3.19
Walking time to bus stop – Bus	−0.04	−1.74	−0.05	−4.22	−0.08	−4.88	−0.51	−4.39	−0.05	−5.25
Weather – Bus	−0.009	−1.89	−0.02	−1.36	−0.03	−2.45	−0.01	−2.23	−0.01	−2.05
Pocket money – Bus	−0.04	−4.26	−0.07	−3.81	−0.14	−7.81	−0.06	−3.68	−0.11	−3.34
Travel time – Walk	−0.01	−2.82	−0.01	−2.36	−0.21	−2.01	−0.12	−3.81	−0.01	−2.86
Wide sidewalks – Walk	0.43	7.18	0.53	4.21	0.43	7.21	0.32	5.72	0.49	4.11
Safety course – Walk	0.87	6.12	0.45	2.74	0.56	3.45	0.61	2.65	0.46	2.98
Weather – Walk	1.16	13.56	1.03	2.12	1.25	14.97	0.99	12.52	1.34	11.53
Female – Walk	−0.79	−7.37	−0.42	−1.95	−0.72	−6.85	−0.89	−8.64	−0.82	−9.45
Age 15–18 years old-Walk	0.47	2.18	0.73	4.12	0.64	1.09	0.23	1.87	0.56	2.54
Travel time – Bike	−0.04	−7.32	−0.05	−3.81	−0.22	−8.62	−0.05	−7.80	−0.04	−6.93
Parking availability – Bike	0.24	5.85	0.26	6.15	0.34	4.12	0.46	7.56	0.57	8.24
Cycle lane – Bike	0.35	3.92	0.22	4.75	0.45	2.76	0.51	4.05	0.62	6.09
Cycle way – Bike	0.89	7.83	1.23	12.46	0.72	8.21	0.67	8.24	0.78	9.89
Safety course – Bike	0.53	6.12	0.44	6.56	0.74	8.62	0.29	7.38	0.26	9.46
Weather – Bike	0.92	11.11	0.88	1.76	0.92	9.60	1.02	12.60	0.93	11.80
Female – Bike	−0.61	−5.77	−0.56	−6.53	−0.58	−5.34	−0.54	−7.80	−0.81	−5.97
Age 15–18 years old – Bike	0.60	6.58	0.59	5.44	0.24	2.34	0.15	6.91	0.37	4.86
Pocket money – Bike	−0.02	−1.34	0.05	1.92	−0.65	−1.57	−0.63	−2.37	−0.34	−0.84
σ^{priv}	3.12	10.13	2.52	12.27	5.31	14.82	3.64	12.67	3.85	10.58
σ^{bus}	4.12	9.05	6.71	12.53	6.03	15.53	7.70	20.34	6.38	22.85
σ^{act}	4.56	12.84	4.39	16.38	3.06	15.64	3.96	13.50	4.86	13.75

specific to PTW, indicates that females from all areas (except Alexandroupolis), do not prefer this transport mode. The gender sign of the rural areas' model indicate that females prefer motorcycles. As this result is contrary to our expectations, we further examined the characteristics of the actual PTW drivers in the rural area and found out that the majority of them were females; this fact, in combination with the results of other surveys (that indicate that, in general, females prefer private motorized vehicles instead of active transport, Kerr et al., 2006; Clifton, 2003; Timperio et al., 2006) made us accept this sign.

As this paper elaborates on the factors that affect the choice of cycling to school, particular focus will be placed on the choice of bicycle among the five geographical areas. As travel time to school by bicycle increases, teenagers from all areas avoid choosing bicycle. This variable has approximately the same statistical significant in all areas, except the rural one. Also, as the coverage with cycle lanes and cycle ways across the route between home and school increases, teenagers are more likely to choose cycling to school. However, the significance of the cycleways is substantially higher, indicating that the availability of cycleways would attract more adolescent cyclists. Undoubtedly cycleways are safer than cycle lanes (Ortúzar et al., 2000), so it is logical that the availability of them increases even more the utility of bicycle. Additionally, this variable has the highest significance in the model of Alexandroupolis, where there are already cycleways that link the centre of the city with the high schools. Also, the cycleways variable is the most significant one in the utility of bicycle in the Alexandroupolis' model, indicating that this is the factor that affects the choice of bicycle in the rural area the most. As these teenagers are familiar with cycleways, they appreciate even more their existence and a wider coverage of the city with cycleways would further boost the choice of cycling to school. Also, this variable has a high t-test in the model of Limassol, where there are cycleways and adolescents are also familiar with this facility. However, the constructed cycleways in Limassol serve more the touristic areas of the town rather than the schools. An expansion of the cycleways network would favour even more the choice of students to cycle to school.

The availability of bicycle parking spaces at the schoolyard also favours the choice of bicycle. It is important for adolescent students to have a place to park and lock their bikes during school hours. The availability of school courses regarding how to walk and cycle with safety also increases the utility of the bicycle alternative for the five areas, indicating how significant it is for participants to be taught about these issues and, in doing so, to obtain bicycle safety skills. A finding that is consistent with previous surveys is that weather conditions affect the choice of cycling (Gallop et al., 2012). Good weather (sunny day) is the factor that affects the utility of bicycle

the most in all areas, with the exception of Alexandroupolis. As 45% of the data from this city were collected in January 2013, when the average temperature was −12 °C, we further enquired about the transport mode that teenagers actually used for their transport to school. Despite low temperature and bad weather conditions, 16% of participants chose to cycle to school, while 29% chose to walk. Thus, the results for the weather variable in the Alexandroupolis' model indicate that sunny weather is not a necessary condition to choose bicycle. On another hand, the weather variable was also interacted with gender with the aim of investigating the behaviour of females. Results indicate that even when the weather is sunny, girls from all areas do not prefer to cycle.

The utility of bicycle also incorporated the daily pocket money of teenagers. In line with many other surveys, which have proven that high income decreases the utility of active transport (see Jara-Díaz and Videla, 1989; Sallis et al., 2004), higher pocket money decreases the utility of cycling to school, but this variable is statistically significant only in the model of Nicosia. The results for rural areas are an exception here. Although the variable was not significant, its sign indicates that even when pocket money increases, teenagers would prefer to bicycle. As recent reports indicate that youths consciously avoid private motorized vehicles (Axhausen, 2013; Davis et al., 2012) and that cycling is a trend and a way of living adopted by youths regardless of their income status, we accept this sign. In addition, since nowadays there is a wide variety of bicycles available in the market, the price of which can reach thousands of Euros/Dollars, we further believe that students from households with higher income levels (i.e. higher pocket money), could choose cycling for other reasons than not being able to afford the cost of travelling by motorized vehicles.

4.3. Policy analysis

The estimated parameters presented in Table 4 were used to identify efficient strategies to promote the use of the bicycle. A policy analysis is conducted on the basis of hypothetical scenarios including the availability of cycleways, cyclelanes, bicycle parking spaces at schoolyards and the introduction of specialised safety courses about cycling at schools. The availability of these facilities should have a positive impact in the choice of bicycle. Although a large number of policy scenarios were tested, due to space limitations we only present here the results of three (Table 5). In Policy 1, we hypothesized that cycleways would cover the whole route between home and school, and that bicycle parking spaces and cycling safety courses would be available at the schools. Policy 2 includes the introduction of safety courses at schools, the availability of parking places at schoolyards and that only one third of the route between home and school would have cyclelanes. Finally, Policy 3 tests the impact of having cycleways in one third of the route, cyclelanes on another third and parking spaces available at schoolyards (i.e. no safety courses available).

Table 6 presents the estimated modal split for the base situation (BS) and under these three policy scenarios. In general, the results indicate that the demand for PTW is barely sensitive to these policy scenarios. This could be explained by the sense of freedom that PTW provide to teenagers. However, the demand for car is significantly reduced in all the three proposed policies.

Policy 1, which presents the ideal situation, has the highest effect on bicycle demand across all the cities: it increases by 7% in all cities, except Chios where it only increases by 5%. Policy 2 also increases the demand for cycling, but its effects are lower in comparison to the other policies; the highest increase under this policy is obtained in Athens (4%); as in this area there are no cycleways or cyclelanes, the availability of a cycleway for one third of the route, in combination with bicycle parking spaces and safety courses, increases more importantly the demand for the bike. Policy 3 has the second highest impact on cycling demand in all cities, i.e. 4–5%, indicating how significant is the construction of cycleways or cyclelanes, even though there are no safety courses at schools.

5. Conclusions

The aim of this paper was to investigate the factors that affect the choice of cycling to school among the adolescent age group from five distinct geographical areas and to forecast the modal split under various policy scenarios, which hypothetically favour the choice of cycling. By promoting cycling to school, there are both high possibilities to alleviate the morning traffic usually recorded around schools and also to develop a (desirable) green travel behaviour, which might be retained through adulthood.

For these purposes, a stated preference survey was conducted in three Greek (Alexandroupolis, Athens and Chios) and two Cypriot (Nicosia and Limassol) cities on high-school students aged between 11 and 18 years old. The total sample consisted of 9554 adolescent students who yielded 20,432 SP observations for model estimation. A mixed logit mode choice model, allowing to capture taste heterogeneity and the panel effect inherent to SP data, was estimated for each city with the aim of investigating the factors affecting the choice of cycling to school. In general, our results indicate that each area has its own characteristics that affect mode choice. The model estimation results for the urban areas are quite similar, indicating that mode choice behaviour in such areas is affected by approximately the same factors and in the same way. The results for rural and insular areas, on the other hand, differ significantly from those of urban areas.

Since the aim of our research was to explain cycling behaviour to school, particular focus is placed on this alternative. We found that the variable affecting the most the choice of bicycle for Athens, Chios, Nicosia and Limassol, is weather conditions, with sunny weather clearly favouring the choice of this mode; this is not the case for Alexandroupolis, where the most significant variable is the percentage of cycleway coverage in the route between home and school. The availability of bicycle parking spaces at schoolyards and the availability of safety courses regarding walking and cycling also increase the utility of the bicycle alternative in all five areas.

The results of the estimated models were used for policy analysis. The modal split for the trip to school was predicted for three different policy scenarios. Policy 1, proposing the full coverage of the route between home and school with cycleways, the availability of parking spaces at schoolyards and the availability of safety courses at schools, has the highest impact in favour of cycling in all the cities. Under this policy bicycle usage would increase approximately 7% in all areas.

Since the latest reports indicate that hundreds of thousands of young people have discovered that their transport future belongs to

Table 5
Policy variables.

	Cycle ways	Cycle lanes	Bicycle parking spaces	Cycling safety courses
Policy 1	100% of the route	0% of the route	Available	Available
Policy 2	0% of the route	1/3 of the route	Available	Available
Policy 3	1/3 of the route	1/3 of the route	Available	Not Available

Table 6
Forecast modal splits.

	Athens				Alexandroupolis				Chios				Nicosia				Limassol			
	BS	P1	P2	P3	BS	P1	P2	P3	BS	P1	P2	P3	BS	P1	P2	P3	BS	P1	P2	P3
Car (%)	25	22	24	23	21	19	20	20	24	21	23	21	38	34	36	35	41	38	39	39
PTW (%)	7	6	7	7	14	11	14	13	23	22	23	23	7	5	7	6	5	4	5	4
Bus (%)	26	24	25	25	11	10	11	10	13	12	12	13	20	18	19	18	16	14	15	15
Walk (%)	20	19	18	18	23	22	21	22	16	16	15	15	18	17	17	17	17	16	17	16
Cycle (%)	22	29	26	27	31	38	34	35	24	29	27	28	19	26	21	24	21	28	24	26

cycling, this survey provides significant insights to policy makers for promoting cycling to school among adolescents. Promoting cycling to school could assist the development of healthy travel behaviour (Forsyth & Oakes, 2015), with a high possibility that it is maintained through adulthood.

City planners should also take schools into consideration when deciding where to construct cycleways or cyclelanes. By linking the major origins to schools (destinations) with cycle paths, the morning traffic recorded around schools could be alleviated. The Greek rural city of Alexandroupolis is an example in this sense; cyclelanes have been constructed in order to link not only workplaces with major origins, but also schools. The results of this policy are reflected in the actual bicycle shares of students, which are high in comparison to the other four areas. Also, cost-effective policies at schools, such as the construction of bicycle parking spaces and the initiation of safety courses, could even expand the usage of bicycle among adolescents and school children.

Future work includes the estimation of latent class models for each area in order to investigate issues such as taste heterogeneity among the participants and more detailed policy analysis for specific groups of the adolescent population (i.e. gender, income level etc.).

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