UNIVERSIDAD POLITÉCNICA DE MADRID
ESCUELA TÉCNICA SUPERIOR
DE INGENIEROS DE CAMINOS, CANALES Y PUERTOS

POLITÉCNICA

INTEGRATING BICYCLE OPTION
IN MODE CHOICE MODELS
THROUGH LATENT VARIABLES

DOCTORAL THESIS

BEGOÑA MUÑOZ LÓPEZ

*Ingeniera de Caminos, Canales y Puertos
Máster Universitario en Sistemas de Ingeniería Civil*

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**ESCUELA TÉCNICA SUPERIOR DE INGENIEROS DE CAMINOS,
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BEGOÑA MUÑOZ LÓPEZ

Ingeniera de Caminos, Canales y Puertos
Máster Universitario en Sistemas de Ingeniería Civil

Directors:

Andrés Monzón de Cáceres

Dr. Ingeniero de Caminos, Canales y Puertos

Ricardo Álvarez Daziano

Dr. Economista

Madrid, 2016

POLITÉCNICA

Tribunal nombrado por el Mgfco. y Excmo. Sr. Rector de la Universidad Politécnica de Madrid, el día ___ de _____ de 2016.

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ABSTRACT

Bicycle use can contribute to alleviate problems such as congestion and environmental nuisance in urban areas. In order to develop effective cycling policies it is essential to understand the key factors influencing bicycle use for urban mobility. The special characteristics of the bicycle as a transport mode make it difficult to explain utilitarian bicycling with the traditional explanatory factors for motorised demand. Additional psychological variables are required that take into consideration the subjective value attached to bicycle use. These psychological factors can be quantitatively modelled as latent variables and require special analysis techniques. Therefore, an adequate study of bicycle travel demand requires considering a comprehensive overview of variables and using the right tools.

This doctoral thesis provides knowledge and tools for the proper incorporation of the bicycle as an option in travel demand models. A comprehensive survey of the modelling literature on the choice of the bicycle for utilitarian purposes summarises and assesses the evolution of the explanatory variables and methodologies used. Considering the main role of latent variables to explain bicycle choice identified in the literature review, two types of methodologies were developed to contribute to this line of research. First, the relationship between psychological factors and bicycle use –for the special case of commuting trips– is explored throughout a sequential modelling framework in two urban contexts in Spain: Madrid and Vitoria-Gasteiz. Second, an integrated choice and latent variable model with simultaneous estimation investigates the effect of several bicycle latent variables on mode choice behaviour in Vitoria-Gasteiz (Spain). This new integrated model is used to test several potential transport measures, and particularly soft measures related to bicycle experience that cannot be tested with traditional discrete choice models.

Based on the literature review, a set of questions is proposed as a uniform measurement scale to identify attitudes toward bicycling and recommendations for future research are also presented. Moreover, by applying the proposed methodologies, several latent variables have been identified which appear to play a higher or lower role depending on the cycling context conditions. A set of customised transport policy initiatives is recommended in the light of the research findings.

RESUMEN

El uso de la bicicleta puede contribuir a aliviar problemas de congestión y medioambientales en entornos urbanos. Para desarrollar políticas ciclistas efectivas es esencial entender los factores clave que influyen en el uso de la bicicleta para movilidad urbana. Las características especiales de la bicicleta como modo de transporte hacen difícil explicar su uso con los factores explicativos tradicionales para la demanda motorizada. Variables psicológicas adicionales que tengan en cuenta el valor subjetivo asociado al uso de la bicicleta son necesarias. Estos factores psicológicos pueden modelarse cuantitativamente como variables latentes y requieren técnicas de análisis especiales. Por ello, un adecuado estudio de la demanda de viajes en bicicleta requiere considerar un amplio espectro de variables y del uso de las herramientas adecuadas.

Esta tesis doctoral proporciona conocimientos y herramientas para la adecuada incorporación de la bicicleta como una alternativa en los modelos de demanda de viajes. Una amplia encuesta sobre la literatura de modelización de la elección de la bicicleta como modo de transporte resume y evalúa la evolución de las variables explicativas y de las metodologías usadas. Teniendo en cuenta el papel principal de las variables latentes a la hora de explicar la elección de la bicicleta, identificada en la revisión literaria, se han desarrollado dos tipos de metodologías para contribuir a esta línea de investigación. En primer lugar, la relación entre factores psicológicos y uso de la bicicleta (para el caso especial de los viajes al trabajo/estudio) es explorada a través de un marco de modelización secuencial, en dos contextos urbanos españoles: Madrid y Vitoria-Gasteiz. En segundo lugar, un modelo integrado de elección y variables latentes con estimación simultánea investiga el efecto de varias variables latentes de la bicicleta en la elección de modo en Vitoria-Gasteiz (España). Este nuevo modelo integrado es usado para testar varias medidas de transporte potenciales, y en especial medidas blandas relacionadas con la experiencia ciclista que no pueden ser testadas con modelos tradicionales de elección discreta.

En base a la revisión literaria, se propone una serie de preguntas como escala uniforme de medida para identificar actitudes hacia el uso de la bicicleta, y se presentan recomendaciones para futuras investigaciones. Además, de la aplicación de las metodologías propuestas se identifican varias variables latentes, las cuales juegan un papel mayor o menor dependiendo de las condiciones ciclistas del contexto. Una serie de iniciativas sobre políticas de transporte a medida es recomendada a la vista de los resultados obtenidos.

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1 Introduction

1.1 Background on bicycle use for urban mobility

This thesis focuses on bicycle use for urban mobility. As a non-motorised transport mode, the bicycle can contribute to alleviate problems of congestion and environmental nuisance due to the increasing number of motorised urban trips.

The benefits of bicycle use are undeniable. Direct benefits to the user include mobility, health and safety benefits, and indirect benefits to society refer to fiscal savings, increased livability and decreased externalities (Krizec, 2007). The latter benefit includes bicycle characteristics such as low occupancy of space and environmental benefits due to being a soft mode of transport with no fuel dependency and with no emission of noise, pollutants or greenhouse gases. Considering this supporting evidence, the bicycle could be a real alternative to many of the trips made in cities, with a very positive impact on mobility and its unintended consequences.

Mainly because of the environmental benefits, the bicycle has captured the attention of transport policies focused on sustainable development, throughout the world but especially in Europe (Alegre and Carbonell, 2015; Pucher et al., 2010; Yang et al., 2010). The European Green Paper on Urban Mobility (European Commission, 2007) established the need to promote bicycle use, to be considered as a real transport mode, and to help reduce congestion and externalities, due to its environmental benefits. In this framework, many countries, regions and cities have started implementing policies to promote cycling in many cases, driven by or the result of sustainable urban mobility plans. Or these policies were continued such as in the Netherlands, Denmark or Germany. These latter countries already had a long history of effective policies to promote cycling, and tradition of high cycling, especially for commuting purposes (Pucher and Buehler, 2008). European research projects, focused on promoting the use of the bicycle, have also been developed in recent years [see e.g. (BYPAD-Bicycle Policy Audit, 2008; Dufour, 2010)].

The current bicycle mode share data, both for national and city level, are summarised in Figure 1.1. At the top of the figure, bicycle use per country was compiled mainly from the corresponding available national travel surveys, and EUROSTAT and census data for work-trips values. The majority of countries have a very low bicycle share: 5% or lower of all trips are made by bicycle. The leading country for use of the bicycle is the Netherlands with a bicycle share in all trips of 27% and of 26% when referring only to work trips (Government of the

Netherlands, 2010). In most cases when both values are available¹ (bicycle share in all trips and bicycle share for work trips), bicycle shares for work trips are even smaller than the general values, showing the importance of other bicycle trip purposes, such as leisure or sports.

Bicycle use per city, summarised at the bottom of Figure 1.1., has been compiled from the European Platform on Mobility Management –EPOMM– (<http://www.epomm.eu>), which provides comparable modal split data of European cities and some non-European cities. Only Germany and the Netherlands have some truly cycling urban areas, with bicycle shares of 30% or higher. Following these two countries we have European countries such as Italy, Switzerland, Austria, Belgium, and other north-European such as Finland, Sweden and Denmark, with bicycle shares in some of their cities over the 20% level. However, most cities in these countries have bicycle shares lower than 10%. From Figure 1.1. we can see that bicycle use is still rather low in many developed countries, where the bicycle is a marginal transport mode.

Following this path, many cities in Spain developed their bicycle mobility master plans in the last decade (see Table 1.1.) when they also started implementing their corresponding policies and measures to promote the use of bicycles for urban mobility. The Spanish Strategy for Sustainable Mobility –SSM– (Spanish Government, 2009) established the national framework for sustainable mobility policies. This gave a new boost for modal shift towards more sustainable modes, such as the bicycle in an urban environment. The SSSM suggested specific measures such as: building cycling lanes and safe bicycle parking, improve intermodality bicycle-public transport and promote public bike share systems. The implementation of these measures, especially the latest, has produced remarkable increases in bicycle shares in cities where the starting values were very low (see Table 1.1.). This has been confirmed thanks to the inclusion of the bicycle as another mode of transport in mobility household surveys and other initiatives such as the Annual Cycling Barometer (Bureau Veritas Foundation, 2011), started in 2008.

Despite the positive trend over the bicycle use in Spain, bicycle shares are still far from those corresponding in other central and northern European countries. However, it should be taken into consideration that walking and public transport shares of trips in Spain are higher, according to EPOMM data (<http://www.epomm.eu>). These higher walking and public transport shares of trips might be influenced by more favourable climate conditions for walking, closer urban areas and good infrastructures for public transport. This situation reduces the target market (car and motorbike users) for transferring to the bicycle, and creates a special case with high interest for studying bicycle use.

¹ All except Ireland, England and Sweden.

Figure 1.1. Bicycle share of trips in different countries and cities worldwide

Table 1.1. Evolution of bicycle mode share in Spanish cities

City	Bicycle share				Source	Cycling Mobility Master Plan	Public bike share system
	Year 1	%	Year 2	%			
Vitoria-Gasteiz	2002	1.4%	2014	12.3%	Council of Vitoria-Gasteiz (2015)	2010	-
Sevilla	2007	3.2%	2011	5.6%	Calvo Salazar et al. (2012)	2008	Yes
Valencia	2009	3.1%	2012	4.8%	*; Council of Valencia (2013)	-	Yes
Donostia-San Sebastián	2006	2.7%	2011	3.9%	Basque Government (2007); Basque Government (2012)	2001	Yes
Burgos	2009	3.8%	2010	3.1%	Council of Burgos (2010)	2010	Yes
Zaragoza	2000	N/A	2007	3.0%	*	2010	Yes
Pamplona	N/A	N/A	2013	2.3%	García and Lopez-Lambas (2015)	-	Yes
Ponferrada	N/A	N/A	2007	2.1%	García and Lopez-Lambas (2015)	-	Yes
Barcelona	2006	1.5%	2013	1.8%	*; García and Lopez-Lambas (2015)	2006	Yes
Málaga	2008	0.4%	2014	1.7%	Council of Malaga (2014)	2014	Yes
Córdoba	2003	0.7%	2010	1.6%	Council of Cordoba (2011)	2014	Yes
Murcia	N/A	N/A	2009	1.1%	Council of Murcia (2010)	2010	Yes
Palma de Mallorca	N/A	N/A	2010	1.1%	*	-	Yes
Madrid	2004	0.04%	2014	0.8%	Council of Madrid (2008); García and Lopez-Lambas (2015)	2008	Yes
Santander	2009	0.3%	2013	0.7%	Alonso et al. (2013)	-	Yes
Tarragona	2001	N/A	2006	0.6%	*	-	-
Bilbao	2006	0.3%	2011	0.5%	Basque Government (2007); Basque Government (2012)	-	Yes
León	N/A	N/A	2009	0.3%	Council of Leon (2009)	-	Yes
Granada	2004	N/A	2007	0.4%	Council of Granada (2013)	2014	-
Cádiz	2004	N/A	2007	0.1%	*	2014	-

*Compiled by the author based on data from the Metropolitan Transport Authorities

The implemented cycling measures have not been as successful as expected, probably due to a poor planning on the effect of these measures on users, especially on the demand perspective. The study of bicycle travel demand in each city comprises not only knowing how it is characterised, but also how it is formed –which factors influence bicycle use choice– and to make a prognosis of bicycle demand once specific measures are implemented.

The traditional modelling approach to explain mode choice is based on the random utility theory, which in turn is based on the hypothesis that the individual is a rational decision-maker that selects the maximum-utility alternative and that the utility of an alternative is a function of the measured attributes –of the individual and the alternative– (Ortúzar and Willumsen, 2011). Travel time and cost are the traditional attributes measured of the alternatives, which moderately explain motorised mode choices. However, the special characteristics of the bicycle as a transport mode (such as that it may be free to use, takes longer, requires physical effort ...) make it difficult to explain utilitarian cycling with the trade-off between time and cost and this creates problems leading to a poor study of bicycle demand. Therefore, bicycle mode choice² requires additional variables –psychological factors– that take into consideration the subjective value attached to bicycle use and derived from its special characteristics. Psychological factors motivating bicycle choice can be quantitatively modelled as latent variables, which cannot be measured directly by the researcher and have to be inferred from

² This applies to all soft modes: walking and cycling. However, this thesis only focuses on cycling.

other variables called indicators. In fact these psychological factors may be the main determinants of demand rather than standard measures of level of service. All the aforementioned explains why the bicycle choice process is different from that of other transport modes and requires special analysis techniques and planning (graphically summarised in Figure 1.2.).

Figure 1.2. The complete process to reach a good bicycle planning

The incorporation of latent variables for modelling choice behaviour was long deemed necessary by behavioural researchers. However, it was not until the beginning of the 2000s when a rigorous and general methodology was presented (Ben-Akiva et al., 1999; Ben-Akiva et al., 2002b; Walker and Ben-Akiva, 2002; Ben-Akiva et al., 2002a). This methodology has been applied to model mode choice, covering all transport modes, including motorised ones: see e.g. Ben-Akiva et al. (2002a), Walker and Ben-Akiva (2002), Johansson et al. (2006), Temme et al. (2008), Hurtubia et al. (2010), Atasoy et al. (2010), Raveau et al. (2010), Yañez et al. (2010), Tam et al. (2011), Daly et al. (2012), Politis et al. (2012), Habib and Zaman (2012) and Bhat and Dubey (2014). The inclusion of latent variables, measured better or worse depending on the case study, but in general somehow limited, has resulted in significant parameters. That is, they add richness to the behavioural process, and therefore, it results in an improvement in the goodness of fit of the models. However, the role of subjective factors is not as critical as for non-motorised modes, as discussed above.

1.2 Thesis objectives

The desire to reach a more effective cycling policy, and therefore to substantially increase the number of bicycle trips for urban mobility and especially those related to commuting –to the work/study place– requires an adequate study of bicycle travel demand. It also requires considering a comprehensive overview of variables and using the right tools to really know which factors influence bicycle use for urban mobility. Therefore, the **general objective** of the present thesis is:

G. OBJ. To provide knowledge and tools for the proper incorporation of the bicycle as an option in travel demand models.

The present thesis has been funded by the Spanish Science and Innovation Ministry under Grant BES-2011-049533 associated with the National Research Project ‘TRANSBICI–Travel behaviour analysis for modelling the potential use of bicycle: transition to a cycling city’ and with TRANSyT-UPM (Transport Research Centre). In the context of this background the general objective of the thesis is among the objectives of the TRANSBICI project.

To achieve the general objective, several steps have been followed –developed in papers– and stated as **specific objectives** (see Figure 1.3.):

Obj-1. To understand the modelling literature about the choice to cycle for transport, in terms of variables being used and modelling issues, in order to form the basis for the thesis.

An extensive bibliographical search collects all the scientific information on bicycle demand modelling and the tools to identify the key variables to estimate the use of this mode of transport in urban areas. With the information collected a list of key variables is identified, which provides the scientific basis for the construction of the demand model.

Obj-2. To understand the urban (commuting) bicycle use in Spanish urban contexts with different levels of bicycle modal share, **throughout the definition and analysis of bicycle latent variables.**

This objective is motivated by the influence of the attitudes and other psychosocial factors in bicycle use, identified by previous but limited research on the field. The definition of the latent variables requires an early-task (previous to the data collection) that consists in identifying the indicators to be the basis for the latent variables’ construction. Therefore, the bibliographical search from Obj-1 is complemented with a review on the bicycle research including psychological factors, to identify a list of cycling indicators that is the basis for the definition of cycling latent variables for the empirical analyses of this thesis. The results may be used as background arguments both to optimize the implementation of the cycling policies to the context areas and for the mode choice model.

Obj-3. To develop a model for travel demand analysis capable of properly accounting for bicycle trips.

The model for travel demand analysis, adapted to consider car, public transport, walking and bicycle trips, consists in an integrated choice and latent variable (ICLV) model including latent variables for the bicycle choice, using integral estimation. This model is a tool to calculate more precise forecasts in order to manage the potential bicycle demand and to help designing and managing bicycle policies at the urban level.

Figure 1.3. Thesis structure: connection between objectives and papers

1.3 Study areas

The present section is a description of the two study areas of the thesis. It has some overlap with papers II, III and IV because they include a brief description of the corresponding contexts. However, this section offers the opportunity to give details of the areas relevant for the whole thesis that could not be included in the papers for space reasons.

The research was conducted in Spain (see Figure 1.4.), which has a rather low bicycle share of trips for urban mobility, especially for commuting which only account 2% (Spanish Statistical Office, 2011). However, the studies were carried out in two opposite examples of cycling environments: Madrid, where the bicycle is a marginal transport mode, with less than 1% of the trips made by bicycle (García and Lopez-Lambas, 2015); and Vitoria-Gasteiz, the current leading cycling city in Spain with 12.3% of bicycle share (Council of Vitoria-Gasteiz, 2015). Vitoria-Gasteiz is the research area of the TRANSBICI project, due to several reasons explained later in the section.

Figure 1.4. Location of the research areas

1.3.1 Madrid

The Spanish capital is a dense city with approximately 3.2 million inhabitants. Its main natural characteristics are a mountainous topography –with elevation differences up to 200 m– and a mild Mediterranean climate (without much rain and dry and hot summers).

Madrid has high walking and public transport shares of trips (33% and 40% respectively), but a very low bicycle culture and use. However, cycling volume counts during recent years show a small positive change of the bicycle share in the city centre from 0.6% in 2009 (Movilidad Foundation, 2010) to 0.8% in 2014 (García and Lopez-Lambas, 2015).

This slight rise may be the result of the increasing support for this mode from the local government, which started with the Director Plan of Cycling Mobility (Council of Madrid, 2008) and continues up to now with the recently approved Sustainable Mobility Urban Plan 2015-

2020 (Council of Madrid, 2014). Therefore, since 2008 a network of cycleways³, bicycle parking and advanced stop lines have been progressively built. Moreover, in 2014 a public bike share system (BiciMAD) was implemented with 1,560 electric bicycles and 123 bike racks around the city centre. The high success of this system prompted a geographical extension to the north part of the city centre (468 bicycles and 42 bike racks) in the summer of 2015. The most recent data (on 31 January 2016) on the system show 60,877 users and an average of 6,822 uses per day (<http://datos.madrid.es>).

The planning of the city Council for 2016 took into account the geographical extension of BiciMAD to the south part of the city centre, €2 million for remodelling the existing cyclist green ring and more than €40 million for building 33 new cycleways to complete the network in the city centre.

1.3.2 Vitoria-Gasteiz

Vitoria-Gasteiz is a municipality in northern Spain with around 240,000 inhabitants. The principal urban area in the municipality is the homonymous city of Vitoria-Gasteiz: a compact city with almost completely flat topography. The climate of the area is moderately cold, with damp winters and cool summers.

In 2007, local authorities and social stakeholders –integrated into the ‘Citizens Forum for Sustainable Mobility’⁴– signed a civic agreement on sustainable mobility (City of Vitoria-Gasteiz, 2007) to define the framework for future mobility guidelines. The agreement and the following Mobility and Public Space Plan (Council of Vitoria-Gasteiz, 2007) were the starting points for an important local support to a sustainable transport policy. Bicycle promotion was made an integral part of the transport policy in 2010, with the Cycling Mobility Master Plan (Council of Vitoria-Gasteiz, 2010). The Plan had the set objective of 15% bicycle share of trips by 2020, while maintaining the city’s high walking share of 49.6% in 2006 (Council of Vitoria-Gasteiz, 2015).

Consequently, at the beginning of the TRANSBICI project –early 2011– Vitoria-Gasteiz was going through an extraordinary process of modal transition, regarding the introduction of the bicycle as a ‘real’ mode in its urban transport system. The transition phase created a unique opportunity for bicycle research in Spain and motivated the selection of the municipality of Vitoria-Gasteiz for the TRANSBICI project.

Some of the remarkable transport measures implemented from 2007 up to now are the following:

- Related to **bicycle**: a new traffic regulation; building of bicycle parking, bicycle lanes and improvement of the city’s bicycle network connectivity; promotion of safe cycling courses; and adjustment of traffic lights to increase the safety of bicycle flows.
- Related to **walking**: pedestrianisation of streets in the city centre.
- Related to **public transport**: extensions of the bus public services; public transport on request to the rural areas; and a new bus station.

³ Bike lanes and bike tracks and streets/lanes with traffic calming (bicycle priority and maximum speed of 30Km/h).

⁴ A civic participation platform on mobility called ‘Foro Ciudadano por la Movilidad Sostenible’.

- Related to the **car**: traffic calming in 47 streets of the city centre; an increase in the regulated parking area fees; and camera control for car access to the city centre.

Thanks to this sustainable transport policy –among other reasons– Vitoria-Gasteiz was the first Spanish municipality to be awarded the title of European Green Capital in 2012 (European Commission, 2011). Another positive result is the evolution in its mode share of trips (Figure 1.5.). Car and motorbike traffic has been reducing since 2006; bicycle use is continuously increasing since 2002, while public transport and walking remained almost constant. Therefore, the bicycle is capturing demand mostly from the motorised private modes.

Figure 1.5. Evolution in the mode share of trips (Council of Vitoria-Gasteiz, 2015)

The bicycle share in 2014 is the highest of any Spanish city (see Table 1.1.) and is close to the city's objective of 15% by 2020, suggesting that it is quite possible to accomplish it –or even exceed it– if the city's transport policy continues as hitherto. Moreover, 66.7% of sustainable trips (bicycle and walking) is the highest percentage of any European medium-size city, according to EPOMM data (<http://www.epomm.eu>).

1.4 Research methodology

This section is an overview of all the methods used and links them with the specific objectives stated and the developed papers (see Figure 1.6.):

- A literature study on the bicycle modelling field and other bicycle research considering psychological factors, to propose:
 - The modelling approaches for bicycle analysis.
 - The cycling indicators and variables to be considered for data gathering.
 - The analysis techniques of latent variables.
- Development of ad-hoc survey methods for bicycle analysis, at three levels:
 - Urban corridor.
 - City, for commuting mobility.
 - City, for general mobility.
- Analysis of bicycle urban mobility throughout bicycle latent variables.
- Development of an integrated choice and latent variable model including the bicycle as an alternative mode.
- Summary of conclusions and policy recommendations and identification of areas for future research.

Figure 1.6. Methodological process

It is remarkable that traditional mobility surveys rarely included bicycle-specific questions either objective but especially subjective. Therefore, bicycle analysis requires new survey methods. Moreover, the study of latent variables implies an extra effort prior to the survey design. Identification of a latent variable requires its definition based on indicator variables, which will be included in the survey design and measured in the survey process. This justifies the importance of the literature review related to the identification of a list of cycling indicators to be the basis for the definition of bicycle latent variables for the empirical analyses.

The following subsections describe the methods for analysis and modelling applied, as well as the methodologies developed for data collection. These subsections therefore overlap somewhat with parts of the papers. However, they provide an overview of all the methods and link them with the specific objectives.

1.4.1 Methodologies of analysis and modelling

This subsection is a description of the methods, qualitative and quantitative, employed in the thesis.

Qualitative research methods were used for the specific objective 1 (Obj-1), largely because of their exploratory character. Obj-1 provides a clear view of the evolution in explanatory variables and methodologies that have been used in previous studies on modelling the choice to cycle for transport. A **literature study** was conducted to answer this question. In particular, the literature study proposes: (1) the list of key variables for bicycle mode choice analyses; (2) the list of cycling indicators to be the basis for the definition of cycling latent variables; and (3) the methodological approaches for modelling the bicycle travel demand, with special focus on the different ways of introducing attitudinal or perceptual indicators and latent variables into the models.

A quantitative approach was used to investigate specific objectives 2 (Obj-2) and 3 (Obj-3), because they require the relationships between the expected variables and cycling to be tested empirically.

Obj-2 focuses on defining bicycle latent variables and analysing their relationship with bicycle use for urban commuting. This study covers two Spanish urban contexts, but with great differences from the cycling perspective: a city with almost no bicycle use and another one with the highest bicycle use of any city in Spain.

- The proposed bicycle latent variables to be tested were based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991). This psychological attitudinal theory states that attitudes towards a behaviour, subjective norm, and perceived behavioural control (PBC) combine to shape an individual's behavioural intention and final behaviour. Therefore, bicycle indicators –defined here as perceptions of cycling characteristics– following this framework were measured to extract the latent variables for the analyses.

Since a definition of the latent variables requires not only reducing dimensionality on bicycle indicators but also identifying and defining the main underlying structures (called latent variables) among them, the proposed methodology was **explanatory factor analysis** (EFA). Factor scores, representing each individual's placement in the latent variable, were calculated and used in the follow-up analyses.

- **Mean differences** in the latent variables (or indicators) between groups was applied to study the bivariate association between each latent variable (or indicator) and bicycle commuting. Groups were established based on the commuting mode and on the bicycle experience. **Categorical techniques** (e.g. Pearson's chi-square test) were applied to find the relationships between objective variables and commuting by bicycle or by other modes.

- **Binary logistic regression analysis** was applied to measure the multivariate association of all latent variables at the same time with the option to choose the bicycle for commuting, in order to determine which are the main drivers affecting bicycle commuting.

Obj-3 focuses on developing a model for travel demand analysis capable of properly encompassing bicycle trips. To achieve this, the proposed model followed the general tendency in mode choice models during the last decade, based on incorporating subjective factors in addition to objective factors into the models. The literature review study of the present thesis shows that bicycle mode choice models are also following this tendency.

The proposed model followed the theoretical framework and methodology for the proper inclusion of subjective factors, in the form of psychological latent variables, into traditional discrete choice models (DCM) presented by (Ben-Akiva et al., 1999). The latent variable is identified through a latent variable model and integrated⁵ into the choice model (see Figure 1.7.). This **integrated choice and latent variable (ICLV)** model was specified by (Ben-Akiva et al., 2002b) and is one out of the four extensions of the ‘generalized random utility model’: latent variables, latent classes, flexible disturbances, and combined revealed and stated preferences (Walker and Ben-Akiva, 2002). This general model framework, expanded from random utility models (RUM) to all predictive choice models, was named as **hybrid choice model (HCM)** by (Ben-Akiva et al., 2002a). Later works expanded the general ICLV model, e.g. to large problems (Bolduc et al., 2005) or to a more general case, through simultaneity among the latent variables and through incorporating discrete indicators variables (Bolduc and Alvarez-Daziano, 2010).

Figure 1.7. Integrated choice and latent variable model (Ben-Akiva et al., 1999)

⁵ Integration at the same time (simultaneous estimation) or afterwards (sequential estimation).

Following this framework, the developed ICLV model considered the bicycle as one of the mode alternatives and included bicycle latent variables into the bicycle utility. The **simultaneous approach** was chosen to estimate both the latent variable and the choice models at the same time, since the simultaneous approach is preferred because it uses all the available information jointly and thus it results in both unbiased and efficient parameters, and it avoids severe consequences when transport policies are forecasted or evaluated (Raveau et al. 2010).

1.4.2 Methodologies of data collection

To address the general objective, mobility data at individual level was needed, including objective and subjective specific bicycle questions. Existing data sources did not include specific bicycle questions and therefore, three ad-hoc travel surveys were designed and developed.

This subsection describes the three ad-hoc surveys developed and used for the three empirical applications –presented as papers II, III and IV– of the thesis. It has some overlap with these papers because they include a brief description of the corresponding data sources. However, this subsection is an opportunity to include details of the survey processes relevant for the whole thesis that could not be included in the papers for space reasons. The specific focus on bicycle use was kept from possible respondents during the approaching phase of the three surveys in order to avoid a bias towards cyclists. A summary of the survey characteristics described below are summarised in Appendix B.

Two out of three of the surveys used in the thesis were developed inside the TRANSBICI project. All three surveys were designed, gathered (or controlled) and refined by the author of the thesis, previous to the corresponding analysis. Therefore, the effort in the data collection process was intensive, not only in economic resources, but especially on the author's time.

Commuting survey for bicycle analysis in two corridors of the city centre of Madrid

This survey was conducted as part of a municipal study to analyse the mobility demand and social impacts before the construction of bicycle lanes in two corridors of the city centre of Madrid (see Figure 1.8.); in Atocha, Mayor and Alcalá streets (Council of Madrid, 2011a) and in Bailén street (Council of Madrid, 2011b). Among the objectives of the municipal study was to capture perceptual and behavioural aspects of bicycle use among users from different transport modes in the surrounding area of the future bicycle lanes. The design of the developed survey included the measurement of perceptual indicators which were the basis for the cycling latent variables analysed in **paper II**, as part of specific objective 2.

During 3 workdays (20th, 21st and 22nd) in September 2011, a face-to-face on-street survey was conducted among municipal residents (tourists were excluded) moving around the aforementioned streets. The typology of the survey (face-to-face on-street) came predefined by the municipal study and was used to test the survey questionnaire directly by the research team. Each survey took approximately 15 min. They were conducted by Civil Engineer Master Students who had been previously trained for by the cycling research team of TRANSyT-UPM (included the author of the thesis), who was developing the municipal study. The research team designed the questionnaire, coordinated the survey progress, supervised the work of the

survey takers in situ and carried out the surveys themselves. There was no incentive to participate, as far as contributing to the urban planning of the area.

The sample was designed according to the specific objectives of the municipal study. The total number of surveys was 321 and according to ‘the respondent last transport mode used’ consisted of 40% cyclists, 20% pedestrians, 20% public transport users, and 20% car and motorbike users. The analysis sample, of 224 individuals, consisted of all surveys that were completely fulfilled. In the year of the research, 2011, the available data from 2009 on modal split in the city centre of Madrid was: 0.6% cycling trips, 37.4% walking trips, 39.0% public transport trips, and 23.0% car and motorbike trips (Movilidad Foundation, 2010). Consequently, the analysis sample was not representative of mobility.

Figure 1.8. Location of the corridors of the municipal study in the city centre of Madrid

Survey questionnaire included three blocks of questions related to: (1) the respondent daily transport mode and intention to change it, (2) perceptions of bicycle use, and (3) perceptions of bicycle facilities in the area. The first block also included socioeconomic questions, availability of transport modes and mobility habits. Regarding the second block, it was based on indicators –perceptions of cycling characteristics– stated through several types of questions: those involving attitudes, those related to the control of bicycle use and to subjective and descriptive norms. Perceptual questions used two types of Likert scales. Some used the following 4-point Likert scale: nothing, few, quite and many. Others used the scale from the Spanish school system, from completely disagree-unimportant (+0) to completely agree-important (+10). This scale was intended to make the answering process easy, due to

the on-street character of the survey. The whole questionnaire can be seen (in Spanish) in Appendix C.

Commuting survey for bicycle analysis in Vitoria-Gasteiz

This survey was part of the first phase of the TRANSBICI project. This first phase consisted in a longitudinal study about the influence of transport measures on attitudes and other psychosocial constructs, and how this influence may in turn affect the decision to begin commuting by bicycle. Therefore, the ad-hoc survey was done through a panel: the same respondents, questionnaire and methodology during three annual waves (from 2012 to 2014). The research area was the municipality of Vitoria-Gasteiz (TRANSBICI project).

This panel mobility survey focused on commuting trips conducted by employees and students, aged from 16 to 64, and made in Vitoria-Gasteiz. It was carried out by telephone, using computer-assisted telephone interviewing (CATI). A local survey company (Append Investigación de Mercados) was hired to carry out the three waves and a previous recruitment phase –for the selection of respondents– due to the appreciable designed sample size (at least 3 times 471 individuals in the third wave). The typology of the survey (telephone) was a compromise solution between a personal survey (for economic reasons) and a web survey (to avoid bias since not everybody has an internet connection). Commuters were approached by their employers/instructors⁶, from 86 companies and 14 study centres from different fields: primary sector, industry, construction, services, high school and university. Commuters who agreed to participate in the three waves had to fill out a short paper recruitment questionnaire. A raffle of several gift cards (from 100€ to 150€ depending on the wave) were offered as incentives in each wave. The TRANSBICI research team for this first phase designed the questionnaire, coordinated the survey progress and supervised the work of the survey takers by monitoring some surveys; the team was a multidisciplinary research team of transportation planners, geographers and psychologists including the author of the thesis. The developed survey design allowed for the measurement of perceptual indicators in three waves. Those from the first wave were the basis for the cycling latent variables analysed in *paper III*, as part of specific objective 2.

The crossectional data from the first wave was carried out during 3 weeks from the 27th of April to the 18th of May 2012. The average survey length was 15 min. The designed sample of 736 employees and students was easily obtained among 934 individuals in the database from the recruitment phase.

According to the available data at the time of the first wave in 2012, the modal split for commuting trips in the city from 2011 was: 11% bicycle, 38% walking, 9% public transport, 37% car, and 5% other modes (Council of Vitoria-Gasteiz, 2015). The sample distribution was designed to be representative of the commuting mode share of trips, divided in two groups: ‘bicycle + walking + public transport’ (58%), and ‘car + motorbike + other modes’ (42%). The sample was also representative of the municipality distribution of gender, age-groups, activity sector and location of place of work/study.

⁶ Employers and instructors were contacted by telephone. If they agreed to collaborate, they received the information for the selection of respondents by email.

The analysis sample consisted of 654 individuals, after excluding motorbike users –due to its low percentage in the sample population– and indirect commuting trips. Spatial distribution of commuters can be seen in Figure 1.9., and by mode were distributed as follows: 13% by bicycle, 27% walking, 17% by public transport, and 41% by car.

Figure 1.9. Trip origins and destinations - 1st wave of the commuting survey in Vitoria-Gasteiz

The questionnaire included the usual urban mobility questions, such as socio-economic and household data, availability of transport modes, commuting trip characteristics –mode and address and time of the origin-destination– and frequency of bicycle use for different purposes. The difference with a usual daily travel survey was on the inclusion of subjective questions.

The subjective part was designed based on the results of a qualitative study on attitudes towards bicycle use, oriented to the Theory of Planned Behaviour (TPB) (Ajzen, 1991). The qualitative study analysed 30 in-depth interviews with commuters by different transport modes in Vitoria-Gasteiz –15 interviews– and Madrid –15 interviews– (Lois et al., unpublished results).

Subjective questions of the survey consisted in indicators –perceptions of cycling characteristics– stated following the TPB. Because of that, four blocks of indicators were asked: (1) attitudes; (2) subjective norm; (3) descriptive norm; and (4) perceived behavioural control (controllability and self-efficacy). Social identity indicators were also included. All indicators were measured using a 7-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7). The whole questionnaire can be seen (in Spanish) in Appendix D.

Household travel survey including bicycle indicators in Vitoria-Gasteiz

This survey was conducted inside the second phase of the TRANSBICI project. This second phase consisted in the development of a model for travel demand analysis capable of properly accounting for bicycle trips, which is the third specific objective of the present thesis. The research area was the municipality of Vitoria-Gasteiz (TRANSBICI project).

Existing data sources from Vitoria-Gasteiz (e.g. the municipal household travel surveys –HTS– from 2006 and 2011) did not include specific bicycle questions such as bicycle indicators. In order to generate the necessary data, an ad-hoc municipal travel survey was designed. Municipal authorities took advantage of this survey and increased the budget so that it could also be used as the 2014 municipal HTS, to compare with previous ones. Therefore, this mobility survey was designed to fulfil two requirements:

- Ad-hoc to the TRANSBICI project, in order to collect a large and representative survey with both revealed preference (RP) travel data and perceptions towards bicycle use for transport and,
- Municipal household travel survey (HTS) about population trips in a workday of 2014, and comparable with previous municipal HTS. Because of this, the survey followed the same methodology as previous municipal HTS:
 - **Sampling:** Stratified random sampling, designed to obtain a representative sample of the municipal resident mobility by transport zone (40 zones); age group (5 groups: 10-19; 20-29; 30-49; 50-64; >64); and gender. Since planned quotes for the strata were not completely reached, weights were required for the analysis of the population results.
 - **Period:** Spring 2014. Interviews were started the first week of May and lasted until the end of the school term (third week of June). A 9% of the total sample, especially teenagers, could not be surveyed during this period and they were finally collected in October, after the beginning of the new academic year.
 - **Days of survey:** The survey asked about the respondent trips in the previous day, and therefore, it was conducted from Tuesdays to Fridays.
 - **Typology:** Surveys were interviews with one member of the household by telephone. Only surveys collected during October from teenagers, used mobile phones. Qualified personnel from a local survey company (Quor) carried out the survey, using computer-assisted telephone interviewing (CATI).
 - **Incentives:** Unlike previous municipal HTS, the survey offered a raffle of a digital tablet as incentive.

The developed survey design allowed for the measurement of perceptual indicators which were the basis for the cycling latent variables analysed in *paper IV*, as part of specific objective 3.

The TRANSBICI research team for the project second phase (including the author of the thesis) managed the whole survey process which is graphically summarised in Figure 1.10., and described below.

Tasks	2014												2015				
	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5		
Coordination of the stakeholders																	
Design of the questionnaire																	
Other survey preparations																	
Training and pilot surveys																	
Surveys' monitoring and correction of errors																	
Supervision of the progress																	
Depuration process																	
(Preliminar) analyses																	
Presentation of results																	

Figure 1.10. Timetable of the HTS's tasks carried out by the author of the thesis

The main stakeholders related to this survey were: the mobility department of the Council of Vitoria-Gasteiz, represented by the Centre for Environmental Studies (Centro de Estudios Ambientales, –CEA–), the statistical department of the Council of Vitoria-Gasteiz and the survey company (Quor). Obviously, they were all located in Vitoria-Gasteiz and this involved several trips during the whole period (from March 2014 to May 2015).

The 2011 HTS questionnaire was adapted and simplified in order to reduce its length, so that the inclusion of the TRANSBICI project questions did not make the survey length excessive⁷. Apart from the design of the questionnaire, other survey preparations included the sample stratification and the equivalence between transport zones and the city street map.

During a week before the beginning of the survey, the author of the thesis worked at the survey company call centre in training the survey takers and in the supervision of the pilot surveys. Due to the complexity of the questionnaire, especially in the questions from the TRANSBICI project, the monitoring of the surveys and correction of errors continued remotely until all survey takers carried out the surveys completely correct.

At the beginning of June 2014, the supervision of the survey progress showed a delay with surveys involving the youngest groups (10-19 and 20-29). A collection of mobile phones in different study centres was carried out to be able to reach the young quotas before the end of the school term. However, it was not possible and the TRANSBICI research team decided to postpone those surveys to an equivalent period from the surveying perspective, that is, October 2014. This situation delayed the whole survey process, but avoided distortions with the number of trips collected, which could have seriously affected the quality of the survey.

After the reception of the database from the survey company, an intensive depuration process was applied consisting mainly of the following tasks: to assemble the two databases required (individuals and trips); to correct household, trip-origin and trip-destination addresses and their corresponding transport zones; to check that all variables had values inside the corresponding boundaries; and to cross different variables to find and correct incoherencies.

The depurated survey database consisted of a sample of 4,192 individuals, representing 218,515 people in the population older than 9. The 96.7% of that population travelled the

⁷ The final average length was about 21 min (seven more minutes than the 2011 HTS).

previous day, representing a total of 911,326 trips (4.3 trips per person per day). The mode share of those trips was: 12.3% by bicycle, 54.4% walking, 7.6% by public transport (bus and tram), 24.7% by car and motorbike, and 1.1% by other modes (taxi, van or truck, school/company bus or coach, railway, public transport on request, and other individual and collective modes). The main descriptive results from the survey were publicly presented in May 2015, during the 'Bicycle Week' of Vitoria-Gasteiz (Muñoz, 2015).

Three considerations were taken into account to obtain the modelling sample:

1. Only urban trips were considered –internal trips to the populated area composed by the city of Vitoria-Gasteiz and the nearby nucleus of Ariñez, Asteguieta, Lopidana, Yurre, Gamarra Mayor and Arkaia (see Figure 1.11.)–, and therefore, trips with origin or destination in the rural municipal area or in other municipalities were dismissed. None of the geographically excluded trips had chosen the bicycle as the main mode.
2. All trip purposes except the one 'Without destination or going for a walk'⁸, were contemplated.
3. The main⁹ modes considered were bicycle (B), walking (W), public transport (PT) –bus and tram– and car (C) –driver and passenger–, dismissing trips by minor modes such as motorbike, coaches, taxi, and van (2,1% of urban transport trips).

The novel of the questionnaire, which can be seen completely (in Spanish) in Appendix E, comes from the inclusion of bicycle indicators –perceptions of bicycle factors– in a usual HTS. Bicycle indicators were designed based on the results of the panel mobility survey from the TRANSBICI project, described earlier in the subsection. They were included at the beginning of the questionnaire to assure a proper response and because the usual HTS questions were easier to answer even though the respondents were a bit tired. All indicators were measured using a 7-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7).

Bicycle indicators, divided by typology, were the following:

11. Degree of agreement or disagreement towards several factors related to the (possible) trip by bicycle for urban mobility: quick, sweat, time reliable, conflicts with pedestrians, relaxing and fun, independent, traffic stressful, environmentally friendly, weather dependent, healthy, accident risky, cheap, flexible, and theft risky.
12. Degree of limitation provoked by several factors related to the (possible) trip by bicycle for urban mobility: no cycleways, long distances, no safe parking, hilliness, ride in the traffic, no showers/ranks at destination, manoeuvring, physical condition, fix a puncture and helmet use.
13. Subjective norm (SN). This is one of the TPB's predictors of intention, defined as 'the perceived social pressure to engage or not to engage in a behavior'. As one of the TPB elements, SN is calculated by multiplying the beliefs linking the behaviour (bicycle use for urban mobility in our case) with their corresponding importance. It was questioned referring to the three following groups of people: family, friends and co-workers/study colleagues.
14. Global perception of bicycle use for urban mobility in Vitoria-Gasteiz; degree of intention to (start using) increase the bicycle use for urban mobility; and degree of intention to use a possible public-bike sharing system.

The usual HTS questions included in the survey were divided in 3 blocks:

1. **Individual** (gender, age, nationality, level of studies, professional situation and type of work/study schedule) **and household socioeconomic characteristics** (position, number of people, number of children < 6, number of elderly >64 and income) and **availability of transport modes and type of parking at home** (car, motorbike and bicycle).
2. **Trips made the previous day**: origin, destination, purpose, mode(s), line(s) and ticket(s) (if public transport used), parking at destination (if car driver, motorbike or van/truck used), infrastructure(s) and parking at destination (if bicycle used). For commuting trips, availability of showers and/or lockers at the work/study place was also included.
3. **Frequency of bicycle use and experience riding a bicycle** for different purposes [work, study, non-commuting transport purposes (visiting, going out, going shopping, or going to the doctor/hospital), and doing sport].

1.5 Thesis outline

The stated objectives were developed in academic papers –one literature review and three empirical applications– either published in or submitted to peer-reviewed international journals. The list of publications as well as the rest of doctoral activities developed during the PhD can be seen at the end of the thesis. The present thesis is organized into 5 chapters, which are based on the four papers (referred in the text by Roman numerals I to IV):

- The present **Chapter 1** introduces the background of the field and states the general and specific objectives of the thesis. It also summarises the methodologies applied in the papers and describes the developed ad-hoc surveys and their contexts.
- **Chapter 2** includes a two-fold literature review. First, 54 of previous studies modelling the choice to cycle for utilitarian purposes are reviewed to summarise and assess the evolution in the explanatory variables and methodologies that have been used (*paper I*). This is complemented with a brief review of other research including bicycle latent variables, in order to identify a wide list of bicycle indicators.
- **Chapter 3** includes the special analysis of bicycle latent variables and their relationship with bicycle use for urban mobility –for the special case of trip commuting–, in two Spanish urban contexts: one with almost no bicycle use –Madrid– (*paper II*) and another one with the highest bicycle use of Spain –Vitoria-Gasteiz– (*paper III*). Comparisons between them and with other contexts are also included.
- **Chapter 4** is an application of an integrated choice and latent variable (ICLV) model to analyse the inclusion of bicycle latent variables in a transport mode discrete choice model and test the influence of several potential transport measures in the mode choice behaviour of Vitoria-Gasteiz (Spain) (*paper IV*).
- **Chapter 5** is a summary of the results of the previous chapters and highlights the main conclusions and contributions of the thesis. It also includes details for further research.

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2 Research into bicycle latent variables

The first part of this chapter –sections 2.1 to 2.9– is a survey of the modelling literature on the choice to use the bicycle for utilitarian purposes, to summarise and assess the evolution in the explanatory variables and methodologies that have been used. A previous review by Heinen et al. (2010) had already summarised the different determinants for bicycle use. However, the present review is from a modelling perspective, by presenting the evolution in different modelling approaches (only bicycle mode choice modelling experiences are reviewed) and emphasising the role of latent variables to this evolution. The chronological evolution of the studies is presented and divided into three stages –initial, intermediate and late– according to the different ways of introducing attitudinal or perceptual indicators and latent variables into the models. The summary of the variables and models used up to now is used as the starting point for the thesis. This part of the chapter includes a paper that has been published as:

- I. Muñoz, B., Monzon, A., and Daziano, R.A. The Increasing Role of Latent Variables in Modelling Bicycle Mode Choice. Published online in *Transportation Reviews: A Transnational Transdisciplinary Journal*. DOI: 10.1080/01441647.2016.1162874.

Section 2.10 of the present chapter is a summary of the attitudinal and perceptual bicycle indicators used to build bicycle latent variables in the modelling studies reviewed¹⁰ and in other bicycle research including psychological latent variables. This way, the whole literature into bicycle latent variables is included and the resulting list of bicycle indicators (see Table 2.1.) is the basis for the definition of bicycle latent variables for the empirical analyses of the present thesis.

Some authors group indicators according to the theory or conceptual model followed [e.g. Theory of Planned Behaviour (TPB) (Ajzen, 1991), Theory of Triadic Influence (Flay et al., 2009), or Ecological models of health behaviour (Sallis et al., 2008)]. Other authors present indicators distinguishing between reasons or motivators for bicycle use and deterrents or barriers for not using the bicycle. Since some indicators can be either motivators or barriers depending on the person, Table 2.1. includes a list of indicators according to their nature.

¹⁰ The studies including latent variables are mainly from the intermediate and late stages.

The Increasing Role of Latent Variables in Modelling Bicycle Mode Choice

Begoña Muñoz^a, Andres Monzon^b and Ricardo A. Daziano^c

^aTRANSyT – Transport Research Centre, Universidad Politécnica de Madrid, c/ Profesor Aranguren s/n – Ciudad Universitaria, Madrid, Spain; ^bTransport, Civil Engineering Department, Universidad Politécnica de Madrid, c/Profesor Aranguren s/n – Ciudad Universitaria, Madrid, Spain; ^cSchool of Civil and Environmental Engineering, Cornell University, Ithaca, NY, USA

ABSTRACT

The growing interest in promoting non-motorised active transport has led to an increase in the number of studies to identify the key variables associated with bicycle use, and especially those related to the bicycle mode choice problem. This paper presents a comprehensive survey of the modelling literature on the choice of the bicycle for utilitarian purposes, and summarises and assesses the evolution of the explanatory variables and methodologies used. We review both the evolution of the incorporation of latent variables in bicycle mode choice models and the critical role they play. The chronological evolution of the studies is divided into three stages —initial, intermediate and late — according to the different ways of introducing attitudinal or perceptual indicators and latent variables into the models. Our review shows that the incorporation of latent variables in bicycle choice models has increased in the last decade, with a progressive use of more sophisticated methodologies until the arrival of complex models that explicitly and properly deal with psychological latent variables. In fact, with the use of hybrid choice models, latent variables have nowadays become the core of bicycle mode choice models. Based on our review, a set of questions is proposed as a uniform measurement scale to identify attitudes towards bicycling. Recommendations for future research are also presented.

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1. Introduction

The growing interest in promoting non-motorised active transport has led to an increase in the number of studies to identify the key variables associated with bicycle use. Of special interest is to identify the factors that would encourage an individual to choose the bicycle over a motorised mode. This ‘bicycle mode choice’ problem (which models mode split, as opposed to bicycle route choices; see, e.g. Stinson and Bhat (2003)) usually focuses on ‘utilitarian’ trips — that is, with a specific destination (such as the workplace for commuting trips) — as opposed to recreational or sport trips.

Sustainable transport policies face problems when seeking to increase demand for utilitarian bicycling due to competition from motorised alternatives, which usually offer

shorter travel times. The special characteristics of the bicycle as a transport mode make it difficult to explain utilitarian bicycling with the traditional trade-off between time and cost — traditionally the key explanatory factors for motorised demand. In fact, the demand for non-motorised, active modes — which require physical effort, take longer, and may be free to use — is insufficiently understood.

The full characterisation of the bicycle as a valid transport option requires additional variables that take into consideration the subjective value attached to bicycle use. In fact the psychological factors motivating bicycle choice may be the main determinants of demand rather than standard measures of level of services. These psychological factors can be quantitatively modelled as latent variables, which cannot be measured directly by the researcher and have to be inferred from other variables called indicators¹. Despite the interest in incorporating latent variables for modelling motorised demand, the role of these subjective factors is critical for non-motorised modes, as discussed above. It is precisely the evolution of the incorporation and critical role of these latent variables in bicycle mode choice models that are reviewed in this paper.

Although there has been a considerable increase in the number of empirical applications exploring the motives behind bicycle choices, to this date there is no comprehensive review to date of the studies that address the problem of modelling bicycle mode choice. The primary aim of this paper is therefore to present a comprehensive survey of the modelling literature on the choice of cycling for utilitarian purposes², and to summarise and assess the evolution in the explanatory variables and methodologies used. Considering the potential explanatory power of psychometric measurement in bicycle mode choice models, we have used the role of latent variables as a thread to develop this literature review.

A total of 54 studies have been identified and examined. Due to the unique nature of bicycle demand, we consider literature from a range of fields, including transport planning, travel behaviour and health science. We review both aggregate and disaggregate modelling approaches. Our survey includes only experiences starting in the 1990s, as this was the period that first saw the emergence of a broad interest in non-motorised demand. Whereas in the earliest studies bicycle mode choice is analysed jointly with walking as a single non-motorised mode, we focus on the bicycle as a single alternative. Finally, we exclude studies focused on modelling cycling frequency, cycling purpose, cycling typology or cycling flows from our review, as this literature considers bicycle choice as exogenous.

In the following section, the main elements of each of the studies are synthesised and analysed comparatively, with a two-fold focus: first, explanatory variables and second, modelling issues. Connecting these two perspectives, the third section presents an analysis of the chronological evolution of the studies, divided into three stages (early, intermediate and late), according to the different ways of introducing attitudinal or perceptual indicators and latent variables into the models. Complementarily to these two sections, detailed information is provided in comprehensive tables in the appendices, in order to be a guide for future studies including bicycle mode choice models. [Appendix 1](#) summarises the variables used and those that were reported to be statistically significant in each of the studies reviewed. Appendices 2, 3 and 4 contain a synthesis of the main characteristics of each study. The last three aforementioned appendices are divided into two parts: aggregate and disaggregate studies. The studies in the disaggregate part are also divided into the three distinct stages — early, intermediate and late — established in the third section.

[Appendix 2](#) provides a summary containing focus, whether latent variables are considered, data reduction method if appropriate, trip purpose and context (city/area and country). [Appendix 3](#) summarises the methodology adopted by describing the type of model, specification, dependent variable, choice set, source of data (revealed preference (RP)/stated preference (SP)) and sample size. [Appendix 4](#) includes inference (provision of elasticities or forecasting) and goodness of fit.

Our review highlights the increase in the incorporation of latent variables in bicycle choice models in the last decade, with the progressive use of more sophisticated methodologies until the arrival of complex models that explicitly and properly treat psychological latent variables. Today with the use of hybrid choice models, latent variables have become the core of bicycle mode choice models. The paper concludes by discussing the findings and methodologies, proposing a uniform measurement scale to identify attitudes towards bicycling and suggesting research prospects for future studies.

2. Bicycle Mode Choice Studies: Comparative Analysis

The analyses in this section start focusing on the different *explanatory variables* used in the bicycle mode choice literature. Then they are complemented with general *modelling issues* such as level of aggregation, approach, field of study, type of model and specification, source of data, context and trip purpose, preference heterogeneity and inference.

2.1. Explanatory Variables

The explanatory variables identified in the literature as influential in the use of the bicycle for utilitarian purposes are numerous and very diverse in nature. There have been some partial literature reviews on this topic (see e.g. Lorenc, Brunton, Oliver, Oliver, & Oakley, 2008; Panter & Jones, 2010; Parkin, Ryley, & Jones, 2007; Reynolds, Harris, Teschke, Cripton, & Winters, 2009; Saelens, Sallis, & Frank, 2003; Sirard & Slater, 2008; Willis, Manaugh, & El-Geneidy, 2015), in addition to the more exhaustive work by Heinen, van Wee and Maat (2010). The variables are usually divided into categories, although different classifications have been proposed depending on the underlying modelling objectives. Some studies such as Goldsmith (1992) and Dill and Carr (2003) classify the variables according to the way they are measured: objectively (directly observed) or subjectively (personal evaluations of specific aspects or characteristics that require the interaction with the individual to be recorded). Subjective variables are measured using indicator variables that tend to be attitudinal or perceptual survey questions, usually implemented using Likert scales — for example — with differing levels of agreement/disagreement. Other studies use a classification that depends on their relation to the individual, the individual's environment or the alternative modes (Parkin et al., 2007; Rietveld & Daniel, 2004). The most recent classifications are a combination of the above-mentioned categories (Fernández-Heredia, Monzon, & Jara-Díaz, 2014; Heinen et al., 2010).

We first group the explanatory variables according to their objective or subjective nature and then propose a classification in which subjective variables are also divided according to whether the variable has an equivalent objective variable.

Objective variables

Socio-economic and household characteristics. Most studies include gender, age, income and level of studies. Whereas most agree that being young and a man increases the likelihood of bicycling, income and education level both show contradictory results. Car availability is widely reported as negatively related to bicycle choice, and bicycle availability is shown to positively influence the bicycle option. Few studies include other socio-economic characteristics such as employment (status, sector, location, working schedule and hours), family (type, size), race, religion, political orientation, health status, exercise taken, house characteristics, availability of other modes (transit, scooter, working vehicle) and facilities (free car parking, public transport benefits), current mode and frequency or type of bicycling experience.

Trip characteristics. The two traditional variables in travel choice behaviour models — time and cost — also negatively affect the bicycle mode choice. Bicycle subsidies and an increase in the cost of other modes have a positive impact on the likelihood of cycling. Few studies include other trip characteristics such as cycling speed and purpose.

Built environment. The design of the city also seems to affect bicycle use. This effect is usually represented by density and distance. Some studies agree that increased bicycle use is associated with higher population density and land-use mix as trip distances decrease. Trip distance is negatively related to bicycle choice, to motorised traffic characteristics (speed and flow) and to the type of road network (arterial). Other built-environment characteristics do not show any significant influence on bicycle choice.

Natural environment. Most studies that include hilliness report that slopes decrease bicycle use. There also seems to be agreement on the positive influence of summer and the negative influence of rain and wind on bicycling. Other less widely studied variables are temperature and darkness.

Cycling facilities. Almost all the studies that include variables related to bicycle infrastructure (cycleway network, parking and complementary infrastructure such as showers and racks) identify a positive influence of bicycling facilities on bicycle choice. A correlation has also been identified between municipal budget and bicycling demand.

Subjective variables

Perceptual indicators of environmental and cycling facilities. This subgroup includes perceptions related to variables that can be measured objectively. Perceptions of hilliness, weather and traffic risks, distance and bicycle facilities (network, parking, shower and racks) are the most common in the studies reviewed. Few studies include perceptions of noise, pollution, traffic flow, theft, conflicts with pedestrians, neighbourhood characteristics and proximity to services, streetlights and car facilities.

Psychological indicators. This subgroup includes perceptions related to variables that cannot be measured objectively. The psychological factors in the literature that encourage bicycling demand include satisfaction with cycling, perceptions of comfort (e.g. 'the effort required to ride a bicycle is comfortable', 'I can ride the bicycle wearing my everyday clothes', 'I do not sweat riding the bicycle' and 'I am comfortable riding the bicycle in motorised traffic'), convenience and awareness, positive social norm and support ('my social environment accepts my decision to ride a bicycle'), high perceived behavioural control (positive perception of one's ability to ride a bicycle), non-commuting cycling habits, 'like riding the bicycle', bicycle community preference, positive cycling experience,

being anti-car and 'prefer to limit motorised driving'. In contrast, perceptions or latent variables discouraging bicycling demand include lack of interest in bicycling, 'like driving a car', having to run errands and 'can rely on parents chauffeuring'. Other variables tested do not show a clear influence (Appendix 1).

Appendix 1 shows the complete list of the variables used in bicycle mode choice research, highlighting those that are reported to be statistically significant in each of the studies in the review. It confirms the wide diversity of the variables used to study this phenomenon. However, the high number of blank cells in the appendix shows that the general rule is to focus on a limited number of variables each time and therefore the complete vision has not been developed yet.

2.2. Modelling Issues

2.2.1. Level of aggregation

Goldsmith (1992) was the first to review the techniques for incorporating bicycles into existing transport planning models. His review was improved by Katz (1995) and Porter, Suhrbier, and Schwartz (1999), and their corresponding American and Australian guidebooks (Katz, 2001; Schwartz et al., 1999) for modelling and forecasting bicycle travel demand.

Aggregate methods — based on zonal information — include aggregate behaviour studies, comparison studies, sketch plan methods and measures of potential demand (facility demand potential and maximal share analysis). With the exception of behaviour studies, they are generally not considered as true demand-forecasting tools in the aforementioned reviews, since they are characterised by a combination of relatively simple techniques, and may have significant errors and misinterpret the results due to the high number of assumptions required. Hence *behaviour studies* are the only aggregate methods reviewed in the present paper. Aggregate behaviour studies have moderate data requirements and aim to relate demand to the characteristics of the local area (population, land-use mix), generally through regression analysis and other multivariate statistical approaches. Regression estimates are used to identify the effects of variables at a zonal level.

Only nine of the studies considered in this review use an aggregate approach. Most aggregate models do not consider psychological indicators or latent variables. Perceptual satisfaction with cycling appears only in Rietveld and Daniel (2004), Parkin, Wardman, and Page (2008) and Vandenbulcke et al. (2011). Since most of the aggregate studies use census data, they typically include socio-economic and environmental variables, supplemented with cycling facility variables from other sources. Aggregate models are mainly used to identify differences between cities (Buehler & Pucher, 2012; Dill & Carr, 2003; Nelson & Allen, 1997; Rietveld & Daniel, 2004; Schoner & Levinson, 2014; Vandenbulcke et al., 2011), but some studies also differentiate between districts (Parkin et al., 2008), metropolitan areas (Baltes, 1996) and counties (Zahran, Brody, Maghelal, Prelog, & Lacy, 2008).

Disaggregate methods — based on household and/or individual data — include discrete outcome models (logistic regressions and discrete choice models (DCMs), structural equation models (SEMs) and combinations of the two. Discrete outcome models predict a discrete dependent variable for an individual such as the probability of choosing the bicycle or any other mode based on a set of independent variables also called covariates. Discrete outcome models include binary or multinomial logistic regressions as well as

DCMs; they are primarily used to investigate variables influencing travel behaviour, and also help answer relevant policy questions. SEMs are used to find causal relations, and allow the dependent relationships among several variables to be tested within the same modelling framework.

Since bicycling behaviour cannot be considered socially standard in many contexts, the vast majority of studies (45) use a disaggregate approach — despite the added complexity these models involve — due to the importance of considering individual differences. The tendency to include psychological indicators and latent variables in the models also explains the focus on individual, disaggregate choices.

2.2.2. Approach

All the studies reviewed use the trip-based approach, except for two that apply the tour-based modelling framework and do not include psychological indicators and latent variables (Frank, Bradley, Kavage, Chapman, & Lawton, 2008; Roorda, Passmore, & Miller, 2009). The latter have limited success in modelling the ‘drive access subway’, taxi and bicycle modes.

2.2.3. Field of study, type of model and specification

- *Standard Linear Regression.* All nine aggregate models in the review come from the transport field. Most of these studies use linear regressions to predict the share of bicycling trips, which is treated as a continuous variable. Treating share as a continuous dependent variable causes the same modelling problems as linear probability regressions such as nonsensical predictions (negative or over-100% share). Extensions to the simple linear model include Rietveld and Daniel (2004) and Buehler and Pucher (2012) with a semi-log specification; Zahran et al. (2008), who use a zero-inflated negative binomial regression due to a high number of zero observations; and Vandenbulcke et al. (2011) who account for multicollinearity, spatial heterogeneity and spatial autocorrelation (using spatial regimes and heterocedasticity correction).
- *Logistic regression.* Logistic regression studies only include alternative-invariant covariates (attributes of the decision-maker such as socio-economic characteristics) and are used more or less to the same extent in the fields of health (Aarts, Mathijssen, van Oers, & Schuit, 2013; De Bruijn, Kremers, Schaalma, van Mechelen, & Brug, 2005; De Geus, de Bourdeaudhuij, Jannes, & Meeusen, 2008; Engbers & Hendriksen, 2010; Panter, Jones, van Sluijs, & Griffin, 2010; Titze, Stronegger, Janschitz, & Oja, 2007, 2008; Winters, Brauer, Setton, & Teschke, 2010) and in travel behaviour and transport planning (Buehler, 2012; Buehler & Pucher, 2012; Emond & Handy, 2012; Goetzke & Rave, 2011; Hamre & Buehler, 2014; Katz, 1996; Ma & Dill, 2015; Muñoz, Monzon, & Lois, 2013; Muhs & Clifton, 2014; Parkin et al., 2008; Plaut, 2005; Rose & Marfurt, 2007). Most of these studies are binary, and the dependent variable is the logarithm of the odds of bicycling — that is, the probability of bicycling divided by the probability of not bicycling. Another four studies develop multinomial logistic regressions, with the following possible alternatives: bicycle or car in Plaut (2005) and Winters et al. (2010); bicycle, walking or motorised mode in Panter et al. (2010) and Aarts et al. (2013); bicycle, walking, public transport or car in Hamre and Buehler (2014) and cycling regularly or irregularly versus not cycling in Titze et al. (2007).

- *SEMs*. SEM allows complex phenomena to be modelled using latent variables. It attaches coefficients to path relationships and thus gives a more precise indication of the interrelationships between variables. SEM studies are significant in the social and psychological sciences although it has not been extensively developed to model the bicycle mode choice problem; Sigurdardottir, Kaplan, Møller, and Teasdale (2013) is the only SEM that looks at intentions towards choosing the bicycle.
- *DCM*. DCM bicycle experiences are used solely in the fields of travel behaviour and transport planning, and most of these studies use specifications based on logit formulations, usually with fixed parameters (Train, 2009). Some DCM specifications can be found where only alternative-invariant covariates are added to the utility function (see column 'AIC' in Appendix 3). These types of specifications are equivalent to logistic regressions that study the choice between cycling or not cycling. Various studies that include alternative-specific attributes simplify choice to a binary, where the second alternative is car/bus (Wardman, Hatfield, & Page, 1997); the current mode among car, bus and walking (Ryley, 2006); and the second-best mode between public transport and car (Börjesson & Eliasson, 2012). Among the multinomial experiences, logit specifications are dominant: multinomial logit model (Akar & Clifton, 2009; Akar, Fischer, & Namgung, 2013; Dell'Olio, Ibeas, & Moura, 2011; Lee, Park, & Sohn, 2011; Noland & Kunreuther, 1995; Ortúzar, Iacobelli, & Valeze, 2000; Wardman, Page, Tight, & Sin, 2000³), nested logit (Frank et al., 2008; Katz, 1996; Rodríguez & Joo, 2004; Taylor & Mahmassani, 1996), heterocedastic logit (Rodríguez & Joo, 2004) and mixed logit (Dell'Olio, Ibeas, Bordagaray, & Ortúzar, 2014). Roorda et al. (2009) is the only study that uses probit.
- *Hybrid choice model*. The proper inclusion of latent variables in DCM — that is the integration of SEM with DCM — is achieved by using the integrated choice and latent variable (ICLV) model from the hybrid choice modelling (HCM) framework. Although this type of model re-emerged during the last decade in transport choice modelling (Ben-Akiva et al. 1999; Ben-Akiva, McFadden, et al. 2002; Ben-Akiva, Walker, et al. 2002; Bolduc, Ben-Akiva, Walker, & Michaud, 2005; Walker & Ben-Akiva, 2002), it was not applied to bicycle mode choice until recently. The extended version of DCM has only been reported in five bicycle mode choice studies until now. Sequential estimators are applied in two studies: Maldonado-Hinarejos, Sivakumar, and Polak (2014) and Fernández-Heredia, Jara-Díaz, and Monzon (2016). However, the two-step procedure where SEM parameters are first estimated before introducing fitted latent variables into DCM has clear disadvantages, such as biased (Bollen, 1989) and inconsistent (Ben-Akiva, Walker, et al. 2002) estimators. Full-information maximum likelihood (simultaneous) estimators are applied in Kamargianni and Polydoropoulou (2013) and Habib, Mann, Mahmoud, and Weiss (2014). The recent study by Kamargianni, Bhat, Polydoropoulou, and Dubey (2015) applies the new probit-kernel-based ICLV model formulation, which allows a large number of latent variables to be incorporated in the choice model without difficulties of convergence or estimation time.

2.2.4. Data source: RP or SP data

All the studies in the review use cross-sectional data. Standard and logistic regressions normally use RP samples. DCM experiences generally use SP samples (see studies 11–13, 21, 33, 36–37, 44, 50–52 and 54 in Appendix 3), except for eight studies that use RP (Akar & Clifton,

2009; Akar et al., 2013; Dell’Olio et al., 2014; Frank et al., 2008; Noland & Kunreuther, 1995; Rodríguez & Joo, 2004; Roorda et al., 2009; Wardman et al., 2000). Wardman et al. (2000) demonstrated the use of a joint RP–SP modelling framework to exploit the benefits of each data collection method. Dell’Olio et al. (2014) use both RP and SP data but develop a different mode choice model with each type of data. Details of the construction of the availability of modes and times and costs for the non-chosen alternatives are usually omitted in the RP studies (exceptions are Akar et al., 2013; Noland & Kunreuther, 1995 and especially Rodríguez & Joo, 2004). Some researchers use self-reported attributes for both the chosen and non-chosen modes (Akar & Clifton, 2009; Wardman et al., 2000).

2.2.5. Context and trip purpose

The majority of the studies focus on bicycle commuting trips (see Appendix 2), which for most people represent demand in peak periods with a fixed character in time and space. There are examples of commuting trip studies derived from genuinely ‘cycling cities’ in the Netherlands (Engbers & Hendriksen, 2010; Heinen, Maat, & van Wee, 2011, 2012) and Denmark (Sigurdardottir et al., 2013), as well as cities with almost no bicycle culture such as Madrid, Spain (Fernández-Heredia et al., 2016; Muñoz et al., 2013).

Only six studies broaden the scope to all transport purposes (De bruijn et al., 2005; De Geus et al., 2008; Maldonado-Hinarejos et al., 2014; Titze et al., 2007, 2008; Winters et al., 2010), while in another eight the authors also consider recreational cycling trips. Most of these eight studies use RP samples, and case studies where bicycle use is low (Frank et al., 2008; Habib et al., 2014; Moudon et al., 2005; Ortúzar et al., 2000; Roorda et al., 2009). Goetzke and Rave (2011) also include recreational bicycle trips, but model them separately from the other trip purposes. The studies of Cervero and Duncan (2003), Gehrke and Clifton (2014) and Muhs and Clifton (2014) specifically analyse non-commuting trips (shopping, visiting, going out) in combination with recreational trips.

Some of the studies contain questions on non-cyclists’ reasons for currently not bicycling. In some cases, safety concerns are the main barriers in less cycling-friendly environments (Katz, 1996; Noland & Kunreuther, 1995; Wardman et al., 1997). In areas with a more ingrained bicycle culture, the most common barriers are related to practical issues (distance, bicycle availability, weather, out-of-work commitments, sweating and effort; Engbers & Hendriksen, 2010; Rose & Marfurt, 2007; Ryley, 2006). This agrees with the work of Akar and Clifton (2009), which analyses the reasons for different cyclist profiles, and found that safety related to motorised traffic is the main barrier for non-cyclists, whereas the need to change clothes or carry things remains the key issue for cyclists.

A large number of studies consider samples of students, faculty and staff at universities or colleges (e.g. Akar & Clifton, 2009; Akar et al., 2013; Fernández-Heredia et al., 2016; Katz, 1996; Rodríguez & Joo, 2004). These environments are actively oriented to alternative transport modes (Balsas, 2003), and data collection and accessibility is more straightforward.

Interest in modelling bicycle choices among teenagers as a means of orienting future bicycle-friendly policies was first seen in Panter et al. (2010) and has increased in recent years (Aarts et al., 2013; Emond & Handy, 2012; Kamargianni & Polydoropoulou, 2013; Kamargianni et al., 2015; Sigurdardottir et al., 2013).

2.2.6. Preference heterogeneity

Some studies model the bicycle mode choice separately for different groups of users (Appendix 3). For example, Ortúzar et al. (2000) modelled separately the willingness to bicycle by current users of car, bus, shared-taxi, metro and mixed modes, and other modes (bicyclists, pedestrians and car passengers). Similarly, Muhs and Clifton (2014) built models by type of user (car, walk and bicycle). In the work of Ryley (2006), the modelling results were split by mode (all modes, car, bus and walk) and the motorist sample was also split according to socio-economic and housing characteristics, and the attitudinal statement of considering cycling safe or not. Plaut (2005) used separate analyses for home-owners and home-renters, and found that the housing sub-groups seem to operate under different sets of constraints and incentives, and manifest different decision behaviour. Lee et al. (2011) segmented their mode choice model according to leisure bicycling experience (total, inexperienced and experienced bicyclists). Finally, Akar et al. (2013) built segments based on gender (male, female). Other segmentation criteria used are trip purpose (Goetzke & Rave, 2011) or spatial parameters: different zones (Vandenbulcke et al., 2011) or ranges of distance (<1 km, 1–2 km and >2 km in Panter et al., 2010; all trips and short trips (<5 km) in Winters et al. (2010); and <5 km, 5–10 km, and >10 km in Heinen et al. (2011)).

2.2.7. Inference

Forecasting is not extensive (Appendix 4). Most studies conclude after discussing point estimates and goodness of fit. A few studies report elasticities (Frank et al., 2008; Goetzke & Rave, 2011; Katz, 1996; Noland & Kunreuther, 1995; Rodríguez & Joo, 2004), marginal effects (Goetzke & Rave, 2011) and values of time (Börjesson & Eliasson, 2012; Dell’Olio et al., 2011; Kamargianni et al., 2015; Rodríguez & Joo, 2004; Wardman et al., 1997, 2000), while another few calculate future market shares using sample enumeration (Dell’Olio et al., 2014; Hamre & Buehler, 2014; Noland & Kunreuther, 1995; Maldonado-Hinarejos et al., 2014; Ortúzar et al., 2000; Rodríguez & Joo, 2004; Roorda et al., 2009; Wardman et al., 1997, 2000). In general, interval estimation of marginal effects, values of time and predicted shares are not reported.

3. Stages in the Incorporation of Latent Variables in Bicycle Mode Choice Studies

Considering the potential explanatory power of subjective factors in bicycle mode choice models, the joint analysis of explanatory variables — subjective variables in particular — and modelling issues, both from the previous section, is shown herein. This joint analysis examines the chronological evolution of disaggregate bicycle mode choice modelling according to the different ways of introducing perceptions and latent variables into the models. This evolution can be divided into three distinct stages — early, intermediate and late: psychological indicators directly in the utility function (early), sequential estimation based on constructing latent variables and then including them in the utility function (intermediate), and the HCM framework (late).

- *Early stage (nine studies)*. Inclusion of subjective variables began in the 1990s. For instance, Noland and Kunreuther (1995), Taylor and Mahmassani (1996), Katz (1996) and Wardman et al. (2000) considered attitudinal indicators such as riskiness and

inconvenience, which represent barriers for commuting. This early stage is characterised by the direct inclusion of social and psychological indicators in the utility function, where the indicators are treated as continuous or categorical variables and no latent variables are constructed. This type of treatment of psychological indicators is the simplest modelling approach, but produces problems of multicollinearity and efficiency loss. An exception is the work of Katz (1996), which contains an exploratory factor analysis (EFA) to reduce the data to six underlying latent variables representing attitudes to cycling.

However, objective variables were still the main target in this stage, and a large number of studies concentrated on them exclusively (see studies 13 and 15–18 in [Appendix 2](#)). The initial focus was on policy-oriented variables such as time (related to the type of cycling infrastructure) and environment characteristics. Wardman et al. (1997) explicitly recognised that attitudes needed to be included in the models for a better understanding of bicycle demand, and this recommendation was addressed by later studies such as Wardman et al. (2000). Ortúzar et al. (2000) indicated the recurrent theme of the safety factor in focus group and in-depth interview surveys, although this factor was not included in the modelling.

- *Intermediate stage (30 studies)*. This stage began in around 2005 and continues to the present day. More than half the studies in this stage include bicycle-related indicators or latent variables which appear to play a significant role. The works of Moudon et al. (2005), Akar et al. (2013) and Muhs and Clifton (2014) are the only studies that still consider attitudinal indicators that directly enter the utility function. Most of the studies that include bicycle-related latent variables follow a sequential estimation based on constructing the latent variable and then including it in the utility function. The first step involves conducting data reduction analyses to avoid problems of multicollinearity. Dimensionality reduction techniques include summated scales — average or sum — principal components analysis (PCA) and EFA (see the column 'Reduction method' in [Appendix 2](#)). However, this stage is still characterised by statistical issues such as lack of causality, poor fit, use of a nominal scale, inefficient estimators (due to the use of two-step estimators) and inability to forecast (as the models describe the current situation but lack causal variables that can be used to evaluate hypothetical scenarios).

Some studies applied conceptual models to orient the formulation of the indicators and the process of constructing the latent variables. For example, de Bruijn et al. (2005) examined how a conceptual model (including variables from the Theory of Triadic Influence (Flay, Snyder, & Petraitis, 2009) and the Theory of Planned Behaviour (TPB) (Ajzen, 1991)) explained both bicycle intention and its use for transport. The framework of ecological models of health behaviour (Sallis, Owen, & Fisher, 2008) was applied to study the association between utilitarian cycling among adults and personal-level, social-environment and built-environment latent variables (Handy & Xing, 2010; Titze et al., 2008). The same approach was used to study bicycle demand among students at university (Titze et al., 2007), high school (Emond & Handy, 2012) and primary school (Aarts et al., 2013). Expanding on TPB, Heinen et al. (2011) and Muñoz et al. (2013) conducted attitudinal and bicycling behaviour surveys and developed binary models including latent variables in two completely different cycling environments. The former used the methodology to study four cities in the Netherlands (between 17% and 29% bicycle share). For distances under 5 km, the perceived behavioural

control (PBC) variable (people's perceptions of their ability to perform a given behaviour) is the most influential, followed by the 'direct benefits' attitudinal factor and habit. However, according to Muñoz et al. (2013) in Madrid (Spain) — with a bicycle share of 0.6% of all trips — the choice of the bicycle for commuting is mainly defined by the existence of a bicycle habit for non-commuting transport trips. Attitudes related to direct benefits in reliability, comfort and time are influential, but to a lesser extent than habit. As pointed out in the paper, the social and physical context might explain the different results. The work by De Geus et al. (2008), in the health science field, focused on psychosocial and environmental latent variables, without framing the work within any specific conceptual model. This was also the case of the work by Panter et al. (2010) — the first study to examine attitudes in teenagers.

Moudon et al. (2005) revisited the issue of built-environment characteristics, including both objective (calculated using GIS) and perceived measures such as destination-based land uses or amenities for cycling in the neighbourhood. This approach has recently been followed by Ma and Dill (2015), who predict whether the person has used the bicycle for utilitarian purposes in the preceding month by means of paired perceived and objective measures such as the presence of off-street bike trails, bike lanes, quiet streets or places within biking distance of home.

Among transport science studies, Akar and Clifton (2009) modelled commuting mode choice to college, including four bicycle attitudinal principal components related to health benefits, safety, costs of other modes and bicycle parking. Campus bicycling was also studied by Akar et al. (2013), although these authors also focused on gender differences. Lee et al. (2011) developed a conventional SP commuting mode choice model that measures the effect of previous leisure cycling experience. The estimates suggest that experienced (leisure-based) cyclists might have hidden motives other than utility (basically travel time) when choosing bicycle commuting compared to experienced (non-leisure-based) cyclists. A second model (including attitudinal latent components such as sensitivity to pollution, symbolic motives for driving a car, concerns about accidents, social activity, passiveness, physical strength and early-bird propensity) was therefore developed to explain the differences between the two groups. Heinen et al. (2012) focused on work-related factors and bicycle commuting, but also included attitudes and social influence using variables such as commuter's attitude or expressed expected opinion of colleagues about how to commute to work.

Some studies in this period still do not include psychological indicators or latent variables (see studies 21–22, 26–27, 31–34, 37–38 and 44–46 in [Appendix 2](#)). Among these, there is a subgroup that uses a very reduced number of explanatory factors (Dell'Olio et al., 2011; Engbers and Hendriksen, 2010; Rose & Marfurt, 2007). In addition to latent variables, some facility-related objective variables appear to be important, such as route connectivity (Titze et al., 2008) and work-related facilities (Buehler, 2012; Hamre & Buehler, 2014; Heinen et al., 2012).

It is worth noting the attention paid to environment characteristics in this stage. Whereas trip length and topography are seen as significant variables, other environment characteristics do not appear to have a high influence on bicycling. Frank et al. (2008) pointed out that urban forms in residential and employment locations are predictors of mode choice, but not very strong. No significant relationships were found between land-use mix diversity or attractiveness/green area and cycling by Titze et al. (2008),

while, according to Muhs and Clifton (2014), built-environment variables do not appear to be significantly associated with bike mode choice. These results are even clearer when both objective and perceived environmental variables are introduced at the same time: the decision to ride a bicycle seems to depend largely on personal and not environmental factors (Moudon et al., 2005). The objective environment may only indirectly affect cycling behaviour by influencing perceptions (Ma & Dill, 2015).

- *Late stage (six studies)*. This stage is characterised by recent studies that consider latent variables as the core of the model. A summary of the latent variables and their constituent indicators in these studies can be seen in Table 1. Their role is explained herein.

Only one SEM study (Sigurdardottir et al., 2013) has attempted to explain the latent variable of adolescents' intention to cycle as adults including social and psychological latent variables from a mixed conceptual framework (TPB and ecological models). The latent variables were defined by a multiple-indicators (attitudes and perceptions) and multiple-causes (individual characteristics) (MIMIC) model, and related with structural equations to the latent intention to cycle. Teenagers' intentions to cycle as adults appear to be positively related with bicycling experience, willingness to accept car restrictions, negative attitudes towards cars and bicycle-oriented future vision, and negatively related to car ownership norms.

The extended version of DCM can be seen in five studies so far, where the incorporation of the latent variables improved the explanatory power of the models. The work of Habib and Zaman (2012) was the first ICLV model to include the bicycle as one of the available modes. However, the latent variable (latent modal captivity) referred to motorised modes. Since the focus of the paper was not bicycle demand, it was omitted from this review. Kamargianni and Polydoropoulou (2013) produced the first ICLV model to include latent variables affecting bicycling utility. The utility obtained from choosing a particular mode is therefore a function of a set of extended explanatory variables that includes objective attributes (cost and time of travel) and an attitudinal latent variable. The latent variable 'teenagers' willingness to walk and to cycle' was identified in a simultaneously estimated ICLV model, using an MIMIC model for the latent variable component of the joint model. The same survey was also used in the study by Kamargianni et al. (2015) to test the Bhat and Dubey (2014) new probit-kernel-based ICLV model formulation. This new application examined the influence of the latent variable 'physical activity propensity' on different modes, including the bicycle. Habib et al. (2014) presented an integrated econometric model of bicycle ownership (yes/no) and usage (utilitarian/recreational) using simultaneous estimators and four latent variables, namely 'bike ownership propensity', 'perception of the city's bikeability', 'safety consciousness' and 'comfortability of biking'.

The studies by Maldonado-Hinarejos et al. (2014) and Fernández-Heredia et al. (2016) focus on demonstrating easily and practically applicable models of bicycling choice behaviour, and the effects of introducing latent variables. Both studies develop ICLV models using sequential estimators. Maldonado-Hinarejos et al. (2014) included in their model variables such as travel time, type of cycle lane, parking facilities and traffic flow from an SP experiment, and four socio-demographic and four attitudinal latent variables identified using PCA ('Pro-bike', 'Context', 'Image' and 'Stress'). The incorporation of these latent variables reduced the power of other key drivers of the decision to ride a bicycle, such as travel time. Fernández-Heredia et al. (2016) extracted four psychosocial latent variables using

an MIMIC model ('Convenience', 'Pro-bike', 'External restrictions' and 'Physical determinants'), and used them as explanatory variables of the stated intention to use a public bike-share system on a Spanish university campus.

4. Conclusions and Identification of Research Gaps

Demand for non-motorised transport modes is poorly understood, especially when compared to motorised alternatives, since objective variables (time and cost) alone cannot sufficiently explain why travellers choose the bicycle for utilitarian purposes. This makes it even more necessary to promote advanced models with the explicit inclusion of psychological latent variables, among other aspects. Considerable data and multidisciplinary technical skills are required, which creates certain difficulties in modelling development but can be compensated with a clear understanding of the explanatory variables and methodologies used in previous studies.

In this paper we have summarised the evolution of modelling in the literature on utilitarian bicycling choice, with a particular focus on the increasing role of psychological (attitudinal or perceptual) variables. We have identified three chronological stages — early, intermediate and late — in modelling development according to the different ways of introducing psychological constructs into bicycling demand models. While studies in the early stage basically neglected psychological constructs, those in the intermediate stage (last decade) progressively recognised the potential explanatory power of these latent variables. It was not until the late stage, however, when researchers resolved the methodological issues associated with estimating DCMs with psychological and attitudinal constructs (these integrated models are part of the HCM framework). In sum, the role of latent variables in bicycle choice models has evolved from a marginal role to being recognised as the main driver explaining bicycle demand. This evolution has been fuelled by the advent of hybrid choice models and computationally efficient estimators capable of determining the weight of psychological constructs in decision-making.

4.1. Towards a Uniform Attitudinal Scale of Bicycling Demand

Although the literature in the last stage advocates the importance of latent variables as a major factor for explaining the use of the bicycle for utilitarian purposes, there is no uniform methodology in practice to identify the underlying relevant factors. The HCM literature generally focuses on deriving estimators with good statistical and computational properties, due to the complex formulation of the likelihood function, but with little description of how the latent variables are actually hypothesised, constructed, and validated, and with the set of indicators for the latent constructs usually shown as ad-hoc measurement scales. This lack of a uniform methodology makes it difficult to compare studies and creates limitations in identifying the potential evolution of changing attitudes. Based on the indicators we reviewed from both the intermediate and late stages, we propose the following set of questions (Table 2) as a uniform measurement scale for identifying attitudes towards bicycling. We are hopeful other studies will adopt this comprehensive list of indicators to enable a systematic comparison across different spatial and temporal contexts. There is still a need for comparisons between cities at different bicycling levels to truly understand how a city can become a 'champion' bicycling city (Dufour, 2010).

Table 1. Latent variables and indicators in the late-stage studies

Positivedurrent cycling experience	Signurdardottir et al. (2013)	Kamargianni and Polydoropoulou (2013)	Maldonado-Hinarejos et al. (2014)
I like to ride a cycle on a daily basis I will arrive faster by bicycle than by other mode to my daily activities When I cycle it is because it is the easiest transport mode for me I do not let bad weather stop me from cycling Cycling gives me personal freedom When I bike daily, I try to use the journey to exercise	WILLINGNESS TO WALK OR CYCLE TO SCHOOL Walk to get physical exercise Walk or cycle to school as it is the most cost-effective mode Cycle to school, there are bike paths Substitute motorized trips with active transport in order to protect the environment Substitute motorized trips with active transport in order to be fit	WILLINGNESS TO WALK OR CYCLE TO SCHOOL Walk to get physical exercise Walk or cycle to school as it is the most cost-effective mode Cycle to school, there are bike paths Substitute motorized trips with active transport in order to protect the environment Substitute motorized trips with active transport in order to be fit	PRO-BIKE Cycling is becoming much more popular Cycling is a method of transport I would be happy to be seen using Cycling is a convenient way of getting about Cycling provides good value for money Cycling is for everybody Cycling is good for rush hour journeys in London Cycling is a good way to get fit Cycling makes a difference to improving the environment Cycling is a family activity It's important for children to learn to cycle Do you feel cyclists are fit? Do you feel cyclists are like you?
The minimum driving license age would be 21 years The speed limit on motorways would be lowered to 90 kph It would be obligatory to purchase greenhouse gas quotas Driving in city centers would be banned Car travel would be limited to a certain number of kilometers per person per year There would be stricter requirements for taking a driving license Tolls would be collected on motorways The prices of gasoline, diesel and cars would increase Cars only were allowed to be jointly owned (car sharing)	PERCEPTION OF BIKEABILITY IN THE CITY Quality of city's bike infrastructure Quality of city's on-street bike lanes Quality of city's off-street bike lanes Quality of bike parking in the city	PERCEPTION OF BIKEABILITY IN THE CITY Quality of city's bike infrastructure Quality of city's on-street bike lanes Quality of city's off-street bike lanes Quality of bike parking in the city	IMAGE Do you feel cyclists are law abiding? Do you feel cyclists are considerate? Do you feel cyclists are harmless?
I am concerned about the environment It feels good to act in an environmentally responsible manner I prefer to choose environmentally friendly transport modes My family behaves in an environmentally friendly manner	COMFORTABILITY OF BIKING IN THE CITY Comfortability of biking on bike trails or paths Comfortability of biking on residential streets Comfortability of biking on major road with bike lanes Comfortability of biking on major road with narrow markings Comfortability of biking on major road without bike lanes	COMFORTABILITY OF BIKING IN THE CITY Comfortability of biking on bike trails or paths Comfortability of biking on residential streets Comfortability of biking on major road with bike lanes Comfortability of biking on major road with narrow markings Comfortability of biking on major road without bike lanes	CONTEXT Cycling is a safe way of getting about London is a city for cycling
SOCIAL INFLUENCE OF ENVIRONMENTAL CONCERN My school encourages environmentally responsible behavior My friends are concerned about environmental responsibility The media convinced me to behave in a more environmentally responsible manner	SAFETY CONSCIOUSNESS Necessity of more bike lanes on-street Necessity of separating bike paths and trails off-street Necessity of separating bike lanes from cars Necessity of better education for motorists Necessity of better education for cyclists Necessity of repairing potholes and bad pavements Necessity of reducing car speed Necessity of lowering car volume on street Necessity of better bike route signage Necessity of more pavement markings	SAFETY CONSCIOUSNESS Necessity of more bike lanes on-street Necessity of separating bike paths and trails off-street Necessity of separating bike lanes from cars Necessity of better education for motorists Necessity of better education for cyclists Necessity of repairing potholes and bad pavements Necessity of reducing car speed Necessity of lowering car volume on street Necessity of better bike route signage Necessity of more pavement markings	STRESS Cycling is an unpleasant experience Cycling is stressful
CAR-ORIENTED POLLUTED FUTURE VISION Congestion in cities will be worse because of more cars Air pollution will be a major health problem in cities The effect of global warming will be a greater problem	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	CONVENIENCE Efficiency Flexibility
NEGATIVE ATTITUDES TOWARDS CARS I believe that cars pollute the environment I believe that buses pollute the environment	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	PRO BIKE Cheap Ecological Healthy Fun
BICYCLE-ORIENTED CLEAN AIR FUTURE VISION More people would choose to cycle on a daily basis The conditions for cyclists would be better Driving will be prohibited in cities	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	PHYSICAL DETERMINANTS Distance Topography Health fitness Climate Comfort
SUBJECTIVE NORM OF OBTAINING A DRIVING LICENSE AND OWNING A CAR Getting your own car is part of growing up Society expects from us to have a driving license as adults Most of my friends are expected to obtain a driving license People whom I care about think that I should obtain a driving license	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	PHYSICAL ACTIVITY PROPENSITY Willing to go to school by bike or on foot to exercise myself Willing to substitute the motorized mode of transport with active mode of transport in order to be fit	EXTERNAL RESTRICTIONS Vandalism Facilities

Note: Latent variables in uppercase and indicators in lowercase.

Table 2. List of indicators to identify bicycle latent variables

Degree of agreement or disagreement towards: bicycle use for urban mobility is ...	
Accident risky (S)	Time reliable (C)
Theft risky (S)	Flexible (C)
Conflicts with pedestrians (S)	Independent (C)
Weather dependent (CM)	Relaxing and fun (C)
Sweat (CM)	Environmentally friendly (A)
Traffic stressful (CM)	Healthy (A)
Quick (C)	Cheap (A)
Degree of limitation provoked by ...	
Ride in the traffic (F)	Hilliness (PBC)
No cycleways (F)	Manoeuvring (PBC)
No safe parking (F)	Physical condition (PBC)
No showers/ranks at destination (F)	Fix a puncture (PBC)
	Helmet use (PBC)
Considering your (possible) bicycle use for urban mobility:	
(1) to what extent (would) the following groups of people approve?	
(2) how important to you is the opinion of the following groups of people in this regard?	
My family (SN)	
My friends (SN)	
My co-workers or classmates (SN)	

Note: Expected latent variables in parentheses next to indicators: (S): Safety; (CM): Comfort; (C): Convenience; (A): Awareness; (F): Bicycle facilities; (PBC): Bicycle ability; (SN): Social norm.

The list of indicators is intended to identify the most common psychological latent variables reviewed in terms of safety, comfort, convenience, awareness, social norm and bicycle ability, and is a compromise between an extensive list identified from the literature and a practice list for inclusion in a municipal household travel survey.

In a companion paper⁴ (Muñoz et al., 2016), we implement this list of indicators in a survey aimed at collecting RP data about bicycling demand in Vitoria-Gasteiz (Spain). Vitoria-Gasteiz is a medium-size (around 242,000 inhabitants) compact city characterised by an almost completely flat topography and a moderately cold climate, with damp winters and cool summers. Data were collected during spring 2014, revealing a bicycle use of 12.3% of total trips, which is the highest in Spain. Using the responses to these indicators (seven-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7)), six latent variables were identified, namely 'Safety and comfort', 'Direct advantages', 'Awareness', 'External facilities', 'Individual capacities' and 'Subjective norm'. To gain a preliminary idea of the structure of these latent variables, we first applied an explanatory factor analysis (EFA) with the indicators. An MIMIC model was then used with the indicators and with socio-economic and household characteristics to construct the latent variables.

4.2. Further Developments

Future research might develop more solid market segmentation approaches when using SEM and HCM in order to improve targeting policies and programmes and encourage bicycling. In particular, the group of people who will never use the bicycle no matter what the circumstances should be explicitly considered as a key segment to be modelled. A closer look at the experience, attitudes and perceptions of the different segments will provide policy-relevant insights into the preferences and motivations for adopting active transport as a lifestyle. To create advanced models of market segmentation requires a better understanding of the cognitive process that associates unobserved taste

heterogeneity, and heterogeneity in the valuation of the latent variables. From an econometric perspective, random parameter models (such as mixed logit, mixed probit or latent class) should be adopted as the kernel of a hybrid choice specification. Interactions between the latent and objective variables might also be considered.

Forecasting processes are notably absent from HCM, and might be reconsidered in future applications with particular care to avoid the endogeneity and cross-sectional issues highlighted by Chorus and Kroesen (2014). In fact, latent constructs appear to be key to a better understanding of current motivations for bicycle choice, but the use of weak structural relationships is weak forecast power. Weak structural relationships are the result of considering few causal factors — which are typically also discrete — to explain the formation of the latent constructs. Better-supported SEMs are thus necessary to improve forecasting power with latent variables. Attitudinal change models are also needed to represent and forecast future bicycle adoption levels under different policy scenarios. The use of a consistent list of indicators such as the one proposed above should facilitate inference, especially if implemented in longitudinal studies. Before-and-after studies on the implementation of specific policies such as bicycle-sharing systems are also essential for capturing attitudinal change.

Finally, many cities and metropolitan areas are keen to encourage bicycle use, and regularly conduct RP surveys to monitor modal share and other mobility characteristics. We suggest including bicycle-related questions — both objective and subjective (attitudes and perceptions) — in these surveys to further develop modelling frameworks with cycling latent variables. Advances in technology (GPS, sensors, cameras, trip-planning software and apps) are making it easier to collect rich data that can be exploited in new bicycle-route-choice and level-of-service models, and in easing the process of constructing time and cost attributes for the non-chosen modes. There is currently a trend towards adding trip satisfaction and other attitudinal questions to smartphone trip-planning apps, while time-consuming RP questions are collected passively. This trend will generate databases that allow objective attributes to be accurately measured and in which the role of latent factors will become even more central.

Notes

1. Indicators are usually responses to attitudinal or perceptual survey questions.
2. Some of the studies reviewed also include recreational or sport bicycle trips.
3. This research was published years later in a journal as Wardman, Tight, and Page (2007).
4. The paper develops a hybrid discrete choice model that includes bicycle as one alternative, and that follows the suggestions of the present paper.

Disclosure statement

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Appendix 1. Summary of significant variables in bicycle mode choice models (part 1/6)

Studies* VARIABLES		OBJECTIVE																															
		Socio-economic and household characteristics																															
		Gender (male)	Age (young)	Income	Level of studies (university)	Parent's level of studies (university)	Employment status (student)	Employment status (un-employed)	Employment status (white collar)	Employment status (self-employed)	Sector (agriculture)	Sector (manufacturing)	Work type (at home)	Inactive job	Hours of work/week	Need to be well dressed for work	Work schedule	Family type (with children)	Family type (^a : living with both parents; ^b : no-single; ^c : married)	Family size	Race (non-white)	Race (Asian)	Race (Hispanic)	Race (black)	Foreigner (^a : no-Dutch; ^b : no-British; ^c : non-Spanish)	Religion (Catholic)	Political (liberal)	Political (green party)	Bad health-Handicap	Hours of exercise/week	Hours of TV/week	Need to transport goods	
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*See appendices 2, 3 or 4 for numeration correspondence. Variables used in each study in grey. Coefficient sign when significant: positive (+); negative (-). Significant level: (+) or (-) at the 10% level; (++) or (..) at the 5% level; (+++) or (..) at the 1% level.

[illegible]

* See appendices 2, 3 or 4 for numeration correspondence. Variables used in each study in grey. Coefficient sign when significant: positive (+); negative (-). Significant level: (+) or (-) at the 10% level; (++) or (- -) at the 5% level; (+++) or (- - -) at the 1% level.

Appendix 1. Summary of significant variables in bicycle mode choice models (part 3/6)

Studies [#]	OBJECTIVE																															
	Built environment																															
VARIABLES	Area ^a / Degree of urbanisation ^b	Population	Population density	Land-use mix	Land-use design ^a / Built environment ^b	Employment accessibility-density	House location (outside)	House location (rural town)	School/University	Bike organisations	Environmental non-profits	Surface in forests, public services...	Surface in single family residential, large commercial	Surface in educational, industrial, small commercial	Distance to transit / Transit supply ^a	Distance to trail	Proximity to services	Proximity to recreational	Proximity to parks-forests	Proximity to commercials	Size closest grocery/restaurant	Intersection density	Traffic lights / Stop frequency	Handraces	Positioning / Priority-turns off / Pavement	Road network type (arterial)	Traffic flow (noise, emissions,...)	Traffic speed	Trip distance	Cycling victims	Cycling thefts	Social network effects
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[#]See appendices 2, 3 or 4 for numeration correspondence. Variables used in each study in grey. Coefficient sign when significant: positive (+); negative (-). Significant level: (+) or (-) at the 10% level; (++) or (-) at the 5% level; (+++) or (-) at the 1% level.

Appendix 1. Summary of significant variables in bicycle mode choice models (part 4/6)

Studies*	OBJECTIVE													SUBJECTIVE																						
	Natural environment							Cycling facilities						Indicators and latent variables of environmental and cycling facilities																						
	Hilliness/slope	Rain	Wind	Temperature	Dark	Natural amenities (topography, climate, access to water bodies)	Season (summer)	Cycling infrastructure	Bicycle parking - origin	Bicycle parking - destination	Showers at destination	Racks at destination	Bicycle municipal plan/budget/incentives	I/ LV - Hilliness/slope	LV - Risk (weather)	I/ LV - Risk (traffic)	I/ LV - Bicycle security	I/ LV - Distance	I - Sensitivity noise	I - LV - Sensitivity pollution	LV - Traffic flow	LV - Safety from bicycle theft	LV - Conflicts with pedestrians	LV - Attractiveness of the surroundings	I - Good transit service	I/ LV - Proximity to destinations	LV - Land-use mix diversity	I - Neighbourhood: safe to walk / walkability score	I - Neighbourhood: sense of community	I/ LV - Cycling infrastructure	I/ LV - Bike parking/storage	I/ LV - Rack /showers at workplace	I - Presence of streetlights	I - Presence of car facilities		
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*See appendices 2, 3 or 4 for numeration correspondence. Variables used in each study in grey. Coefficient sign when significant: positive (+); negative (-). Significant level: (+) or (-) at the 10% level; (++) or (-) at the 5% level; (+++) or (-) at the 1% level.

Appendix 1. Summary of significant variables in bicycle mode choice models (part 5/6)

Studies*	SUBJECTIVE																			
	Other psychological indicators and latent variables																			
VARIABLES	I - Satisfaction with cycling levels	I / LV - No major sweat problem	I / LV - Comfort / No-Effort	I - Comfortable (clothes)	I / LV - Comfortable (with traffic)	LV - Practical means of transport	I / LV - Convenience (speed, freedom, high mobility...)	I - Cyclists' freedom	I / LV - Cost (importance)	I - Time important	I - Flexibility important	I - Need car	I - Motorists considerate; Breakdown worry	I / LV - Environment important	I / LV - Sportiness / Health benefits	LV - Pro-bike / Awareness (pleasure, fitness, relax, nature)	LV - Concerned about dignity	I / LV - Lack of time	I / LV - Subjective-social norm (general)	I / LV - Social norm (colleagues/friends)
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*See appendices 2, 3 or 4 for numeration correspondence. Variables used in each study in grey. Coefficient sign when significant: positive (+); negative (-). Significant level: (+) or (-) at the 10% level; (++) or (-) at the 5% level; (+++) or (-) at the 1% level.

Appendix 1. Summary of significant variables in bicycle mode choice models (part 6/6)

Studies*	SUBJECTIVE																											
	Other psychological indicators and latent variables																											
	VARIABLES																											
	I - Intention	LV - Attitude	LV - Perceived behavioural control / cycling ability	LV - Perseverance	LV - Self-esteem	LV - Relation with parents	I - Cars' problems	LV - Lack of interest	LV - Physical well-being	LVs - Psychosocial; Body image; Lack of skills; External obstacles	I - Like riding the bicycle	I / LV - Like walking (pro-walk)	I - Like transit (pro-transit)	I / LV - Like driving (pro-car)	I / LV - Limit driving	I - Bike community preference	LV - Commute errands	I / LV - Descriptive norm	I - Carry things	Is - Well-dressed; Incentives	I - Non-commuting cycling habit	I - Go off-campus for lunch	I - I can rely on parents chauffeuring	Is - hate helmet; bike usual mode; rush in the morning; regular schedule; driving is cool; like to travel with friends	I - Have several travel options	LV - Anti-car	LV - Positive cycling experience	LV - Bicycle oriented future vision
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*See appendices 2, 3 or 4 for numeration correspondence. Variables used in each study in grey. Coefficient sign when significant: positive (+); negative (.). Significant level: (+) or (.) at the 10% level; (++) or (..) at the 5% level; (+++) or (...) at the 1% level.

Appendix 2. Studies: selected characteristics — explanatory variables

No.	Author (s) (Year)	Focus	Latent variables	Reduction method ^a	Trip purpose ^b	Context: city/area (country)
AGGREGATE						
1	Baltes (1996)	Census data	No	—	C	Metropolitan statistical areas (USA)
2	Nelson and Allen (1997)	Bicycle facilities	No	—	C	Cities (USA)
3	Dill and Carr (2003)	Census data and bicycle facilities	No	—	C	Cities (USA)
4	Rietveld and Daniel (2004)	Municipal policy-related variables	Yes	—	ALL	Cities (The Netherlands)
5	Parkin et al. (2008)	Socio-economic, physical and transport variables	Yes	—	C	All wards in England and Wales (UK)
6	Zahran et al. (2008)	Socio-economic, built, natural and civic variables	No	—	C	All continental counties (USA)
7	Vandenbulcke et al. (2011)	Spatial determinants	Yes	—	C	All municipalities (Belgium)
8	Buehler and Pucher (2012)	Separate bicycle facilities typology	No	—	C	90 large cities (USA)
9	Schoner and Levinson (2014)	Bicycle facility network quality	No	—	C	74 cities (USA)
DISAGGREGATE						
Early stage						
10	Noland and Kunreuther (1995)	Perceived risk and convenience	Yes	No	C	Philadelphia metropolitan area, PA (USA)
11	Taylor and Mahmassani (1996)	Cycle & Ride	Yes	No	C	Texas State (USA)
12	Katz (1996)	Attitudes	Yes	EFA	C	New South Wales (Australia)
13	Wardman et al. (1997)	Improved cycling facilities and weather	No	—	C	Leeds (England)
14	Wardman et al. (2000)	Joint RP-SP model	Yes	No	C	Leicester, Norwich, York and Hull (England)
15	Ortúzar et al. (2000)	Potential users of a new transport mode	No	—	ALL	Santiago (Chile)
16	Cervero and Duncan (2003)	Built environment (origin and destination)	No	—	NCT and R	San Francisco Bay Area, CA (USA)
17	Rodríguez and Joo (2004)	Local physical environment	No	—	C	University of North Carolina, living in Chapel Hill and Carboro, NC (USA)
18	Plaut (2005)	Individual and household characteristics	No	—	C	(USA)
Intermediate stage						
19	de Bruijn et al. (2005)	Psychological (TPB and Theory of Triadic Influence)	Yes	SE	T	(The Netherlands)
20	Moudon et al. (2005)	Built environment (objective + subjective)	Yes	—	ALL	King County, WA (USA)
21	Ryley (2006)	Model segmentation	No	—	C	West Edinburgh (Scotland)
22	Rose and Marfurt (2007)	Impact of a cycling event on travel behaviour	No	—	C	Victoria (Australia)
23	Titze et al. (2007)	Ecological model (university students)	Yes	PCA	T	Graz (Austria)

24	Titze et al. (2008)	Ecological model (adults)	Yes	PCA	T	Graz (Austria)
25	de Geus et al. (2008)	Psychosocial and environmental variables	Yes	SE	T	Flanders (Belgium)
26	Frank et al. (2008)	Tour-based framework	No	-	ALL	King, Kitsap, Pierce and Snohomish Counties, WA (USA)
27	Roorda et al. (2009)	Tour-based framework	No	-	ALL	Toronto (Canada)
28	Akar and Clifton (2009)	Individual perceptions	Yes	PCA	C	University of Maryland, College Park; DC (USA)
29	Handy and Xing (2010)	Ecological model	Yes	SE	C	Davis, Woodland, Chico and Turlock; CA (USA)
30	Panter et al. (2010)	School children's attitudes	Yes	SE	C	Boulder, CO (USA); Eugene, OR (USA)
31	Engbers and Hendriksen (2010)	Physical activity	No	-	C	Norfolk (England)
32	Winters et al. (2010)	Built environment (origin, route, and destination)	No	-	T	Metro Vancouver (Canada)
33	Dell'Olio et al. (2011)	Bike-sharing system implementation	No	-	ALL	Torrelavega, Cantabria (Spain)
34	Goetzke and Rave (2011)	Social network effects	No	-	C/NTC/R	20 municipalities (Germany)
35	Heinen et al. (2011)	Psychological (TPB) by distances	Yes	EFA	C	Delft, Zwolle, Midden-Delfland and Pijnacker-Nootdorp (The Netherlands)
36	Lee et al. (2011)	Background on leisure cycling	Yes	PCA	C	Seoul (South Korea)
37	Börjesson and Eliasson (2012)	Value of time	No	-	ALL	Stockholm (Sweden)
38	Buehler (2012)	Work-related facilities	No	-	C	Washington, DC region (USA)
39	Heinen et al. (2012)	Psychological and work-related facilities	Yes	SE	C	Delft, Zwolle, Midden-Delfland and Pijnacker-Nootdorp (The Netherlands)
40	Emond and Handy (2012)	Ecological model (high school students)	Yes	SE	C	Davis, CA (USA)
41	Aarts et al. (2013)	Ecological model (primary school students)	Yes	SE	C	4 medium-sized cities (The Netherlands)
42	Akar et al. (2013)	Bicycling to campus and gender	Yes	No	C	Ohio State University Campus, Columbus, OH (USA)
43	Muñoz et al. (2013)	Psychological (TPB)	Yes	EFA	C	Madrid (Spain)
44	Dell'Olio et al. (2014)	Potential users of a bike-sharing system	No	-	ALL	Santander, Cantabria (Spain)
45	Hamre and Buehler (2014)	Work-related facilities	No	-	C	Washington, DC region (USA)
46	Gehrke and Clifton (2014)	Built environment: land use diversity measures	No	-	NCT and R	Portland, OR (USA)
47	Muhs and Clifton (2014)	Built environment	Yes	No	NCT and R	Portland, OR (USA)
48	Ma and Dill (2015)	Built environment (objective + subjective)	Yes	EFA	C	Portland, OR (USA)
Late stage						
49	Sigurdardottir et al. (2013)	Teenagers' intentions to ride a bicycle (TPB+ecological model)	Yes	MIMIC	C	(Denmark)

(Continued)

Appendix 2. Continued.

No.	Author (s) (Year)	Focus	Latent variables	Reduction method ^a	Trip purpose ^b	Context: city/area (country)
50	Kamargianni and Polydoropoulou (2013)	Attitudes in teenagers	Yes	MIMIC	C	(Cyprus)
51	Maldonado-Hinarejos et al. (2014)	Attitudes and perceptions	Yes	PCA	T	London (England)
52	Habib et al. (2014)	Integrated modelling framework: biking and bicycle ownership	Yes	MIMIC	ALL	Toronto (Canada)
53	Kamargianni et al. (2015)	Attitudes in teenagers	Yes	MIMIC	C	(Cyprus)
54	Fernández-Heredia et al. (2016)	Attitudes and perceptions towards a bike-sharing system	Yes	MIMIC	C	Ciudad Universitaria Campus, Madrid (Spain)

^aSE: summated scales; EFA: explanatory factor analysis; PCA: principal component analysis; MIMIC: multiple indicators multiple causes; SEM: structural equations model.

^bALL: All purposes (including sport/leisure/recreational); T: transport; C: commuting; NCT: non-commuting transport; R: recreational.

Appendix 3. Studies: selected characteristics — modelling issues (part 1/2)

No.	Author(s) (year)	Type of model ^a	Alc ^b	Specification	Dependent variable	Choice set ^c	Source of data ^d (zones or individuals)
AGGREGATE							
1	Baltes (1996)	R	–	–	% of bicycle commuting trips	–	RP (284)
2	Nelson and Allen (1997)	R	–	–	% of bicycle commuters	–	RP (18)
3	Dill and Carr (2003)	R	–	–	% of bicycle commuters	–	RP (42)
4	Rietveld and Daniel (2004)	R	–	Semi-log	% of bicycle trips	–	RP (103)
5	Parkin et al. (2008)	LR	–	With saturation level	% of bicycle commuters	–	RP (8,800)
6	Zahran et al. (2008)	ZINBR	–	–	Bicycle commuters	–	RP (2,974)
7	Vandenbulcke et al. (2011)	R	–	With spatial regimes and heteroscedasticity correction	% of bicycle commuting trips	–	RP (308+281)
8a	Buehler and Pucher (2012)	R	–	Semi-log	Bicycle commuters/10,000 inhabitants	–	RP (90)
8b		LR	–	–	% of bicycle commuters	–	
9	Schoner and Levinson (2014)	R	–	–	Bicycle commuters/10,000 commuters	–	RP (74)
DISAGGREGATE							
Early stage							
10	Noland and Kunreuther (1995)	DCM	–	Multinomial logit	Commuting mode choice	BK, W, PT, C	RP (354)
11	Taylor and Mahmassani (1996)	DCM	–	Nested logit (sequential)	Commuting mode choice	Upper: PT*, C Lower: B&R, P&R	SP (814)
12a		LR	–	Binary logistic	Cycling regularly or not	Yes, No	RP (295)
12b	Katz (1996)	DCM	–	Nested logit	Commuting mode choice	Upper: Tx, Non-Tx* Lower: BK, B, C	SP (30)
13	Wardman et al. (1997)	DCM	–	Binary logit	Commuting mode choice	C or (BK, B)	SP (221)
14	Wardman et al. (2000)	DCM	–	Multinomial logit	Commuting mode choice	BK, W, P, B, T, C	RP + SP
15a	Ortúzar et al. (2000)	DCM	Yes	Binary logit	Willingness to cycle	Yes, No	RP (3,57+1,560)
15b		DCM	–	Multinomial logit	Mode choice	BK, BK-M, M, B, P&R, FB, C	SP (357)
16	Cervero and Duncan (2003)	DCM	Yes	Binary logit	Choice of cycling	Yes, No	RP (7,836)
17	Rodríguez and Joo (2004)	DCM	–	Multinomial logit	Commuting mode choice	BK, W, B, C	RP (509)
18	Plaut (2005)	LR	–	Nested logit Heteroskedastic logit Binary logistic	Commuting mode choice	–	RP (21,228+7,140)
Intermediate stage							
19	de Bruijn et al. (2005)	LR	–	Binary logistic	Choice of cycling for transport	Yes, No	RP (3859)
20	Moudon et al. (2005)	DCM	Yes	Binary logit	Choice of cycling	Yes, No	RP (608)

(Continued)

Appendix 3. Continued.

No.	Author(s) (year)	Type of model ^a	AIC ^b	Specification	Dependent variable	Choice set ^c	Source of data ^d (zones or individuals)
21	Riley (2006)	DCM		Binary logit	Commuting mode choice	BK, current mode (W, B, C) Yes, No	SP (100+58+37)
22	Rose and Marfurt (2007)	LR		Binary logistic	Choice of cycling for commuting		RP (1952)
23	Titze et al. (2007)	LR		Multinomial logistic	Cycling for transport mode choice	BK (regular), BK (irregular), No-BK	RP (512)
24	Titze et al. (2008)	LR		Binary logistic	Choice of cycling for transport	Yes, No	RP (1,000)
25	de Geus et al. (2008)	LR		Binary logistic	Choice of cycling for transport	Yes, No	RP (343)
26	Frank et al. (2008)	DCM		Nested logit	Home-based work tour; Home-based other tours	BK, W, PT, C, P	RP (8707)
27	Roorda et al. (2009)	DCM		Probit	Mode choice	BK, W, M, T, B, Tx, C, P	RP (8552)
28	Akar and Clifton (2009)	DCM		Multinomial logit	Commuting mode choice	BK, W, PT, C	RP (997)
29	Handy and Xing (2010)	DCM	Yes	Binary logit	Commuting mode choice	BK, C	RP (420)
30	Panther et al. (2010)	LR		Multinomial logistic	Commuting mode choice	BK, W, Motorised mode	RP (654+475+617)
31	Engbers and Hendriksen (2010)	LR		Binary logistic	Choice of cycling for commuting	Yes, No	RP (799)
32	Winters et al. (2010)	LR		Binary logistic	Transport mode choice	BK, C	RP (1902)
33	Dell'Olio et al. (2011)	DCM		Multinomial logit	Mode choice	BK, B, C	SP
34	Goetzke and Rave (2011)	LR		Binary logistic	Choice of cycling for commuting	Yes, No	RP (840)
					Choice of cycling for shopping	Yes, No	RP (706)
					Choice of cycling for going on errands	Yes, No	RP (644)
					Choice of cycling for recreation	Yes, No	RP (1091)
35	Heinen et al. (2011)	DCM	Yes	Binary logit	Choice of cycling for commuting	Yes, No	RP (1531+784+1863)
36a	Lee et al. (2011)	DCM		Multinomial logit	Commuting mode choice	BK, PT, C	SP (131+172)
36b		DCM	Yes	Binary logit	Previous leisure cycling experience	Yes, No	SP (303)
37	Börjesson and Eliasson (2012)	DCM		Binary logit	Mode choice	BK, second-best mode (PT, C)	SP (740)
38	Buehler (2012)	LR**		Binary logistic	Choice of cycling for commuting	Yes, No	RP (5091)

39	Heinen et al. (2012)	DCM	Yes	Binary logit	Choice of cycling for commuting	Yes, No	RP (4171)
40	Emond and Handy (2012)	LR		Binary logit	Choice of cycling for commuting	Yes, No	RP (1190)
41	Aarts et al. (2013)	LR		Multinomial logit	Commuting mode choice	BK, W, Inactive mode	RP (5963)
342	Akar et al. (2013)	DCM		Multinomial logit	Commuting mode choice	BK, W, PT, C	RP (953+614)
43	Muñoz et al. (2013)	LR		Binary logit	Choice of cycling for commuting	Yes, No	RP (224)
44a	Dell'Olio et al. (2014)	DCM		Mixed logit	Mode choice	BK, W, PT, C	RP (1987)
44b		DCM		Mixed logit	Mode choice	BK, W, PT, C	SP (117)
45	Hamre and Buehler (2014)	LR		Multinomial logit	Commuting mode choice	BK, W, PT, C	RP (4630)
46	Gehrke and Clifton (2014)	DCM	Yes	Multinomial logit	Non-commuting mode choice	BK, W, PT, C, P	RP (4183)
47	Muhs and Clifton (2014)	LR		Binary logit	Choice of cycling for non-commuting	Yes, No	RP (411+167+63)
48	Ma and Dill (2015)	LR		Binary logit	Choice of cycling for transport	Yes, No	RP (616)
Late stage							
49	Sigurdardottir et al. (2013)	SEM		-	Intention to cycle	-	SP (3025)
50	Kamargianni and Polydoropoulou (2013)	HCM		Simultaneous estimation. Logit-kernel	Mode choice to school	BK, W, B, C	SP (4174)
51	Maldonado-Hinarejos et al. (2014)	HCM		Sequential estimation. Mixed logit	Mode choice for transport	BK, W, PT, C	SP (1,985)
52	Habib et al. (2014)	HCM	Yes	Simultaneous estimation. Probit-kernel	Choice of cycling for transport	Yes, No	RP (708)
					Choice of cycling for recreation	Yes, No	
53	Kamargianni et al. (2015)	HCM		Simultaneous estimation. Probit-kernel	Choice of owning bikes	1,2,3,4,5	
					Commuting mode choice	BK, W, B, C, PTW	SP (2171)
54	Fernández-Heredia et al. (2016)	HCM	Yes	Sequential estimation. Binary logit	Choice of cycling for commuting	Yes, No	SP (3048)

^aR: Linear regression; LR: Logistic regression; ZINBR: zero-inflated negative binomial regression; DCM: discrete choice model; HCM: hybrid choice model; SEM: structural equation model.

^bAIC: DCM with only alternative-invariant covariates.

^cBK: bike; W: walking; PT: public transport; B: bus; FB: feeder bus; M: metro; T: train; C: car; P: passenger; B&R: bike and ride; P&R: park and ride; Tx: taxi; PTW: powered two wheelers.

^dRP: revealed preference data; SP: stated preference data.

*Reference nest for the lower level in nested DCM.

**ReLogit: Rare Events Logistic Regression.

Appendix 4. Studies: selected characteristics — modelling issues (part 2/2)

No.	Author(s) (Year)	Inference	Goodness of fit ^a
AGGREGATE			
1	Baltes (1996)	—	Adj. $R^2 = 0.486$
2	Nelson and Allen (1997)	—	Adj. $R^2 = 0.825$
3	Dill and Carr (2003)	—	Adj. $R^2 = 0.34$
4	Rietveld and Daniel (2004)	—	Adj. $R^2 = 0.7260$
5	Parkin et al. (2008)	Sample enumeration	Adj. $R^2 = 0.816$
6	Zahran et al. (2008)	—	AIC, SIC, $R^2 = 0.69$ (Cragg and Uhler's)
7	Vandenbulcke et al. (2011)	—	AIC, SIC
8a	Buehler and Pucher (2012)	—	Adj. $R^2 = 0.64$
8b		—	$\bar{\rho}^2 = 0.62$ (McFadden)
9	Schoner and Levinson (2014)	Elasticities	Adj. $R^2 = 0.833$
DISAGGREGATE			
Early stage			
10	Noland and Kunreuther (1995)	Elasticities and sample enumeration	$\bar{\rho}^2 = 0.528$ (McFadden)
11	Taylor and Mahmassani (1996)	—	85.084% correctly explained
12	Katz (1996)	Elasticities	ρ^2 (C) = 0.175 (McFadden)
			$\bar{\rho}^2 = 0.52$ (McFadden)
			$\rho^2 = 0.161$
13	Wardman et al. (1997)	Sample enumeration	ρ^2 (C) = 0.28
14	Wardman et al. (2000)	Sample enumeration	ρ^2 (C) = (0.0905; 0.1897)
15	Ortúzar et al. (2000)	Sample enumeration	ρ^2 (C) = 0.1409
16	Cervero and Duncan (2003)	—	$\rho^2 = 0.131$ (McFadden)
17	Rodríguez and Joo (2004)	Relative importance and elasticities	$\bar{\rho}^2 = 0.321$ (McFadden)
			$\bar{\rho}^2 = 0.312$ (McFadden)
			$\bar{\rho}^2 = 0.268$ (McFadden)
			AIC, SIC
18	Plaut (2005)	—	$\rho^2 = 0.29$
Intermediate stage			
19	de Bruijn et al. (2005)	—	$\rho^2 = 0.131$
20	Moudon et al. (2005)	—	ρ^2 (C) = (0.1125 ; 0.1863; 0.0853)
21	Ryley (2006)	—	69.4% correctly explained
22	Rose and Marfurt (2007)	—	$\rho^2 = 0.379$ (Nagelkerke)
23	Titze et al. (2007)	—	—
24	Titze et al. (2008)	—	—
25	de Geus et al. (2008)	—	—
26	Frank et al. (2008)	Elasticities	ρ^2 (C) = (0.639; 0.475)
27	Roorda et al. (2009)	Sample enumeration	$\bar{\rho}^2 = 0.7210$ (McFadden)
28	Akar and Clifton (2009)	—	—
29	Handy and Xing (2010)	—	$\bar{\rho}^2 = 0.662$ (McFadden)

30	Panter et al. (2010)	-	-
31	Engbers and Hendriksen (2010)	-	-
32	Winters et al. (2010)	-	-
33	Dell'Olio et al. (2011)	-	-
34	Goetzke and Rave (2011)	-	-
		Marginal effects and elasticities	
			$\rho^2 = 0.257$
			$\rho^2 = 0.271$
			$\rho^2 = 0.243$
			$\rho^2 = 0.197$
35	Heinen et al. (2011)	-	$\rho^2 = (0.35; 0.47; 0.56)$ (McKelvey-Zavoina)
36	Lee et al. (2011)	-	$\tilde{\rho}^2 = (0.365; 0.239)$ (McKelvey-Zavoina)
			$\rho^2 = 0.463$ (Estrella)
			$\tilde{\rho}^2 = 0.377$
37	Börjesson and Eliasson (2012)	-	
38	Buehler (2012)	-	$\rho^2 = 0.30$ (McFadden)
39	Heinen et al. (2012)	-	$\rho^2 = 0.81$ (McKelvey-Zavoina)
40	Emond and Handy (2012)	-	$\tilde{\rho}^2 = (0.368; 0.372; 0.377)$ (McFadden)
41	Aarts et al. (2013)	-	-
42	Akar et al. (2013)	-	$\rho^2 = (0.71; 0.61)$
43	Muñoz et al. (2013)	-	$\rho^2 = 0.41$ (Cox & Snell)
44	Dell'Olio et al. (2014)	-	-
45	Hamre and Buehler (2014)	Sample enumeration	
46	Gehrke and Clifton (2014)	Sample enumeration	
47	Muhs and Clifton (2014)	-	-
48	Ma and Dill (2015)	-	$\rho^2 = 0.12$ (Cox & Snell)
			$\tilde{\rho}^2 = 0.288$ (McFadden)
Late stage			SRMR=0.072, RMSEA =0.067
49	Sigurdardottir et al. (2013)	-	-
50	Kamargianni and Polydoropoulou (2013)	-	-
51	Maldonado-Hinarejos et al. (2014)	Sample enumeration	
52	Habib et al. (2014)	-	$\tilde{\rho}^2 = 0.504$ (McFadden)
53	Kamargianni et al. (2015)	-	$\rho^2 = 0.28$
54	Fernández-Heredia et al. (2016)	-	RMSE, MAPE, = 0.144
			$\rho^2 = 0.1872$ (McFadden)

 $\bar{\rho}^{-2}$: adjusted ρ^2 .

2.10 Bicycle indicators

Table 2.1. List of indicators from the studies reviewed (Part 1/2)

Indicators \ Studies*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cost		x	x	x		x					x		x		x	x	x	x	x			x		x
Travel time/travel savings		x	x			x	x																	x
To be in a hurry		x	x				x								x							x		
Distance		x									x					x			x					
Interesting places to bike to											x		x	x										
Hills				x	x						x		x	x					x					
Weather			x	x		x	x	x					x	x		x		x						
Night-time/darkness			x			x	x	x					x	x		x		x	x					
Bicycle infrastructures											x	x	x	x		x			x	x				
Bicycle parking		x					x					x	x	x		x			x	x			x	
Ranks, shower and changing facilities		x										x				x				x				
Surface condition					x						x													
Convenient/efficient/quick								x		x			x	x			x	x			x		x	
Availability (flexibility of departure)																x								x
Errands (flexibility of route)						x												x	x	x				x
Time reliable																								
Easy to park																								
Pleasure/enjoy/fun		x		x				x	x				x	x				x				x		x
Relaxing			x	x			x						x	x								x		x
Freedom			x				x						x	x								x		
Offers privacy																								x
Fitness/healthy/exercise		x		x		x	x	x		x		x	x	x		x	x	x	x	x		x		x
Environmentally friendly		x				x	x	x			x	x	x	x	x		x	x	x	x		x		x
Air quality/pollution/quality of life				x	x						x		x	x										
Noise					x								x	x										
Seeing the sights/closeness to nature				x									x	x				x						
Like bicycling											x	x							x	x				
Want to/preference/motivation								x		x	x	x			x	x						x		
Capability/ cycling ability		x			x							x				x	x					x		x
Easy to ride		x							x		x													
Physical well-being																x	x			x	x			
Effort		x			x			x					x	x										
Comfort			x				x				x	x								x			x	x
Sweat		x											x	x										
Clothing/Helmet													x	x					x					
Dangerous/unsafe			x		x						x	x	x	x		x		x	x	x	x		x	
Crash/accident risk		x	x	x		x		x					x	x		x			x	x		x		x
Traffic safety-flow-speed		x	x	x			x				x		x	x		x		x			x			
Neighbourhood safety		x						x			x									x	x			
Conflicts with pedestrians				x									x					x	x	x				
Threat			x		x		x									x					x	x		
Theft			x				x	x					x	x		x						x	x	
Luggage		x	x	x			x						x			x				x				
Mechanical maintenance			x														x							
Laws and regulations																		x						
Education on bicycle riding/information																		x						
Support/Encouragement: family			x				x							x							x	x		x
Support/Encouragement: friends				x				x						x							x	x		
Support/Encouragement: colleagues			x	x				x												x				
Descriptive norm: family, friends													x	x								x		
Descriptive norm: co-workers																				x				
Biking is normal																			x					
Social status of cyclists													x											x
Cycling identity/lifestyle																								x
Accompany/ joint activity		x		x																				

*See Table 2.2. for numeration correspondence

Table 2.1. List of indicators from the studies reviewed (Part 2/2)

Indicators	Studies*	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Cost		x				x		x	x		x		x	x						x	x	x		
Travel time/travel savings		x	x		x								x											
To be in a hurry							x					x	x											
Distance		x	x				x	x	x			x		x		x					x			
Interesting places to bike to			x																					
Hills		x	x											x	x						x			
Weather		x	x	x		x			x		x	x	x	x	x				x		x			
Night-time/darkness		x	x									x												
Bicycle infrastructures				x	x		x	x		x		x			x					x	x		x	
Bicycle parking		x	x	x		x					x	x	x	x							x		x	
Ranks, shower and changing facilities		x	x												x						x			
Surface condition		x	x							x		x											x	
Convenient/efficient/quick									x				x	x	x				x		x	x		
Availability (flexibility of departure)				x		x	x				x		x	x	x		x				x			
Errands (flexibility of route)				x		x	x						x	x	x						x			
Time reliable													x	x	x									
Easy to park															x			x						
Pleasure/enjoy/fun					x									x	x						x	x		
Relaxing					x									x								x		
Freedom						x													x					
Offers privacy					x																			
Fitness/healthy/exercise	x				x	x			x		x		x	x					x	x	x	x		x
Environmentally friendly					x	x			x				x	x					x	x	x	x		x
Air quality/pollution/quality of life										x			x	x					x					
Noise	x		x																					
Seeing the sights/closeness to nature			x																					
Like bicycling						x						x				x			x					
Want to/preference/motivation																x								
Capability/ cycling ability		x				x						x		x										
Easy to ride												x					x	x		x				
Physical well-being	x	x				x																		
Effort		x											x	x							x			
Comfort					x								x	x				x			x		x	
Sweat																								
Clothing/Helmet		x				x						x												
Dangerous/unsafe		x	x			x			x	x	x	x	x				x	x			x	x		
Crash/accident risk	x		x	x								x		x										x
Traffic safety-flow-speed			x	x		x				x	x	x	x	x	x				x				x	
Neighbourhood safety						x				x		x				x								
Conflicts with pedestrians																								
Threat			x							x		x												
Theft			x			x				x		x	x								x			
Luggage		x	x	x		x			x							x								
Mechanical maintenance			x																					
Laws and regulations			x	x				x														x		
Education on bicycle riding/information			x					x														x	x	
Support/Encouragement: family					x	x						x		x	x	x								
Support/Encouragement: friends						x						x		x										
Support/Encouragement: colleagues														x	x									
Descriptive norm: family, friends						x						x		x		x								
Descriptive norm: co-workers												x		x		x								
Biking is normal												x											x	
Social status of cyclists	x			x	x	x	x	x						x								x		
Cycling identity/lifestyle					x											x						x		
Accompany/ joint activity			x				x															x		

*See Table 2.2. for numeration correspondence

Table 2.2. List of studies reviewed

Study nº	Author(s) (year)	Included in paper I	Study nº	Author(s) (year)	Included in paper I
1	Noland and Kunreuther (1995)	Yes	25	Lee et al. (2011)	Yes
2	Katz (1996)	Yes	26	van Bakkum et al. (2011)	
3	Forward (1998)		27	Winters et al. (2011)	
4	Gardner (1998)		28	Cheng and Liu (2012)	
5	Wardman et al. (2000)	Yes	29	Heinen and Handy (2012); Heinen et al. (2012)	Yes (2 nd)
6	Bergström and Magnusson (2003)		30	Emond and Handy (2012)	Yes
7	Forward (2004)		31	Nkurunziza et al. (2012)	
8	Stinson and Bhat (2004)		32	Whannell et al. (2012)	
9	de Bruijn et al. (2005)	Yes	33	Aarts et al. (2013)	Yes
10	Ryley (2006a)	Yes	34	Akar et al. (2013)	Yes
11	Dill and Voros (2007)		35	Dill and McNeil (2013); Ma and Dill (2015)	Yes (2 nd)
12	Gatersleben and Appleton (2007)		36	Li et al. (2013)	
13	Titze et al. (2007)	Yes	37	Muñoz et al. (2013)	Yes
14	Titze et al. (2008)	Yes	38	Damant-Sirois et al. (2014)	
15	de Geus et al. (2008)	Yes	39	Dill et al. (2014)	
16	Akar and Clifton (2009)	Yes	40	Ma et al. (2014)	
17	Sener et al. (2009)		41	Muhs and Clifton (2014)	Yes
18	Gatersleben and Haddad (2010)		42	Sigurdardottir et al. (2013)	Yes
19	Handy et al. (2010); Xing et al. (2010)		43	Kamargianni and Polydoropoulou (2013)	Yes
20	Handy and Xing (2010)	Yes	44	Fernández-Heredia et al. (2016); Fernández-Heredia et al. (2014); Rondinella et al. (2012)	Yes (1 st)
21	Panther et al. (2010)	Yes	45	Maldonado-Hinarejos et al. (2014)	Yes
22	Eriksson and Forward (2011)		46	Habib et al. (2014)	Yes
23	He et al. (2011)		47	Kamargianni et al. (2015)	Yes
24	Heinen et al. (2011)	Yes			

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3 Latent variables and bicycle commuting

Considering the main role of latent variables for explaining bicycle choice identified in the literature review, this chapter is a continuation and in depth exploration of this relationship. Hence, this work follows the recommendation for future research from chapter 2 of a closer look at the experience, attitudes and perceptions of the different segments to provide policy-relevant insights.

The literature review has also shown the diversity in modelling techniques and in the bicycle indicators used in previous studies. Moreover, this study has highlighted the need for comparisons between cities at different bicycling levels to truly understand how a city can become a ‘champion’ bicycling city (Dufour, 2010). Since most previous studies on this topic were developed in countries with a high daily use of the bicycle for urban mobility, the current analysis focuses on two urban contexts in Spain –which has a rather low bicycle share of trips for urban mobility–, following the research work by Heinen et al. (2011), to enable a systematic comparison.

The two urban contexts were chosen to be opposite examples of cycling environments so as to compare results between them and analyse the influence of the contexts. First, the big and mountainous city of Madrid (***paper II***), which has a mild Mediterranean weather and low bicycle culture and use. Second, the medium and flat city of Vitoria-Gasteiz (***paper III***): moderately cold weather and a strong increase in bicycle use and culture during recent years.

For the special case of commuting trips, the analyses employed in this chapter include the identification of bicycle indicators to be the basis for the latent variables, the construction of the latent variables and the bivariate and multivariate associations between the bicycle indicators/latent variables and the bicycle commuting trip. Ad-hoc recommendations for cycling policies are made based on the results.

This chapter includes two papers that have been published as:

- II. Muñoz, B., Monzon, A., and Lois, D. (2013) Cycling habits and other psychological variables affecting commuting by bicycle in Madrid, Spain. Transportation Research Record: Journal of the Transportation Research Board, 2382, 1-9, DOI: 10.3141/2382-01.
- III. Muñoz, B., Monzon, A., and Lopez, E. (2016) Transition to a cyclable city: latent variables affecting bicycle commuting. Transportation Research Part A: Policy and Practice, 84, 4-17, DOI: 10.1016/j.tra.2015.10.006.

Cycling Habits and Other Psychological Variables Affecting Commuting by Bicycle in Madrid, Spain

Begoña Muñoz, Andres Monzon, and David Lois

To develop effective cycling policies, decision makers and administrators should know the factors influencing the use of the bicycle for daily mobility. Traditional discrete choice models tend to be based on variables such as time and cost, which do not sufficiently explain the choice of the bicycle as a mode of transportation. Because psychological factors have been identified as particularly influential in the decision to commute by bicycle, this paper examines the perceptions of cycling factors and their influence on commuting by bicycle. Perceptions are measured by attitudes, other psychological variables, and habits. Statistical differences in the variables are established in relation to the choice of commuting mode and bicycle experience (commuter, sport-leisure, no use). Doing so enables the authors to identify the main barriers to commuting by bicycle and to make recommendations for cycling policies. Two underlying structures (factors) of the attitudinal variables are identified: direct benefits and long-term benefits. Three other factors are related to variables of difficulty: physical conditions, external facilities, and individual capacities. The effect of attitudes and other psychological variables on people's decision to cycle to work-place of study is tested by using a logit model. In the case study of Madrid, Spain, the decision to cycle to work-place of study is heavily influenced by cycling habits (for noncommuting trips). Because bicycle commuting is not common, attitudes and other psychological variables play a less important role in the use of bikes.

The benefits of bicycle use are undeniable, both for users (in health, flexibility, availability, cost, speed) and for society (low emissions, sustainability). As a result of these benefits, the bicycle as a transportation mode has become a key element of many transportation policies designed to foster sustainable development. Many countries, regions, and cities have initiated policies supporting bicycle use. In Spain, these policies include measures such as creating cycling lanes and safe bicycle parking, improving bicycle-public transportation intermodality, and public bicycle-sharing systems. These measures have fueled a positive trend in bicycle use in Spain (1). However, cycling levels are still low, especially for commuting trips.

To develop effective cycling policies, policy makers and administrators should know the factors that influence the use of the bicycle

for daily mobility. Traditional discrete choice models are mainly based on variables such as time and cost. These variables do not sufficiently explain the choice of the bicycle as a mode of transportation. Some researchers have noted a significant influence of psychological factors—such as attitudes, social norms, perceived behavioral control and habits—in the decision to commute by bicycle. Bicycle commuters show more positive attitudes toward bicycle use (2–5), more perceived social norms or psychological support for using the bicycle (2, 3, 6), more positive perceived behavioral control toward bicycle use (2), and less perception of barriers (4, 6). However, habits reduce the influence of these constructs in the decision to use the bicycle (7). Habits of using other modes have a negative impact on bicycle use (8), while the habit of using the bicycle for noncommuting mobility increases the frequency of bicycle use for commuting trips (7, 9). In view of the limited research on the relationship between attitudes, other psychological constructs, and cycling (10), this research project aims to continue analyzing the relationship between psychological factors and bicycle commuting by following the research work of Heinen et al. (5).

The paper is organized as follows. The theoretical framework is presented in the next section. That is followed by descriptions of the case study, data collection, and variables. Next come the results, which determine the differences between various types of users in their perceptions of cycling factors. On the basis of those factors, the main structures underlying attitudinal and other psychological variables are identified and defined. The analysis continues with an examination of the psychological factors influencing bicycle commuting through a binary logit model. The final section contains some policy recommendations and conclusions.

FRAMEWORK

The framework of this paper is the theory of planned behavior (TPB) (11), which is the best-known and most widely supported attitudinal psychological theory in most studies relating to behavioral decisions. This theory has been used in various studies on cycling (2, 5, 12) and in the field of active travel behavior (7, 13). TPB states that attitudes toward a behavior, subjective norms, and perceived behavioral control combine to shape an individual's behavioral intention and final behavior, which in the case of the current research is commuting by bicycle. These components are described by Ajzen as follows: the attitude toward a behavior is “the degree to which performance of the behavior is positively or negatively valued”; the subjective norm is “the perceived social pressure to engage or not to engage in a behavior”; and the perceived behavioral control (PBC) refers to “people's

B. Muñoz, Transport Research Center, and A. Monzon, Department of Civil Engineering, Universidad Politécnica de Madrid, c/ Profesor Aranguren s/n, Ciudad Universitaria, 28040 Madrid, Spain. D. Lois, Department of Social Psychology, Universidad Nacional de Educación a Distancia, c/ Juan del Rosal 10, 28040 Madrid, Spain. Corresponding author: B. Muñoz, b.muñoz@upm.es.

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FIGURE 1 Application of theory of planned behavior to cycling behavior.

perceptions of their ability to perform a given behavior" (14). The descriptive norms, which were included by Ajzen and Fishbein (15) in a revision of the TPB so as to complete the subjective norm, have also been incorporated into this study. They are defined as perceptions of what others are doing. Some studies have shown that habit also has a significant influence on behavior, specifically on bicycle use (7). Therefore, habit was also included as part of this research. All these elements were applied to the study of cycling behavior, as shown in Figure 1.

This study focused on the choice of commuting mode to work or study: the mode used three or more times per week. It also takes into account the subjects' cycling experience for purposes other than commuting. As Figure 1 shows, three categories were established for the analyses: the person's (a) use or nonuse of a bicycle for the daily commute [cycling commuter (CC) or noncycling commuter (NCC)]; (b) commuting mode choice [bicycle (CC), pedestrian (P), public transport (PT), or car–motorbike (CM)]; and (c) bicycle experience [commuter cyclist (CC), sport–leisure cyclist (SLC), or noncyclist (NC)].

Each psychological component was studied through several variables. A number of variables related to attitudes and to PBC were selected after a review of the literature on the reasons that encourage or discourage cycling. The most common reasons found in the literature are these:

- Positive. Health reasons—fitness, environmental awareness, perceived cost, speed, fun, flexibility, image prestige, relaxation, availability, reliability, ease of parking, and quality of life (1, 4–6, 9, 16–18); and
- Negative. Too dangerous, lack of sufficient fitness, lack of motivation, lack of facilities at work (showers, bike racks, etc.), no bike lanes, personal safety during journey, bad weather, lack of proper lighting, distance, topography, lack of safe parking at destination, lack of cycling knowledge or experience, too much traffic,

uncomfortable, difficulties with trip chaining, need to carry things, air pollution, free car parking at work, lack of time, and bad road conditions (3, 4, 6, 9, 16, 18–22).

The attitudinal questions included all the positive and some of the negative reasons. The PBC questions included negative reasons but only a limited number because of time–survey limitations. A summary of the variables used in the research appears in the later section on valuation of psychological components.

METHODOLOGY

A three-step methodology was used to analyze the relationship between psychological factors and bicycle commuting. Psychological factors were measured by asking about perceptions of cycling factors. These were the variables used for the study. First, statistical differences in the variables between groups were determined: between CCs (mode) and other mode commuters and between CCs (bicycle experience), SLCs, and NCs. Determining these differences enabled the authors to identify the main barriers to commuting by bicycle. Second, an explanatory factor analysis was performed to identify and define the main underlying structures among the attitudinal and perceived behavioral control variables. The appropriate summated scales for the rest of the variables (norms and habits) were also defined. Third, a binary logit model was constructed on the basis of the abovementioned factors and scales to determine the key psychological factors influencing bicycle commuting. SPSS, Version 18, was used as the statistical tool for the analyses.

Case Study

Madrid is a dense city, with 3.2 million inhabitants. It has a mountainous topography, with elevation differences up to 200 m. Madrid

has a low cycling culture, and bicycle use in the city center is 0.6% (23). However, the local government is increasing its support for this mode and progressively building a network of bicycle lanes and bicycle parks.

Survey Description

The survey discussed in this paper was conducted as part of a municipal study to analyze the mobility demand and social impacts of two future cycling lanes in the city center of Madrid (24). Behavioral aspects of cycling were introduced in the survey, as shown in Figure 1.

The survey was conducted during workdays in the third week of September 2011. Surveys were short face-to-face on-street interviews taking approximately 15 min. They were conducted on four streets in the center of Madrid. Because the survey focused on residents' mobility, tourists were excluded.

The final valid sample was 224, which is a reasonable sample size. However, it is somehow limited for a detailed analysis of the comparison of the variables across different groups. The sample was designed according to the specific objectives of the municipal study and consisted of 40% cyclists, 20% Ps, 20% PT users, and 20% CM users. Today, the modal split in the city center of Madrid is as follows: 0.6% cycling trips, 37.4% walking trips, 39.0% PT trips, and 23.0% CM trips (23). Consequently, the sample is not representative of mobility.

Perceptions of cycling factors were obtained through two types of questions: those involving attitudes and those related to the control of bicycle use [perceived behavioral control (PBC)]. The survey also included several questions related to subjective and descriptive norms and mobility habits. Also part of the survey were socio-economic questions and those on issues such as parking availability, use of a PT travel card, and perceptions of cycling facilities in Madrid. The results of the survey enabled assessment of the psychological components of cycling decisions.

Valuation of Psychological Components

Psychological components were measured by asking about attitudinal beliefs, descriptive norm beliefs, and perceived behavioral control beliefs (Table 1). The subjective norm was calculated as its respective beliefs weighted by the corresponding importance (Table 2).

Cycling habit was measured by following the response frequency measure established by Verplanken et al. (25). Respondents were asked, "Which mode of transportation do you use most frequently for the following activities?" A five-item version of the original response-frequency measure was used, including five noncommuting trip purposes: shopping for daily consumer items, going shopping, accompanying children—the elderly, going out (restaurants, cinema, etc.), and visiting family or friends. The strength of cycling habit was indexed by the number of choices of the bicycle mode.

Table 1 shows the valuation of the main variables used. All variables were treated as scalars, as the authors adopted the same distance between valuations as the hypothesis. (Mean scores are shown in parentheses for the remainder of the paper.) The appropriate summated scales for the variables of subjective norm, descriptive norm, and habit have been defined, and their corresponding Cronbach's α coefficients have been calculated. Cronbach's α coefficient is a weighted average of the correlations between the variables of a scale. It is used to measure the internal consistency or reliability of a scale (26). In this case, all Cronbach's α coefficients are greater than the

TABLE 1 Psychological Components Valuation

Variable	Mean	SD
Attitudinal Beliefs Toward Bicycle Characteristics^a		
Environmental benefits	9.75	0.73
Health benefits	9.21	1.67
Quality of life	9.16	1.65
Cheap	9.16	1.32
Available	9.00	1.59
Flexible-independent	8.41	2.12
Easy to park	8.21	2.36
Fun	8.00	2.11
Quick	7.67	2.30
Image prestige	7.56	2.22
Reliable	7.42	2.46
Comfortable	7.13	2.30
Relaxing	7.04	2.51
Traffic safety (safe, without accidents)	5.19	2.37
Weather independent (independent of weather)	4.73	2.89
Descriptive Norm Beliefs Toward Bicycle Commuting^b		
Young people	7.21	2.19
People in general	6.31	2.11
Friends	4.26	3.23
Coworkers-fellow students	3.44	3.05
Family members	2.50	3.21
Perceived Behavioral Control Beliefs Toward Bicycle Commuting^c		
Safe parking at home	3.25	1.12
Physical fitness	3.08	1.04
Safe parking at destination	2.78	1.19
Cycling in traffic	2.65	1.20
Facilities at destination	2.56	1.18
Topography	2.35	1.02
Distance	2.25	1.06
Traffic aggression	1.94	0.99
Cycling Habit (range: 0 to 5) (scale: 5 items; Cronbach's $\alpha = .80$)	0.84	1.56

NOTE: SD = standard deviation. Descriptive norm beliefs toward bicycle commuting: mean = 4.76; SD = 1.91 (scale: 5 items; Cronbach's $\alpha = .72$).

^aQuestion: Considering the characteristics of the bicycle as a mode of transportation, evaluate to what extent you agree with the following (range: 0 to 10).

^bQuestion: To what extent do you think bicycle use has increased in Madrid among the following groups of people (range: 0 to 10)?

^cQuestion: To what extent do you consider it possible (or would it be possible) to commute by bicycle, considering the following factors (range: 1 to 4)?

suggested minimum acceptable level of 0.7 (27), indicating that internal consistency is acceptable. It is therefore acceptable to use the summated scales instead of the original variables.

The highest scores among attitudinal beliefs correspond to environmental benefits (9.75), health benefits (9.21), quality of life (9.16), and cheap (9.0). The lowest averages correspond to weather independent (4.73) and traffic safety (5.19). In relation to the subjective norm belief, friends score the highest value (7.29), which indicates that friends' support is considered the most positive. However, the most important influencing group is family (4.77). As a result, the highest perceived social pressure to commute by bicycle comes from

TABLE 2 Subjective Norm Belief and Importance

Influencing Group	Belief	Importance	Mean	SD
Family	6.98	4.77	34.63	33.43
Friends	7.29	3.84	29.71	31.50
Coworkers–fellow students	6.78	3.23	24.51	29.29

NOTE: Subjective norm toward bicycle commuting–aggregated value (range: 0 to 100) (scale: three items; Cronbach's $\alpha = .90$): mean = 29.57; SD = 28.66.

the family, followed by friends and then coworkers–fellow students. In relation to the descriptive norm beliefs, the respondents consider that young people are the group that is increasing its use of the bicycle the most (7.21). In contrast, respondents' family members are seen as the group that has increased its bicycle use the least (2.50). Safe parking at home is the perceived behavioral control factor with the highest average score (3.25), followed by physical fitness (3.08) and safe parking at destination (2.78). These results mean that respondents show fewer difficulties in relation to these factors. However, traffic aggression shows the lowest control value (1.94); hence, it is the largest barrier to overcome. On average, the bicycle is more frequently used for 0.84 times of the five noncommuting trip purposes described. Therefore, the cycling habit in the sample is extremely low.

EMPIRICAL APPLICATION

Descriptive Analysis

When the categories for type of commuter, mode choice, and bicycle experience are considered, the sample is distributed as follows:

- According to choice of commuting mode:
 - 27% CCs and
 - 73% NCCs:
 1. 12% Ps,
 2. 39% PT [bus (8.0%), subway–railway (30.5%), and cab (0.5%)], and
 3. 22% CM [car (17%) and motorbike (5%)] and
- According to bicycle experience:
 - 27% CC,
 - 27% SLC, and
 - 46% NC.

Most respondents are male (59%), with the 25–34 age group most heavily represented. It is also worth noting that 16% of the sample is foreigners, mostly in the younger age groups (up to 45). Fifty-nine percent of respondents have CM availability to commute. However, only 22% of them use it for their commuting trips. The remaining potential CM users mainly choose PT (18%), cycling (12%), or walking (7%). The majority of the respondents (72%) are able to ride a bicycle and have a bicycle available for their daily trips. However, only 38% of them (27% of all respondents) choose the bicycle for commuting.

Comparisons Across Groups

This section analyzes whether any statistical differences exist in the mean score of the variables between different groups. Because the authors conducted multiple comparison tests, it was necessary to use adjusted *P*-values. The adjusted *P*-value for a particular hypothesis within a collection of hypotheses is the smallest overall significance level at which the particular hypothesis would be rejected (28).

Table 3 shows that cycling commuters value all bicycle characteristics more positively than noncycling commuters, as expected. The

TABLE 3 Attitudinal Beliefs Toward Bicycle Characteristics, NCC Compared with Cycling Commuters

Bicycle Characteristic	Reference Group	Aggregated		Mode Choice for NCC				Bicycle Use for NCC		
	CC Mean	NCC Mean	Sig. ^a (ref. to CC)	P Mean	PT Mean	CM Mean	Sig. ^a (ref. to CC)	SLC Mean	NC Mean	Sig. ^a (ref. to CC)
Quick	8.85	7.23	0.000	7.73	7.40	6.66	0.000	7.85	6.85	0.00
Environmental benefits	9.84	9.71	0.092	9.58	9.82	9.60	0.128	9.79	9.67	0.15
Cheap	9.46	9.04	0.017	9.23	8.99	9.04	0.057	9.11	9.00	0.10
Available	9.39	8.86	0.025	8.69	9.05	8.62	0.070	8.92	8.82	0.07
Traffic safety	6.10	4.85	0.000	4.62	4.93	4.84	0.000	5.38	4.54	0.00
Reliable	8.77	6.91	0.000	7.00	6.92	6.86	0.000	7.77	6.40	0.00
Health benefits	9.51	9.09	0.150	9.31	9.21	8.78	0.057	9.36	8.93	0.23
Comfortable	8.23	6.71	0.000	6.81	6.99	6.18	0.000	7.70	6.12	0.00
Flexible–independent	9.33	8.07	0.000	8.12	8.48	7.32	0.000	8.59	7.75	0.00
Weather independent	6.20	4.18	0.000	4.35	4.08	4.26	0.000	5.26	3.53	0.00
Relaxing	8.20	6.61	0.000	6.50	6.78	6.36	0.000	7.77	5.91	0.00
Fun	8.92	7.65	0.000	7.35	7.85	7.46	0.000	8.57	7.10	0.00
Image prestige	7.85	7.45	0.390	7.54	7.28	7.72	0.480	7.52	7.41	0.43
Easy to park	8.54	8.08	0.037	8.19	8.17	7.86	0.000	8.77	7.67	0.16
Quality of life	9.51	9.03	0.007	8.92	9.24	8.72	0.013	9.38	8.82	0.02

NOTE: Sig. = significance; ref. = referred. Significant differences shown in gray. Sample size: CC = 61, NCC = 163, P = 26, PT = 87, CM = 50, SLC = 61, NC = 102. ^aMann–Whitney (*U*) test when two groups and Kruskal–Wallis (*H*) test when three or four groups. Adjusted significance levels: $p < (.05/15) = .003$; $p < (.10/15) = .007$.

most positive attitudinal beliefs of cycling commuters correspond to the variables environmental benefits (9.84), health benefits (9.51), and quality of life (9.51). The lowest value for cycling commuters is shown by the variable traffic safety (6.10), while, for noncycling commuters, it is the characteristic weather independent (4.18), followed by traffic safety (4.85). In relation to the noncycling commuter group, Ps and PT commuters are attitudinally close to cyclists, while the lowest values for most variables are given by CM commuters. By bicycle experience, the attitudinal beliefs of SLCs appear to be midway between cyclists and noncyclists. All these differences between groups are statistically significant for the variables quick, traffic safety, reliable, comfortable, flexible-independent, weather independent, relaxing, fun, and quality of life. Easy to park shows statistically significant differences only for the mode choice grouping.

As the purpose of cycling policies is to shift trips from CM to bicycle, the authors examined the differences in the factor valuation for CM and bicycle users. The variables quick, comfortable, flexible-independent, weather independent, reliable, and relaxing show the greatest differences between CCs and CM commuters. Most CM commuters do not use a bicycle at all (60%). Therefore, differences between these factors are influenced by the lack of knowledge by CM commuters of the cycling experience itself (29).

Differences in average perceived social pressure (subjective norm) to commute by bicycle only appear to be statistically significant between bicycle use groups (Table 4). In relation to the descriptive norm, its corresponding scale shows statistically significant differences for the three groupings. Perceptions of an increase in bicycle use can be seen to be more positive in cycling commuters, followed by PT commuters, Ps, and CM commuters. The descriptive norm is also higher for SLCs than for NCs but lower than for commuter cyclists.

A comparison of the mean score of the perceived behavioral control beliefs toward bicycle commuting (PBC) variables between groups

shows that cycling commuters give the highest scores (Table 5). These high scores indicate that their difficulties in using the bicycle to commute are lower than the corresponding difficulties for NCCs. As for the total sample, the variables traffic aggression, distance, and topography are the greatest difficulties for both cycling commuters and NCCs. With reference to NCCs, PT commuters and CM commuters perceive all difficulties to be more important than any other group. Therefore, in this case only, Ps appear to be close to cycling commuters. In relation to bicycle experience, the barriers decrease as cycling experience increases. All these differences between groups are statistically significant except for the variables facilities at destination, safe parking at destination, and traffic aggression.

Rating all these cycling barriers according to differences between cycling commuters and CM commuters, one can see the following:

- Cycling commuters give the highest scores to all variables, except for safe parking at home and safe parking at destination. These results show that nonusers do not perceive problems related to parking the bicycle.
- Variables such as distance, topography, cycling in traffic, and physical fitness, which are widely perceived as barriers to bicycle use, provoke fewer difficulties to cycling commuters than to NCCs. Thus, differences in these variables seem to be the consequence of ignorance about the cycling experience itself by CM commuters (29). These difficulties can therefore be overcome by the cycling experience.
- Variables that affect both types of commuters (traffic aggression, facilities at destination, safe parking at home, and safe parking at destination) cannot be overcome by the cycling experience. Therefore, cycling policies should focus on these variables.

When the bicycle habits for noncommuting trips between groups are compared, all differences are statistically significant (Table 6).

TABLE 4 Subjective and Descriptive Norm Toward Bicycle Commuting, NCC Compared with Cycling Commuters

Social Group	Reference Group	Aggregated		Mode Choice for NCC				Bicycle Use for NCC		
	CC Mean	NCC Mean	Sig. ^a (ref. to CC)	P Mean	PT Mean	CM Mean	Sig. ^a (ref. to CC)	SLC Mean	NC Mean	Sig. ^a (ref. to CC)
Subjective norm scale	32.20	28.59	0.567 ^b	29.54	30.15	25.38	0.682 ^b	34.75	24.90	0.066 ^b
Family	33.02	35.23	0.739 ^c	37.54	36.34	32.10	0.866 ^c	41.13	31.71	0.201 ^c
Friends	33.92	28.13	0.362 ^c	27.85	30.07	24.90	0.620 ^c	34.41	24.37	0.096 ^c
Coworkers-fellow students	29.61	22.60	0.178 ^c	23.35	24.38	19.12	0.273 ^c	29.74	18.33	0.015 ^c
Descriptive norm scale	<i>n</i> = 59 5.30	<i>n</i> = 158 4.56	0.011 ^b	<i>n</i> = 25 4.58	<i>n</i> = 86 4.66	<i>n</i> = 47 4.38	0.068 ^b	<i>n</i> = 59 5.03	<i>n</i> = 99 4.29	0.002 ^b
People in general	<i>n</i> = 59 6.73	<i>n</i> = 158 6.15	0.021 ^d	<i>n</i> = 25 6.20	<i>n</i> = 86 6.10	<i>n</i> = 47 6.21	0.130 ^d	<i>n</i> = 59 6.47	<i>n</i> = 99 5.96	0.023 ^d
Young people	<i>n</i> = 58 7.38	<i>n</i> = 158 7.15	0.351 ^d	<i>n</i> = 25 7.40	<i>n</i> = 86 7.17	<i>n</i> = 47 6.98	0.734 ^d	<i>n</i> = 59 7.07	<i>n</i> = 99 7.20	0.646 ^d
Family members	<i>n</i> = 56 2.98	<i>n</i> = 155 2.32	0.188 ^d	<i>n</i> = 25 1.72	<i>n</i> = 84 2.61	<i>n</i> = 46 2.13	0.257 ^d	<i>n</i> = 57 3.33	<i>n</i> = 98 1.73	0.007 ^d
Friends	<i>n</i> = 58 5.24	<i>n</i> = 158 3.90	0.003 ^d	<i>n</i> = 25 4.24	<i>n</i> = 86 3.86	<i>n</i> = 47 3.79	0.027 ^d	<i>n</i> = 59 4.85	<i>n</i> = 99 3.33	0.000 ^d
Coworkers-fellow students	<i>n</i> = 56 4.02	<i>n</i> = 157 3.24	0.104 ^d	<i>n</i> = 25 3.32	<i>n</i> = 86 3.49	<i>n</i> = 47 2.72	0.226 ^d	<i>n</i> = 59 3.34	<i>n</i> = 98 3.17	0.262 ^d

NOTE: Significant differences shown in gray. Sample size: CC = 61, NCC = 163, P = 26, PT = 87, CM = 50, SLC = 61, NC = 102.

^aMann-Whitney (*U*) test when two groups and Kruskal-Wallis (*H*) test when three or four groups.

^bSignificance levels: $p < .05$; $p < .10$.

^cAdjusted significance levels: $p < (.05/3) = .017$; $p < (.10/3) = .033$.

^dAdjusted significance levels: $p < (.05/5) = .010$; $p < (.10/5) = .020$.

TABLE 5 PBC Beliefs Toward Bicycle Commuting, NCC Compared with Cycling Commuters

Bicycle Characteristic	Reference Group	Aggregated		Mode Choice for NCC				Bicycle Use for NCC		
	CC Mean	NCC Mean	Sig. ^a (ref. to CC)	P Mean	PT Mean	CM Mean	Sig. ^a (ref. to CC)	SLC Mean	NC Mean	Sig. ^a (ref. to CC)
Distance	2.59	2.13	0.002	2.73	2.06	1.94	0.000	2.20	2.09	0.007
Topography	2.70	2.22	0.001	2.81	2.14	2.06	0.000	2.49	2.06	0.000
Physical fitness	3.48	2.94	0.001	3.00	2.91	2.96	0.007	3.31	2.72	0.000
Facilities at destination	2.80	2.47	0.063	2.77	2.43	2.40	0.147	2.52	2.44	0.161
Safe parking at destination	2.62	2.84	0.227	2.77	2.82	2.92	0.596	2.82	2.85	0.477
Safe parking at home	3.23	3.25	0.605	2.88	3.23	3.48	0.085	3.72	2.97	0.000
Cycling in traffic	3.11	2.48	0.000	2.54	2.41	2.56	0.005	2.85	2.25	0.000
Traffic aggression	2.02	1.91	0.568	2.04	1.95	1.76	0.539	1.93	1.89	0.821

NOTE: Significant differences shown in gray. Sample size: CC = 61, NCC = 163, P = 26, PT = 87, GM = 50, SLC = 61, NC = 102.

^aMann–Whitney (*U*) test when two groups and Kruskal–Wallis (*H*) test when three or four groups. Adjusted significance levels: $p < (.05/8) = .006$; $p < (.10/8) = .013$.

Cycling commuters show a greater cycling habit (1.61) than NCCs (0.08). This difference indicates that cycling commuters also use this mode for noncommuting trips such as shopping, visiting friends, and so on. NCCs use the bicycle mainly for sport (which is not included in this measure of bicycle habit); hence, their bicycle habit is extremely low.

Factor Analysis

An exploratory factor analysis was used to reduce the number of attitudinal and perceived behavioral control variables and to identify their main underlying structures (factors). Variables with high correlation are components of the same factor. Table 7 shows the association of variables and defines two factors for attitudinal variables and three factors for perceived behavioral control variables.

TABLE 6 Bicycle Habit for Noncommuting Trip Purposes, Except Sport, NCC Compared with Cycling Commuters

Commute Mode	Sample Size	Habit
Reference group		
CC	61	1.61
Aggregated		
NCC	163	0.08
Sig. ^a (ref. to CC)	na	0.00
Mode choice for NCC		
P	26	0.12
PT	87	0.08
CM	50	0.06
Sig. ^a (ref. to CC)	na	0.00
Bicycle use for NCC		
SLC	61	0.21
NC	102	0.00
Sig. ^a (ref. to CC)	na	0.00

NOTE: na = not applicable; ref. = referenced.

^aMann–Whitney (*U*) test when two groups and Kruskal–Wallis (*H*) test when three or four groups.

Significance levels: $p < .05$; $p < .10$.

The characteristics cheap, available, image prestige, and easy to park were removed from attitudinal beliefs because of low communality (<0.30). Direct and long-term benefits are the new factors identified and explain a variance of 49.18%. The importance of direct benefits comes from bicycle characteristics, such as reliable and comfortable. The second factor, long-term benefits, is mainly defined by characteristics such as health benefits and quality of life and, to a lesser extent, by flexible-independent and environmental benefits.

For perceived behavioral control beliefs, traffic aggression was removed because of low communality (<0.20). Three factors explaining the 49.19% variance were identified. The factor physical conditions is explained by the distance and topography variables. The second factor, external facilities, is linked to parking and other facilities. The third factor is mainly defined by the variable physical fitness and is therefore designated individual capacities.

The assumptions underlying factor analysis were previously checked (27): minimum sample size ($224 > 5 * 15$ items of attitudes; $224 > 5 * 8$ items of PBC), and multicollinearity (Bartlett's test significance = 0.00; measure of sampling adequacy > 0.6). The Oblimin rotation (with delta zero) was used to find the factors. Factor scores were calculated by the Anderson–Rubin method.

Explanatory Factors of Cycling Behavior

A binary logit model was used to observe the effect of attitudes and other psychological variables on the decision to commute by bicycle or to choose another mode. The dependent variable BC is obtained from the survey, and it is equal to 1 if the respondents commute daily by bicycle and 0 otherwise. The factors and scales calculated in the previous sections are the independent variables. The estimation of the discrete choice model was made by using SPSS software, seeking the model with best explanatory power. The influence of sociodemographic variables is partially incorporated into the model. These variables are treated as previous ones, as influencing the formation of attitudes, social norms, and perceived behavioral control (30).

The variables of Model 1 include attitudes, norms, and perceived behavioral control. The results of this model show that direct benefits and individual capacities appear to influence significantly the

TABLE 7 Correlations Between Factors and Attitudes, PBC Variables

Belief	Factor		Belief	Factor		
	Direct Benefits	Long-Term Benefits		Physical Conditions	External Facilities	Individual Capacities
Attitudinal Beliefs Toward Bicycle Characteristics			PBC Beliefs Toward Bicycle Commuting			
Reliability	0.78	na	Distance	0.87	na	na
Comfort	0.68	na	Topography	0.61	na	na
Traffic safety	0.64	na	Safe parking at destination	na	0.83	na
Weather independent	0.62	na	Safe parking at home	na	0.54	na
Quickness	0.52	na	Facilities at destination	na	0.41	na
Health benefits	na	0.75	Physical fitness	na	na	0.86
Quality of life	na	0.70	Cycling in traffic	na	na	0.47
Flexibility-independence	na	0.65				
Environmental benefits	na	0.55				
Fun	na	0.43				
Relaxation	na	0.43				

NOTE: Values below 0.4 are not reported.

likelihood of cycling to work–place of study (Table 8). A positive perception of the bicycle’s direct benefits (reliable, comfortable, traffic safety, weather independent, and quick), and a positive perception of individual capacities (physical fitness and cycling in traffic), positively affects the decision to cycle for commuting purposes ($\beta = 1.23$ and $\beta = 0.42$, respectively).

If the variable cycling habit is included (Model 2), the choice process is mainly influenced by current habit. Respondents with a cycling habit for purposes other than commuting (except sport) have a greater likelihood of cycling to work–place of study ($\beta = 1.74$). This variable shows the greatest odds ratio (5.68), which means that, with every unit of increase in habit, the increase in the likelihood of that person being a cycling commuter is multiplied by 5.68. The variable direct benefits loses explanatory power (β from 1.23 to 1.02), and the PBC variable individual capacities (PBC Factor 3) is not statistically significant. Because the chi-square likelihood ratio test (61.03) is more than the critical value (3.84 for $p < .05$), Model 2 (including habit) is an improvement over Model 1 (without habit).

CONCLUSIONS AND POLICY RECOMMENDATIONS

This paper examined perceptions of different cycling factors and their influence on bicycle commuting. Perceptions were measured by using psychological constructs: attitudes, social norms, PBC—people’s perceptions of their ability to perform a given behavior—and habit.

First, statistical differences of the variables were determined between cycling commuters and commuters by other modes and between commuter cyclists, SLCs, and NCs. The main barriers to commuting by bicycle affecting different types of commuters were identified. These results can be used to reorient cycling policy efforts to achieve visible improvements in commuting by bicycle in Madrid.

The study confirms that cycling commuters value all cycling factors more positively than NCCs (2–5). It also demonstrates that the difficulties for cycling commuters in using the bicycle to commute are lower than the corresponding difficulties for NCCs (2, 4, 6).

TABLE 8 Results of Logistic Regressions of Cycle Commuting

Variable	Model 1			Model 2		
	β	Sig.	Exp(β)	β	Sig.	Exp(β)
Attitudinal factor 1: direct benefits	1.23	0.00	3.44	1.02	0.00	2.78
Attitudinal factor 2: long-term benefits	0.31	0.23	1.37	0.05	0.85	1.05
Subjective norm	0.00	0.81	1.00	0.01	0.41	1.01
Descriptive norm	0.03	0.73	1.03	−0.01	0.97	1.00
PBC factor 1: physical conditions	0.22	0.23	1.25	0.23	0.33	1.26
PBC factor 2: external facilities	−0.15	0.41	0.86	−0.13	0.58	0.88
PBC factor 3: individual capacities	0.42	0.05	1.52	0.20	0.43	1.22
Cycling habit	—	—	—	1.74	0.00	5.68
Constant	−1.62	0.00	0.20	−2.30	0.00	0.08

NOTE: — = not included. Significance levels: $p = .05$; $p < .10$. Significant variables shown in gray. Model 1: $N = 217$; model chi-squared = 54.81; Cox and Snell $R^2 = .22$. Model 2: $N = 217$; model chi-squared = 115.84; Cox and Snell $R^2 = .41$.

Moreover, the findings show that increasing the cycling experience (including sport) increases the valuation of attitudinal beliefs and decreases the barriers to commuting by bicycle. CM commuters are the most strongly opposed to cycling commuters, showing the greatest differences. These differences indicate that negative perceptions from CM commuters (the bicycle is slow, uncomfortable, inflexible, weather dependent, unreliable, and stressful), and their barriers (distance, topography, cycling in traffic, and physical fitness), could be improved by policies that allow NCCs to experience cycling more easily, for example, measures that allow easy daily access to bicycles (public bike sharing), free availability of bicycles in companies for employees, tax discounts when buying a bicycle, and integration with public transportation.

Traffic safety is the worst-perceived attitudinal factor for cycling commuters and the second worst for other commuters. Moreover, all respondents show more difficulties in relation to traffic aggression (PBC item). This finding highlights a real problem in the relationship between bicycles and motorized traffic in the congested city center of Madrid. This paper demonstrates that this problem cannot be solved simply by increasing the cyclist commuting experience. It is also necessary to provide dedicated cycle lanes, to restrict car access, and to implement traffic calming in certain areas.

Other factors involving bicycle facilities (lack of showers or bike racks at destination, lack of safe parking at home or at destination) are also impossible to resolve through the cycling experience. These variables should therefore be included as measures in the cycling mobility strategy of local administrations and organizations.

In the case study, family is the social group with the most positive influence on the decision to commute by bicycle. Moreover, young people are seen as the group that is increasing its bicycle use the most in Madrid. Therefore, cycling publicity campaigns should have a twofold objective: to encourage families to support more bicycle use and to dispel the image of bicycles as being only for young people.

Second, two underlying structures (factors) have been identified among the attitudinal variables: direct benefits and long-term benefits. As for PBC variables, three other factors are relevant: physical conditions, external facilities, and individual capacities.

Third, the effects of attitudes, norms, PBC, and habit have been tested for cycling to work–place of study. Choosing the bicycle as a commuting mode is mainly defined by the existence of bicycle habit for noncommuting trips. Attitudes related to direct benefits in reliability, comfort, and time are influential on the choice of the bicycle as a commuting mode but to a lesser extent than habit. This result represents the case of a city with low bicycle use, which is in contrast with cases where cycling is a normal practice. In cycling cities, both habit and TPB factors (attitudinal direct benefits and PBC) show a significant influence on cycling commuting (5). The social and physical context, as well as the method of measuring the PBC (disaggregated in several items in the present study), might explain the different results.

Some of the aforementioned policies could foster noncommuters to start experiencing cycling and then to develop their habit for noncommuting trips and finally for commuting. Thus, Park et al. mention that 57% of commuter cyclists began as leisure cyclists (31). However, the increase in the number of commuting trips must come from motorized trips so as to maintain high levels of Ps and PT users. When the bicycle is considered to be a real mode of transportation in the city, the importance of attitudes, norms, and PBC is likely to increase, as bicycle use is less dependent on habit.

This is the first application of the TPB model in a context with low bicycle modal share. This research can therefore be used as a case

study, because it is likely to be highly comparable to other locations with a low mode share for cycling. Moreover, this application has used disaggregated measures of subjective norm, descriptive norm, and PBC. Further development of the proposed model could be a hybrid model, including the relationship between the physiological variables and other sociodemographic and socioeconomic variables.

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Transition to a cyclable city: Latent variables affecting bicycle commuting

Begoña Muñoz^{a,*}, Andres Monzon^b, Elena López^a^a TRANSyT – Transport Research Centre, Universidad Politécnica de Madrid, c/Profesor Aranguren s/n, Ciudad Universitaria, 28040 Madrid, Spain^b Civil Engineering-Transport Department, Escuela de Caminos, Universidad Politécnica de Madrid, c/Profesor Aranguren s/n, Ciudad Universitaria, 28040 Madrid, Spain

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ABSTRACT

An understanding of the key factors influencing bicycle commuting is essential for developing effective policies towards a cyclable city. This paper contributes to this line of research by proposing a methodology for including cycling-related indicators in mobility surveys based on the Theory of Planned Behaviour (TPB), and applying an exploratory factor analysis (EFA) to evaluate the structure of latent variables associated with bicycle commuting. The EFA identified six cycling latent variables: *Lifestyle, Safety and comfort, Awareness, Direct disadvantages, Subjective norm*, and *Individual capabilities*. These were complemented with a latent variable related to habit: *Non-commuting cycling habit*. Statistical differences and regression analysis were applied with the cycling latent variables. The study also includes the relationship between objective factors and bicycle commuting, which reveals minor associations. This methodology was applied to the “starter cycling city” of Vitoria-Gasteiz (Spain). The results confirm that in this context – in transition to a cyclable city – safety and comfort issues are not the main barriers for all commuters, although more progress needs to be made to normalise cycling. A set of customised policy initiatives is recommended in the light of the research findings, including marketing campaigns to encourage non-commuting cycling trips, bicycle measures to target social groups as opposed to individuals, bicycle-specific programs such as “Bike-to-work Days”, and cycling courses.

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1. Introduction

Problems of sustainability in urban transport are well known and very common in developed countries. The public policies enacted to tackle them have focused mainly on promoting public transport and non-motorised commuting modes – including cycling – through policy documents such as the Green Paper on Urban Mobility (European Commission, 2007). In the last decade many cities in Spain have developed bicycle mobility plans aimed at increasing bicycle share, and the corresponding measures are already underway. Recent increases in cycling demand (Monzon and Rondinella, 2010) indicate that Spanish cycling levels are progressing adequately, although still in the early stages. One indication of this is the lack of information on cycling, as this is not generally included in household mobility surveys.

* Corresponding author. Tel.: +34 91 336 52 66.

E-mail addresses: b.mlopez@upm.es (B. Muñoz), andres.monzon@upm.es (A. Monzon), elena.lopez@upm.es (E. López).<http://dx.doi.org/10.1016/j.tra.2015.10.006>

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In order to develop effective cycling policies it is essential to understand the key factors influencing bicycle commuting. Increased efforts have been made in both policy-making and academic research. Variables such as time and cost are not sufficient to explain why cyclists choose this mode of transport, and a wide array of variables – including latent variables – are currently under study using a variety of methodologies. Latent variables are not observed by the researcher and must be inferred from other observable variables called indicators – usually responses to attitudinal or perceptual survey questions – and require specific analysis techniques. Previous studies using a range of methodologies have identified cycling latent variables as influential in the decision to choose cycling. This is an active research field due to the complexity of latent variables.

This paper contributes to this line of research by focusing on commuting, and proposing cycling-related indicators based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) for their inclusion in mobility surveys. It also evaluates the structure of the latent variables that influence bicycle commuting using exploratory factor analysis (EFA). Statistical differences for cycling latent variables were determined between bicycle commuters and other modes, showing medium and high associations. These variables were also used in a regression analysis to explain bicycle commuting choice. The study also defined the bicycle commuter profile by analysing the relationship between certain objective factors and bicycle commuting. This methodology was applied to Vitoria-Gasteiz (Spain). According to Dufour (2010) this is a “starter cycling city” with a bicycle share of 6.9% (Council of Vitoria-Gasteiz, 2015) – the highest in Spain in 2011 – and with moderate cycling conditions due to a favourable transport policy over the last decade. However, it has continued working to improve its bicycle use. Vitoria-Gasteiz can therefore be said to be in transition to a cycling city. The results confirm that safety and comfort issues are not the main barriers for all commuters, but more progress needs to be made to normalise cycling. The results also support the recommendation of a wide array of policy initiatives.

The paper is organised as follows. The conceptual model and literature review are presented in the next section. The methodology of the paper is described in the third section. The fourth section contains a description of the context and the data collection process. The empirical application is described in the fifth section, which is further divided into two subsections. The first contains the analyses of a number of traditional objective factors (socio-economic and household characteristics, mode availability, and trip characteristics). The second determines the cycling latent variables, analyses their differences among different types of commuters and shows the regression analysis. The last section contains some policy recommendations and conclusions.

2. Conceptual model and literature review

This study focuses on commuting trips and applies the Theory of Planned Behaviour (TPB) (Ajzen, 1991) as the conceptual framework for measuring cycling indicators – defined here as perceptions of cycling characteristics – in order to extract the latent variables for the study. This is a well-known and widely supported psychological attitudinal theory in studies relating to behavioural decisions. The TPB states that attitudes towards a behaviour, subjective and descriptive norms, and perceived behavioural control (PBC) combine to shape an individual’s behavioural intention and final behaviour. According to the TPB, attitude towards a behaviour is “the degree to which performance of the behaviour is positively or negatively valued”; subjective norm refers to “the perceived social pressure to engage or not to engage in a behaviour”; descriptive norm is related to “perceptions of what others are doing”; and the PBC is considered as “people’s perceptions of their ability to perform a given behaviour”.

This study is part of a research work using the TPB, as it analyses how changes to infrastructures and transport policies may affect attitudes and other psychological constructs, and how these may in turn affect the decision to begin commuting by bicycle. The TPB has also been successfully applied in a number of studies on bicycle use during the last decade and more recently. However, taking into account criticisms of this theory – namely that strong habit reduces the influence of TPB constructs – we have extended its application by including habit. Previous studies have shown that habit has a significant impact on bicycle use (Forward, 2004; de Bruijn et al., 2009; Heinen et al., 2011; Muñoz et al., 2013).

Most of the studies on cycling using the TPB focused on modelling applications. Some used the “intention” to choose the bicycle as the dependent variable. In studies using regression analysis, the extended version of the TPB in Forward (2004) explained between 47% and 78% of variance in intention to bike in four different cities with different levels of cycling. The TPB regression model in Eriksson and Forward (2011) explained 45% of variance in intention to use a bicycle for daily trips. Sigurdardottir et al. (2013) used a structural equation model and found that adolescents’ cycling intention to commute by bicycle as adults was related to a positive cycling experience, willingness to accept car restrictions, negative attitudes towards cars, and a bicycle-oriented future vision; and was negatively related to car ownership norms. Lois et al. (2015) recently extended the TPB model to predict cycling commuting intention by including social identity, and their logistic regression model revealed that the psychosocial variables alone predicted 32% of the variance in car users’ intention to start commuting by bicycle.

Other studies predicted the behaviour rather than the intention in the TPB framework. The binary logistic regression in de Bruijn et al. (2005) showed that the TPB elements had the highest odds ratios after some distal factors such as ethnicity or school type. Heinen et al. (2011) and Muñoz et al. (2013) explored statistical differences in cycling indicators among commuter modes, and developed binary bicycle mode choice models including cycling latent variables based on the extended version of TPB (including habit). They applied this methodology in two completely different cycling environments.

Regardless of the differences in context, both studies identified the importance of attitudes and other psychological factors in the choice to commute by bicycle. Analysing the environment both objectively and subjectively with structural equation modelling, Ma et al. (2014) concluded that the objective environment may affect bicycling behaviour only indirectly by influencing perceptions.

Other types of analysis also based on the TPB framework can be seen in Gatersleben and Uzzell (2007) and in Heinen and Handy (2012). The first centred on discriminant analysis and included statistical differences of perceptions among commuters using different modes. The second was a qualitative study based on in-depth interviews which analysed the similarities and differences in attitudes and norms affecting the decision to commute to work by bicycle in two cycling-oriented cities.

Other than the TPB, in earlier research on bicycle commuting only Dill and Voros (2007) studied statistical differences in cycling indicators among different groups based on cycling frequency and purpose. Cycling indicators have also been directly used in some modelling studies (Wardman et al., 2007; Akar et al., 2013; Muhs and Clifton, 2014). Many authors use a reduced number of cycling indicators to avoid problems of multicollinearity when modelling. Some use summated scales – average or sum – (de Bruijn et al., 2005; de Geus et al., 2008; Handy and Xing, 2010; Panter et al., 2010; Emond and Handy, 2012; Heinen et al., 2012), while others apply Principal Component Analysis (PCA) (Moudon et al., 2005; Titze et al., 2007, 2008; Akar and Clifton, 2009; Lee et al., 2011; Maldonado-Hinarejos et al., 2014). PCA has also been used in other cycling experiences such as association studies (Whannell et al., 2012) and market segmentation studies (Damant-Sirois et al., 2014).

Another technique is exploratory factor analysis (EFA), which is applied when both indicators and expected latent variables are metrical. This method conveys the information contained in the interrelationships of the indicators, to a good approximation, in a much smaller set of latent variables. It thus reduces the dimensionality of the indicators and improves the understanding of their structure (Bartholomew et al., 2011). This technique has recently been applied to some cycling studies using different methodologies such as descriptive analysis (Winters et al., 2011), modelling (Ma and Dill, 2015), and market segmentation (Li et al., 2013). EFA has been also applied in TPB studies using statistical differences in cycling indicators and modelling (Heinen et al., 2011; Muñoz et al., 2013). A confirmatory extension of EFA, including explanatory variables for the estimation of the latent variables – multiple indicators multiple causes (MIMIC) model – is also possible in more advanced research with discrete choice models (Kamargianni and Polydoropoulou, 2013; Fernández-Heredia et al., 2014; Habib et al., 2014). Other methodologies such as the Rasch model have been applied by Cheng and Liu (2012) to study bicycle-transit users' latent inconvenience.

3. Methodological approach

This study focuses on commuting trips. The commuting mode is considered as any mode used three or more times a week to go to a place of work/study: bicycle (B), walking (W), public transport (PT) and car (C).

The factors identified in the literature as influential in bicycle use are numerous and very diverse (Heinen et al., 2010). In the present study they have been divided according to the way they are measured into “objective” and “subjective”. We denote as “objective” the factors that can be directly observed. Three types of objective factors have been considered here: socio-economic and household characteristics, mode availability, and trip characteristics. In addition, there are “subjective” factors which must be measured through interaction with the person. In the subjective part of this study we have considered the latent variables, which in most cases do not have an equivalent objective variable. The paper's methodology is summarised in Fig. 1, and comprises three parts: one on objective factors, another on subjective factors, and a final one on policy recommendations. SPSS[®]v20 has been used as the statistical tool for the analyses.

We first investigate the objective factors, starting with a sample distribution analysis according to the objective factors specified for bicycle and non-bicycle commuters. Categorical techniques (e.g. Pearson's chi-square test) are applied to find the relationships between the objective factors and commuting by bicycle or by other modes. The commuting modal share is also analysed, especially for the bicycle, comparing each specific value in the various categories in each objective factor.

We then investigate the structure of cycling latent variables extracted with an explanatory factor analysis (EFA) and applied to indicators of attitudes, subjective norm, descriptive norm and PBC (through the two elements of controllability and self-efficacy). The habit latent variable is obtained through the self-reported frequency of past behaviour (Verplanken et al., 2005). The assumptions underlying the factor analysis (Hair, 2009) are checked previously, and are: minimum sample size ($654 > 5 * 14$ indicators of attitude; $654 > 5 * 3$ indicators of subjective norm; $654 > 5 * 5$ indicators of descriptive norm; $654 > 5 * 4$ indicators of controllability; $654 > 5 * 6$ indicators of self-efficacy); and multicollinearity (Bartlett test: Sig = 0.00; MSA > 0.5). Among the various “common factor analysis” extraction methods, the principal factor analysis (Principal Axis Factoring¹ in SPSS) is applied following the recommendation of Fabrigar et al. (1999), as the indicators violated multivariate normality. A rotational method is used to achieve a simpler and theoretically more meaningful solution to the latent variables. The oblique Oblimin rotation (with delta zero) is applied to allow the latent variables to correlate. The names of the latent

¹ A method of extracting factors from the original correlation matrix, with squared multiple correlation coefficients placed in the diagonal as initial estimates of the communalities. Iterations continue until the changes in the communalities from one iteration to the next satisfy the convergence criterion for extraction (SPSS[®]v20).

Fig. 1. Methodological process.

variables are assigned according to their constituent indicators, and by taking into consideration previous works mentioned in Section 2 that identified cycling latent variables through principal component analysis and explanatory factor analysis. Factor scores representing each individual's placement in the latent variable(s) for use in the follow-up analyses are calculated with the Bartlett method to obtain unbiased estimates of the true factor scores (DiStefano et al., 2009). The factor scores are then standardised to make the mean equal to zero and the standard deviation equal to one to allow comparison with the other latent variables.

We also examine any associations between these cycling latent variables and the commuting mode by determining statistical differences in the cycling latent variables between commuters by bicycle or by other modes. Non-parametric techniques are used, as the latent variables violate the normality distribution in the groups. A multivariate regression analysis with cycling latent variables is used to explain the bicycle commuting choice. Finally, the analysis of the two types of factors allows us to identify some policy recommendations to reinforce bicycle use.

This research follows the course initiated by Heinen et al. (2011) and Muñoz et al. (2013) in analysing the relationship between psychological factors and bicycle commuting, but contributes two additional aspects. First, the questionnaire was designed by a multidisciplinary research team of transportation planners, geographers and psychologists. This well-executed TPB survey included not only questions related to beliefs but also to importances, in order to measure attitudes and subjective norms more accurately. The second value of the questionnaire is that the PBC is addressed both by controllability and self-efficacy indicators (only for beliefs). A further difference between this and previous works is that this study has been applied in a city where cycling has only recently become the subject of promotion. The results highlight the differences with cities with other levels of cycling use – either advanced such as Dutch cities (Heinen et al., 2011) or in the early stages such as Madrid (Muñoz et al., 2013).

4. Context and data collection

Vitoria-Gasteiz is a dense, medium-size city (243,298 inhabitants in 2012) in northern Spain. It has a flat topography and a climate with moderately cold, damp winters (8 °C average temp) and cool summers (20 °C average temp). Bicycle use in Vitoria-Gasteiz is the highest of any city in Spain, and increased sharply from 3.3% in 2006 to 6.9% in 2011, and to 12.3% in 2014 (Council of Vitoria-Gasteiz, 2015). New cycling infrastructures and services are continuously being implemented. These measures receive strong support from the local authorities, and are developed within the framework of the Mobility and Public Space Plan (Council of Vitoria-Gasteiz, 2007) and the city's Cycling Mobility Master Plan (Council of Vitoria-Gasteiz, 2010). Thanks to this sustainable transport policy – among other reasons – Vitoria-Gasteiz was awarded the title European Green Capital in 2012 (European Commission, 2011).

This work uses data obtained from an ad-hoc telephone mobility survey, the first wave of a panel mobility survey on commuting trips conducted in Vitoria-Gasteiz among a sample of 736 employees and students in April 2012. The sample distribution was designed to be representative of commuting mobility, in terms of the modal share for the group “bicycle + walking + public transport” (58%), and for the group “car + motorbike + other modes” (42%). In 2011, the modal split for commuting trips in the city was: 11% bicycle, 38% walking, 9% public transport, 37% car, and 5% other modes (Council of Vitoria-Gasteiz, 2015). Specific sampling procedures were also conducted in order to guarantee a realistic distribution of gender, age, activity sector and location of place of work/study (Fig. 2). The survey included objective factors such as socio-economic and household data, availability of transport modes, commuting trip characteristics and detailed origin–destination trip data for each of the respondents. Minimum network distance was determined by entering the origin–destination information into a geographic information system (ESRI® ArcMap™ 10.0).

The subjective part was measured by indicators – perceptions of cycling characteristics – and designed based on the results of a qualitative study on attitudes towards bicycle use in Vitoria-Gasteiz, consisting of 15 in-depth interviews with commuters by different transport modes (Lois et al., unpublished results).

Fig. 2. Sample distribution of workers and students in the city.

Following the TPB, each element is calculated by multiplying the beliefs linking the behaviour (commuting by bicycle in our case) with their corresponding importances. We applied this method to calculate attitudes and subjective norm. Indicators related to descriptive norm and PBC (controllability and self-efficacy) were only measured through beliefs. All indicators (beliefs and importances) were measured using a 7-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7). The question on the frequency of bicycle use for non-commuting purposes (excluding sport) used the following scale: never, occasionally, almost always or always. The exact questions and indicators are summarised in Table 1.

5. Empirical application

The valid final sample consisted of 654 respondents, as the motorbike sample (6 respondents) was discarded due to its low percentage in the sample population; and because only direct trips from home to the place of work/study were considered. In the final sample, the distribution of commuters was as follows: 13% by bicycle, 27% by walking, 17% by public transport, and 41% by car.

5.1. Objective factors

Table 2 shows the sample distribution according to objective factors, specified for bicycle and non-bicycle commuters. The column proportions are compared between cycling and other commuting modes. Table 3 presents the commuting modal share – bicycle (B), walking (W), public transport (PT), car (C) – for the different categories of objective factors. Specific modal shares are compared between the categories in each objective factor.

Table 2 reveals that the majority of cyclists are men (72%); this proportion is significantly greater than for other modes (46%). Bicycle share is significantly more important among men (19%) than women (7%). In contrast, public transport is more preferred by women (26%) than men (10%). For groups aged 25–54, there is no difference in column proportions between cyclists and other commuters. However, the proportion of cyclists aged 16–24 (47%) is significantly higher than for other modes (19%). Among cyclists, 27% of the share for the 16–24 age group is statistically higher than for the other age groups. This group mainly comprises students, who are more limited in terms of driving. Car share increases significantly over age 25, while bicycle share decreases to 8% (on average). Almost half the cyclists (45%) are children (both male and female) aged >16 years, still living with their parents. This proportion is significantly higher than for the other modes (21%). This family

Table 1

Summary of perceptual questions and cycling indicators.

Attitudes towards bicycle commuting characteristics	
Belief question: “Considering your (possible) commuting trip by bicycle to the place of work/study, to what extent do you agree with the following statements...?”	Importance question: “And how important are the following things to you as a commuter...?”
I (would) commute quickly	Commuting quickly
I (would) know how long it (would) take(s) me to get to my destination	Knowing how long I’m going to take to reach my destination
It (would be)/is difficult for me to transport people	Being able to transport people
It (would be)/is difficult for me to transport objects	Being able to transport objects
I (would be)/am free because I (would)/do not depend on any other transport mode	Being free, not having to depend on any mode of transport
I (would) save money compared to other transport modes	Saving money compared to other modes of transport
I (would be)/am at high risk of having an accident	Reducing the risk of having an accident
I (would) get some physical exercise	Doing physical exercise
I (would be)/am able to park easily	Being able to park easily
There (would be)/is a high risk that my bike (would be)/is stolen or damaged	Reducing the risk of having my mode of transport stolen or damaged
I (would) pollute the environment less	Causing less environmental pollution
I (would be)/am breathing polluted air	Not breathing polluted air
I (would be)/am a nuisance to pedestrians	Not being a nuisance to pedestrians
I (would be)/am very dependent on the weather	Not being dependent on the weather
I (would) wear the proper clothes for my activities	Wearing proper clothes for my activities
I (would) make a good impression on others	Making a good impression on others
I (would be)/am stressed when I arrive(d) at my destination	Not being stressed when I arrive at my destination
I (would) enjoy the ride	Enjoying my ride
I (would be)/am sweaty when I arrived at my destination	Not being sweaty when I arrive at my destination
I (would) relax during the trip	Relaxing during the trip
Subjective norms towards bicycle commuting characteristics	
Belief question: “Considering your (possible) commuting trip by bicycle to the place of work/study, to what extent (would) the following groups of people approve?”	Importance question: “And how important to you is the opinion of the following groups of people with regard to your (possible) commuting by bicycle?”
My family	My family
My friends	My friends
My co-workers or classmates	My co-workers or classmates
Descriptive norms towards bicycle commuting characteristics	
Belief question: “How much do you think the following groups of people use the bicycle to get to their place of work/study?”	
Young people	
My family	
My friends	
My co-workers or classmates	
Immigrants	
Controllability towards bicycle commuting characteristics	
Belief question: “To what extent do you agree with the following statements...?”	
The infrastructures along my route to my place of work/study (cycle lanes, cycleways, and cycle pavements) (would) make it easier for me to move around by bike	
I could/can park my bike securely in my place of work or study	
I could/can park my bike securely at home	
Along my route to my place of work/study there are hills, changes in level and slopes which (would) hinder routine use of a bicycle	
The distance I (would) have to travel on my route to my place of work/study is suitable for travel by bicycle	
The traffic along my route to my place of work/study would allow(s) me to travel by bicycle on the road alongside the cars	
Self-efficacy towards bicycle commuting characteristics	
Belief question: Indicate how far you (would) consider yourself capable of performing the following tasks	
Riding your bicycle through traffic	
Parking your bicycle safely to avoid theft	
Regularly checking your bicycle to keep it in good condition	
Fixing a puncture on a bicycle wheel	
Using personal protection elements	
Safely performing manoeuvres on the bicycle	
Going up hills or changes in level on the bicycle	
Planning the route before you travel	
Interpreting the traffic signals and the road safety regulations	

Table 1 (continued)

Non-commuting cycling habit
Question: "Thinking of activities other than your usual journey to your place of work/study, how often have you used the bicycle in the last year to...?"
Going to the doctor, shopping, to visit people, for administrative purposes, etc.
For leisure (meeting friends, going to the cinema, having lunch or dinner out...)

Table 2

Distribution of the sample according to objective factors.

Variables	Total		Commuting mode	
	Frequency	%	Bicycle (%)	Other modes (%)
Gender ^{*,a}	654	100	100	100
Male	325	50	72	46
Female	329	50	28	54
Age group ^{*,a}	654	100	100	100
16–24	149	23	47	19
25–34	197	27	21	28
35–44	204	25	20	25
45–54	128	18	11	19
55–64	52	7	1	8
Family status ^{*,a}	654	100	100	100
Father/mother	264	40	28	42
Son/daughter	157	24	45	21
Couple no children	132	20	16	21
Without family ties	101	15	11	16
Professional situation ^{*,a}	654	100	100	100
Employed	521	80	58	83
Student	133	20	42	17
Car licence ^{*,a}	654	100	100	100
Yes	503	77	66	79
No	151	23	34	21
Car availability	654	100	100	100
Yes	550	84	80	85
No	104	16	20	15
Know how to ride	654	100	100	100
Yes	618	94	100 ^b	94
No	36	6	0 ^b	6
Bicycle availability ^{*,a}	654	100	100	100
Yes	479	73	100 ^b	69
No	175	27	0 ^b	31
Bicycle parking at home ^{*,a}	479	100	100	100
Inside home	128	27	39	24
In storeroom/warehouse/street	351	73	61	74
Travel time ^{*,a}	654	100	100	100
<10 min	64	10	8	10
10–30 min	448	69	80	67
>30 min	142	22	12	23
Travel distance ^{*,a}	654	100	100	100
<1 km	83	13	1	14
1–5 km	472	72	98	68
5–10 km	67	10	1	12
>10 km	32	5	0 ^b	6

Bold values in the same row and sub-table are significantly different at $p < 0.05$ in the two-sided test of equality for column proportions.

* The Chi-square statistic is significant at 0.05 level for bicycle commuting.

^a Small size association.^b This category is not used in comparisons as its column proportion is equal to zero or one.

Table 3

Commuting modal share according to objective factors.

Variables	Commuting mode				Total
	Bicycle (B)	Walking (W)	Public transport (PT)	Car (C)	
	13%	27%	18%	41%	
Gender					
Male	19%	27%	10%	44%	100%
Female	7%	28%	26%	39%	100%
Age group					
16–24	27%	45%	19%	9%	100%
25–34	10%	18%	16%	56%	100%
35–44	11%	19%	22%	48%	100%
45–54	8%	27%	17%	48%	100%
55–64	2%	35%	19%	44%	100%
Family status					
Father/mother	9%	23%	15%	50%	100%
Son/daughter	24%	34%	21%	20%	100%
Couple no children	11%	15%	25%	49%	100%
Without family ties	9%	43%	9%	40%	100%
Professional situation					
Employed	9%	22%	19%	49%	100%
Student	27%	48%	14%	11%	100%
Car licence					
Yes	11%	22%	15%	52%	100%
No	19%	44%	31%	5%	100%
Car availability					
Yes	12%	23%	15%	49%	100%
No	16%	50%	34%	0% ^a	100%
Know how to ride					
Yes	14%	27%	17%	42%	100%
No	0% ^a	36%	36%	28%	100%
Bicycle availability					
Yes	18%	25%	16%	41%	100%
No	0% ^a	33%	23%	43%	100%
Bicycle parking at home					
Inside home	26%	28%	14%	32%	100%
In storeroom/warehouse/street	15%	24%	17%	44%	100%
Travel time					
<10 min	11%	50%	0% ^a	25%	100%
10–30 min	15%	27%	12%	45%	100%
>30 min	7%	17%	46%	30%	100%
Travel distance					
<1 km	1%	94%	0% ^a	5%	100%
1–5 km	18%	21%	21%	40%	100%
5–10 km	1%	1%	22%	75%	100%
>10 km	0% ^a	0% ^a	13%	88%	100%

Bold values in the same column and sub-table are significantly different at $p < 0.05$ in the two-sided test of equality for row proportions.

^a This category is not used in comparisons as its row proportion is equal to zero or one.

status has a significantly higher bicycle share (24%) than the others. With regard to professional status, Table 3 shows that students use the bicycle for commuting three times more (27%) than workers (9%). Significantly more students (48%) prefer walking than workers (22%), who choose the car in a significantly higher percentage (49%). Gender, Age group, Family status and Professional situation are associated at a level of 0.05 with the Bicycle commuting (yes/no) variable with small size effects (Cramer's statistics < 0.30) (Field, 2009).

Considering mode availability variables, Table 2 shows that most respondents have a driving licence (77%) and a car available to commute (84%). Car licence shows statistically significant differences in column proportions between bicycle commuters and other modes, and also in bicycle share. These results are in line with the association between Car licence and Bicycle commuting, but with a small size effect. In contrast, Car availability shows no statistically different proportion relating to the bicycle, and this variable is therefore not significantly associated with bicycle commuting. Almost all respondents can ride a bicycle (94%) and the majority have a bicycle available for their commuting trips (73%). However, only 18% of this last group (13% of all respondents) choose the bicycle for commuting. A storeroom, warehouse or parking space in the building of their place of residence is the preferred place to keep the bicycle at night (73%). Pearson's chi-square test for

the variables *Know how to ride a bicycle* and *Bicycle commuting* may be invalid because it does not fulfil the assumption of expected frequencies >5 (Field, 2009). *Bicycle availability* and *Bicycle parking at home* also have a small association with the variable *Bicycle commuting* (yes/no) at the level of 0.05.

Characteristics such as *Travel time* and *Travel distance* are both statistically associated at the level of 0.05 with bicycle commuting, with a small size effect. Most trips have a duration of between 10 and 30 min (69%). Bicycle trips of 10–30 min (80%) are significantly higher than those for other modes (67%), and the opposite is true when the trip duration is over 30 min. Vitoria-Gasteiz is a medium-size and compact city; and most bicycle commuters therefore ride a distance of between 1 and 5 km (98%). The bicycle share for this distance (18%) is statistically higher than for other distances. The variables *Nationality*, *Family size*, *Children < 12*, *Level of studies*, *Car parking at home* and *Schedule type* are not included in the results as they are not associated with bicycle commuting, and show no statistically significant differences.

5.2. Subjective factors

5.2.1. Exploratory factor analysis

Tables 4–6 show the association of indicators and the definition of latent variables, along with the total proportion of the common variance explained in the indicators. These tables contain factor loadings from the pattern matrix (weights determining the effect of each latent variable on a particular indicator), and Cronbach's alpha coefficients for each latent variable, as a measure of internal consistency or reliability. All Cronbach's alpha coefficients are equal to or greater than the suggested minimum acceptable level of 0.7 (Hair, 2009), indicating that internal consistencies are acceptable, and it is therefore acceptable to use each latent variable instead of the original indicators.

The characteristics *Theft safe*, *Weather independent*, *Easy to park*, *Easy to carry objects*, *Easy to carry people* and *Independent* were removed from the attitudinal indicators due to their low communality² (<0.20). Table 4 shows the four attitudinal latent variables defined: *Lifestyle*, *Safety and comfort*, *Awareness* and *Direct disadvantages*. The larger the factor loadings, the more a particular indicator is said to load on the corresponding latent variable. The importance of *Lifestyle* is therefore derived from the bicycle characteristics *Fun*, *Relaxing*, and – to a lesser extent – *Good image* and *Daily clothing*. The latent variable *Safety and comfort* combines safety issues (*Safe for pedestrians*, *Low accident risk*, *Pollution safe*) with comfort issues (*No sweat*, *No stress*). The latent variable *Awareness* explains the long-term benefits of commuting by bicycle, such as *Environmentally friendly*, *Healthy*, and *Cheap*. Finally more immediate indicators such as *Quick* and *Time reliable* are explained by a latent variable. Their factor loadings are all negative, which means that indicators are negatively correlated to the latent variable. We therefore call this latent variable *Direct disadvantages*, to express the opposite of the *Quick* and *Time reliable* indicators. These attitudinal latent variables correlate moderately (between 0.27 and 0.42).

The latent variable for psychological support for bicycle commuting was defined and is shown in Table 5. The *Subjective norm* latent variable is mainly explained by the *My friends* indicator, and – to a lesser extent – *My co-workers or classmates* and *My family*. Table 6 summarises the latent variable identified for self-efficacy indicators: *Individual capabilities*. It reflects respondents' ability to deal with certain cycling circumstances such as going up hills, safely manoeuvring the bicycle, fixing a puncture, riding in traffic, planning a bicycle route, and making frequent bicycle repairs. *Park safely*, *Interpreting road signs*, and *Using safety elements* were removed due to low communality (<0.20).

The corresponding latent variables were extracted from the indicators of descriptive norm and controllability. However, they could not take the place of the original indicators due to the very low variance they explained, and to their unacceptable measure of internal consistency. They were not therefore used in subsequent analyses. Among the six latent variables identified, it is worth noting the high factor loadings of the indicators in the *Subjective norm* latent variable (from 0.79 to 0.97), and the high percentage of the common variance of the indicators explained (75%).

5.2.2. Differences in latent variables between groups

Six cycling latent variables were identified by EFA. A seventh latent variable for the habit of using the bicycle for non-commuting trips – *Non-commuting cycling habit* – was also calculated from the self-reported frequency of past behaviour (Verplanken et al., 2005). We investigated the possible associations between these seven cycling latent variables and the commuting mode using non-parametric techniques, due to the fact that latent variables violated the normality distribution in the groups. A Bonferroni correction (adjusted- p) was applied to control the overall Type I error rate, as multiple significance tests were done (Field, 2009). Table 7 shows that all the means of the latent variables significantly differ among the commuting modes (all $H(3) > 7.82$; adjusted- $p < [0.05/7 = 0.071]$). Mann–Whitney tests (U) between cyclists and other groups were used to follow up these findings. These effects are reported at $[0.05/(7 * 3) = 0.0024]$ the adjusted level of significance. The size effects, measured by the Pearson's correlation coefficient (r) (Field, 2009), are also reported.

The results confirm that the values of the cycling latent variables in the present sample are more positive (in absolute value) for bicycle commuters (B) than non-bicycle commuters. The most important latent variables for B are *Non-commuting cycling habit* (1.06) and *Individual capabilities* (0.53), while the latent variables *Lifestyle* (0.31) and *Awareness* (0.27) score lowest. The negative value for *Direct disadvantages* in B and walking commuters (W) means that both groups perceive the speed and time reliability of the bicycle commuting trip as a benefit, as opposed to public transport (PT) and

² Total amount of variance each indicator shares with all the indicators included in the analysis (Hair, 2009).

Table 4

Factor loadings of attitudes towards bicycle commuting characteristics.

Latent variables	Attitudinal indicators	Latent variables			
		Lifestyle	Safety and comfort	Awareness	Direct disadvantages
Lifestyle α : 0.74	Fun	0.80			
	Relaxing	0.75			
	Good image	0.52			
	Daily clothing	0.42			
Safety and comfort α : 0.67	No sweat		0.58		
	Safe for pedestrians		0.55		
	Stress-free		0.53		
	Low accident risk		0.51		
	Pollution safe		0.47		
Awareness α : 0.84	Environmentally friendly			0.81	
	Healthy			0.75	
	Cheap			0.74	
Direct disadvantages α : 0.72	Quick				−0.76
	Time reliable				−0.70

% Of indicators' common variance explained: 46%.

 Values below 0.4 are not reported. α = Cronbach's alpha coefficient.

Table 5

Factor loadings of subjective norm towards bicycle commuting characteristics.

Latent variable	Subjective norm indicators	Latent variable Subjective norm
Subjective norm α : 0.89	My friends	0.97
	My co-workers or classmates	0.82
	My family	0.79

% Of indicators' common variance explained: 75%.

 Values below 0.4 are not reported. α = Cronbach's alpha coefficient.

Table 6

Factor loadings of self-efficacy towards bicycle commuting characteristics.

Latent variable	Self-efficacy indicators	Latent variable Individual capabilities
Individual capabilities α : 0.80	Hills	0.77
	Manoeuvring	0.76
	Fixing a puncture	0.67
	Riding in traffic	0.65
	Planning a route	0.49
	Repairs	0.48

% Of indicators' common variance explained: 42%.

 Values below 0.4 are not reported. α = Cronbach's alpha coefficient.

car (C) users. W has the highest values almost equal to the aspects of *Direct disadvantages* (−0.23) and *Awareness* (0.21). PT users score more positively in the *Lifestyle* latent variable (0.22), while C users score higher in *Individual capabilities* (−0.03).

Lifestyle, *Safety and comfort*, *Awareness* and *Subjective norm* show no differences between B and W, or between B and PT users. *Direct disadvantages* show no difference between B and W; although they do between B and PT users, with a medium size effect ($r = -0.27 \approx -0.30$). The only latent variables where all comparisons differ are *Individual capabilities* and *Non-commuting cycling habit*, with medium and large size effect differences respectively. This result reveals that B users significantly see themselves as more prepared than other commuters to cope with certain cycling-related circumstances; and they also use the bicycle for daily non-commuting trips more frequently than others.

The study confirms that C commuters are very strongly in opposition to B commuters, with the highest difference (Muñoz et al., 2013). All latent variables are significantly higher for B than for C users, but *Direct disadvantages* – where the cyclists' mean is significantly more negative – are less important for B than for C users. *Non-commuting cycling habit* has the greatest difference (1.21) with a large size effect ($r = -0.47$), followed by *Direct benefits* (0.75) and *Safety and comfort* (0.73) with medium size effects (−0.32 and −0.31 respectively). Although the rest of the latent variables are significantly associated with the commuting mode choice, their size effects are small ($r < 0.3$).

Table 7

Differences in means of cycling latent variables between commuting modes.

Cycling latent variables	B	W	PT	C	H_{test}	U_{test} : B-W		U_{test} : B-PT		U_{test} : B-C	
	Mean	Mean	Mean	Mean	Sig.	Sig.	S.E. (r)	Sig.	S.E. (r)	Sig.	S.E. (r)
Lifestyle	0.31	−0.02	0.22	−0.18	0.00*	0.00	−0.17	0.46	−0.05	0.00**	−0.20
Safety and comfort	0.45	0.14	0.10	−0.28	0.00*	0.00	−0.16	0.01	−0.16	0.00**	−0.31 _m
Awareness	0.27	0.21	0.15	−0.29	0.00*	0.00	0.00	0.71	−0.02	0.00**	−0.20
Direct disadvantages	−0.49	−0.23	0.10	0.26	0.00*	0.00	−0.16	0.00**	−0.27 _m	0.00**	−0.32 _m
Subjective norm	0.40	0.04	0.04	−0.17	0.00*	0.00	−0.18	0.02	−0.15	0.00**	−0.25
Individual capabilities	0.53	−0.11	−0.15	−0.03	0.00*	0.00**	−0.36 _m	0.00**	−0.33 _m	0.00**	−0.23
Non-commuting cycling habit	1.06	−0.19	−0.15	−0.14	0.00*	0.00**	−0.61 _l	0.00**	−0.47 _l	0.00**	−0.47 _l

B: Bicycle; W: Walking; PT: Public transport; C: Car.

 H_{test} : Kruskal–Wallis test when there are three or more groups; U_{test} : Mann–Whitney test when there are two groups.S.E.: size effect; _l: Large size effect; _m: Medium size effect (medium and large size effects in grey).*Significance at adjusted level: $p < (0.05/7) = 0.0071$.**Significance at adjusted level: $p < (0.05/(3 * 7)) = 0.0024$.**Table 8**

Logistic regression results.

Variables	β	Sig.	Exp(β)
Lifestyle	−0.17	0.26	0.84
Safety and comfort	0.28	0.04	1.32
Awareness	0.26	0.11	1.29
Direct disadvantages	−0.42	0.01	0.66
Subjective norm	0.30	0.04	1.35
Individual capabilities	0.19	0.30	1.21
Non-commuting cycling habit	1.07	0.00	2.93
Constant	−2.62	0.00	0.07

 $n = 654$; $\chi^2(7) = 131.96$; $R^2 = 0.34$ (Nagelkerke).Significance level: $p = .05$. Significant variables shown in grey.

5.2.3. Regression analysis

A regression analysis was carried out with the cycling latent variables to complement the bivariate analyses. Table 8 shows the results of the binary logistic regression model, where the dependent variable was “Bicycle commuter” (1 if the commuting mode is the bicycle and 0 otherwise) and the independent variables were the identified cycling latent variables.

Respondents with a **Non-commuting cycling habit** have the greatest likelihood of commuting by bicycle (2.93). The influence of friends, family and co-workers/classmates (**Subjective norm**) also fosters the decision to cycle for commuting purposes ($\beta = 0.30$). The **Safety and comfort** latent variable also has a positive effect on the decision to commute by bicycle ($\beta = 0.28$). This result may be influenced by the low value of this latent variable from car commuters, who account for 41% of the total sample. In fact, the model for a subsample of non-car commuters confirms that this variable is not significant for them. The constructed attitude **Direct disadvantages** is statistically significant with a negative sign, confirming that a positive perception of the speed and time reliability of the bicycle increases the likelihood of choosing it for commuting.

6. Conclusions and policy recommendations

This paper proposes a number of cycling indicators based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) for their inclusion in mobility surveys, and contributes to a deeper understanding of the structure of cycling latent variables, using exploratory factor analysis (EFA). We examine both objective and latent variables and their association with, and influence on, bicycle commuting.

The results for the objective factors showed that socioeconomic and household characteristics (*Gender*, *Age group*, *Family status* and *Professional situation*), mode availability (*Car licence*, *Bicycle availability*, and *Bicycle parking at home*) and trip characteristics (*Travel time* and *Travel distance*) were associated with bicycle commuting, albeit all with minor size effects. However, this analysis allowed the bicycle commuter profile to be identified.

The TPB survey developed in this study included not only questions related to beliefs but also importances, and therefore provided a more accurate measurement of attitudes and subjective norm. As a consequence the association and regression analysis of the six cycling latent variables identified have a sound basis. The EFA identified four attitudinal latent variables – **Lifestyle**, **Safety and comfort**, **Awareness**, and **Direct disadvantages**; another – **Subjective norm** – related to psychological support for using the bicycle to commute; and a final variable – **Individual capabilities** – referring to respondents' ability to cope with certain cycling circumstances. The study also calculated a seventh latent variable – **Non-commuting cycling habit**

– for the habit of using the bicycle for non-commuting trips. All these cycling latent variables were significantly associated with the commuting mode, with medium and large effects, unlike the objective factors. The results showed the performance of the city of Vitoria-Gasteiz (Spain), which is currently in the process of using the bicycle as a viable transport mode.

Although the present study is cross-sectional, the findings allow the selection of certain policy recommendations, as suggested by Handy et al. (2014). The results for **Non-commuting cycling habit** show the greatest difference between bicycle and non-bicycle commuters. This latent variable appears to be the strongest latent predictor of bicycle commuting. One potential strategy to change this that could be considered by the city authorities is the launch of *marketing campaigns* to encourage non-bicycle commuters to increase their bicycle use for going out, shopping, running errands and so on. It should however be noted that habit may not be easy to change. For this reason, and because **Subjective Norm** is another latent variable influencing bicycle commuting, it may be more positive to target bicycle measures to social groups rather than individuals. We suggest prioritising marketing campaigns and other infrastructure investments (cycleways and bicycle parks) around leisure zones and social and cultural centres/associations to maximise the significant influence of friends on bicycle commuter behaviour. The second most important social group to target is co-workers and classmates, suggesting measures in work/study environments.

Further efforts could also be made to foster the speed and time reliability of the bicycle (**Direct advantages** for bicycle commuters) – especially in the case of public transport or car users – through policies aimed at encouraging people to experience the cycling trip. Some 59% of these commuters have never tried commuting by bicycle, and 67% of them make trips of less than five km. A lack of experience in this area may impact the results of this latent variable (Rondinella et al., 2012). One positive measure would be to launch bicycle-specific programmes such as *Bike-to-work days*. There is encouraging evidence from other places of the effect of this type of programmes on cycling (Pucher et al., 2010; Yang et al., 2010). **Safety and comfort** is another important predictor for bicycle commuting, although only for car commuters, for whom this is probably seen as a deterrent due to their lack of experience. Safety and comfort issues are not major barriers to bicycle commuting for non-car commuters. Therefore the recent policy in Vitoria-Gasteiz of providing cycleways and improving bicycle network connectivity appears to be effective. With regard to the latent variable **Individual capabilities**, the extension of measures such as cycling courses (how to ride safely on the proper infrastructures and near cars, how to fix a puncture and repair/maintain the bicycle and so forth) would benefit non-bicycle commuters, and especially pedestrians and public transport users.

These results differ from those in cities with less bicycle use such as Madrid, where safety is a clear barrier for all commuters, and social pressure is not an influential factor (Muñoz et al., 2013). Vitoria-Gasteiz shares with Madrid the importance of the latent variable **Non-commuting cycling habit**, and more progress is thus needed to normalise the bicycle as a mode of transport. The importance of habit diminishes the influence of other latent variables such as **Individual capabilities** (PBC), which appears to be significant in more cyclable contexts such as the Netherlands (Heinen et al., 2011).

The results of this study correspond to an intermediate stage, and could help shed light on the process of so-called cities in transition towards a cyclable city. The cycling latent variables extracted can serve as the starting point for more sophisticated modelling schemes such as structural equation models (Golob, 2003) and hybrid choice models (Ben-Akiva et al., 2002a, 2002b; Walker and Ben-Akiva, 2002).

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4 Integrated choice and latent variable model for cycling

The traditional modelling framework is not appropriate for studying bicycle demand, because this requires choice variables other than time and cost. As pointed out in chapter 2, this makes it more necessary, among other aspects, to promote advanced models with the explicit inclusion of psychological latent variables.

As shown in chapter 2, the number of studies using extended discrete choice models –following the hybrid choice model (HCM) framework– for analysing the bicycle choice is limited: there are only five empirical applications up to now. These studies omitted the forecasting issue, following both the sequential estimation approach (Fernández-Heredia, et al. 2016), or the simultaneous estimation approach (Kamargianni and Polydoropoulou, 2013; Habib et al., 2014; Kamargianni et al., 2015). Only Maldonado-Hinarejos et al. (2014) developed a forecasting application, although applying sequential estimation –which produces inefficient estimators– and constructed the latent variables using Principal Component Analysis (PCA), which lacks causal variables that can be used to properly evaluate hypothetical scenarios.

Considering all previous points, this chapter is about the effect of several bicycle latent variables on mode choice behaviour, throughout the development of an integrated choice and latent variable (ICLV) model, with simultaneous estimation, whilst paying special attention to the forecasting issue. This way, the developed ICLV model is used to test several potential transport measures, and particularly soft measures related to bicycle experience that cannot be tested with traditional discrete choice models.

Therefore, the developed ICLV model in this chapter, applied to the city of Vitoria-Gasteiz (Spain), solves the problems in the applications from chapter 3 of:

- Inefficient estimators (due to the use of two-step estimators) and,
- Inability to forecast (due to lack of causal variables of the latent variables),

and it follows some of the recommendations for future research from chapter 2 of:

- Including bicycle-related questions –both objective and subjective– in RP surveys to further develop modelling frameworks with cycling latent variables.
- Using of advances in technology, such as trip-planning software in this case, to ease the process of constructing time and cost attributes for the non-chosen modes.

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Additional details that have been kept outside, due to following a paper format, have been included in the appendices:

- A summary of the sequential ICLV models can be seen in Appendix F.
- Aggregate direct and cross elasticities of probability of bicycling and using the car, with respect to changes in time and cost, can be seen in Appendix G.

Manuscript details

Manuscript number	TRA_2016_298
Title	Modelling the effect of policy measures for improving cycling for urban transport
Article type	Research Paper
Abstract	<p>For the bicycle demand analysis it is essential to know the factors that influence in the bicycle choice and to make prognosis about the bicycle demand once policy measures are implemented. Considering the limited number of studies using extended discrete choice models for analysing the bicycle choice, this paper aims to investigate the effect of several bicycle latent variables on mode choice behaviour throughout an integrated choice and latent variable model with simultaneous estimation, and paying special attention to the forecasting issue. Data for the model building comes from the household travel survey of Vitoria-Gasteiz (Spain) in 2014 which specifically included perceptual indicators towards the bicycle use for urban mobility that were used to define six bicycle latent variables. The study revealed the importance of the latent variables (Direct advantages, Safety and comfort, External facilities and Individual capacities) which played a significant role in the bicycle choice process. The final model entered two latent variables (Direct advantages and Individual capacities)</p>

directly into the bicycle utility function. It was used to test the effectiveness of several potential transport measures, with the special interest in three real-world soft measures related to bicycle experience that cannot be tested with traditional discrete choice models. Forecasting results showed that the proposed urban toll to cars would be the preferred measure. Moreover, the effectiveness of the soft measures was more limited than those of the hard measures, probably due to weak structural relationships in the latent variable model. Future research might focus on finding better-supported SEM to improve forecasting power with latent variables.

Keywords

words: integrated choice and latent variable model; simultaneous estimation; bicycle latent variables; policy analysis

Corresponding Author

Begoña Muñoz Lopez

Corresponding Author's Institution

Universidad Politecnica de Madrid

Order of Authors

Begoña Muñoz Lopez, Ricardo Daziano, Andres Monzon

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Modelling the effect of policy measures for improving cycling for urban transport

ABSTRACT

For the bicycle demand analysis it is essential to know the factors that influence in the bicycle choice and to make prognosis about the bicycle demand once policy measures are implemented. Considering the limited number of studies using extended discrete choice models for analysing the bicycle choice, this paper aims to investigate the effect of several bicycle latent variables on mode choice behaviour throughout an integrated choice and latent variable model with simultaneous estimation, and paying special attention to the forecasting issue.

Data for the model building comes from the household travel survey of Vitoria-Gasteiz (Spain) in 2014 which specifically included perceptual indicators towards the bicycle use for urban mobility that were used to define six bicycle latent variables. The study revealed the importance of the latent variables –‘Direct advantages’, ‘Safety and comfort’, ‘External facilities’ and ‘Individual capacities’– which played a significant role in the bicycle choice process.

The final model entered two latent variables –‘Direct advantages’ and ‘Individual capacities’– directly into the bicycle utility function. It was used to test the effectiveness of several potential transport measures, with the special interest in three real-world soft measures related to bicycle experience that cannot be tested with traditional discrete choice models. Forecasting results showed that the proposed urban toll to cars would be the preferred measure. Moreover, the effectiveness of the soft measures was more limited than those of the hard measures, probably due to weak structural relationships in the latent variable model. Future research might focus on finding better-supported SEM to improve forecasting power with latent variables.

Highlights:

- A MIMIC model identified a set of six bicycle latent variables
- First ICLV simultaneous model with several bicycle LVs used for policy analysis
- Most bicycle latent variables were the key drivers of bicycle mode choice
- Effectiveness of the soft measures was more limited than those of the hard measures

Key words: integrated choice and latent variable model; simultaneous estimation; bicycle latent variables; policy analysis.

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1 Introduction

Due to the increasing number of motorised urban trips, the bicycle as a non-motorised transport mode is one of the possible solutions for problems of congestion and environmental nuisance. Because of that, the bicycle has captured the attention of transport policies focused on sustainable development, worldwide and especially in Europe (Alegre and Carbonell, 2015; Pucher et al., 2010; Yang et al., 2010).

In Spain many cities developed their bicycle mobility plans during the last decade and started implementing their corresponding measures to promote the use of the bicycle for urban mobility. These measures mainly consist in building bicycle lanes and safe bicycle parking, improving intermodality bicycle-public transport and promoting public bike-share systems. Although they have produced remarkable increases in bicycle demand in cities where the starting values were very low, Spanish cycling levels are still far from high levels in other north-European countries, especially referring to commuting trips. Therefore, it seems that sometimes policies used have not been as successful as one would expect from them.

Some of the partial failures are due to a poor planning on the effect of cycling policies on users, especially on the demand perspective. The study of the bicycle travel demand in each city comprises not only to know how it is characterised, but also how it is formed—which factors influence bicycle choice— and to make prognosis about the bicycle demand once designed measures are implemented. Problems for a poor study of the bicycle demand are related to the difficulties of the traditional modelling approach and their objective variables, which are not sufficiently explaining bicycle mode choice. Bicycle mode choice requires additional variables—psychological factors—that take into consideration the subjective value attached to bicycle use and derived from the special characteristics of the bicycle as a transport mode. Psychological factors motivating bicycle choice can be quantitatively modelled as latent variables, which cannot be measured directly by the researcher and have to be inferred from other variables called indicators. In fact these psychological factors may be the main determinants of demand rather than standard measures of level of services. This makes it more necessary to promote advanced models with the explicit inclusion of psychological latent variables, among other aspects (Muñoz et al., in press).

As shown in the review by Muñoz et al. (in press), the number of studies using extended discrete choice models—following the hybrid choice model (HCM) framework—for analysing the bicycle choice is limited: there are only five empirical applications up to now. They are not used to forecast, following both the sequential estimation approach (Fernández-Heredia, et al., 2016), or the simultaneous estimation approach (Kamargianni and Polydoropoulou, 2013; Habib et al., 2014; Kamargianni et al., 2015). Only Maldonado-Hinarejos et al. (2014) developed a forecasting application, although applying sequential estimation—which produces inefficient estimators—and constructed the latent variables using Principal Component Analysis (PCA)—which lacks causal variables that can be used to properly evaluate hypothetical scenarios.

Considering all those research gaps, this paper aims to investigate the effect of several bicycle latent variables on mode choice behaviour throughout the development of an integrated choice and latent variable (ICLV) model—with simultaneous estimation—and paying special attention to the forecasting issue. Then, the developed ICLV model is used to test several potential transport measures, and particularly soft measures related to bicycle experience that cannot be tested with traditional discrete choice models. Data for the model building comes from the 2014 household travel survey (HTS) of Vitoria-Gasteiz (Spain). The modelling sample consisted of big sample, representative of the urban mobility. Data specifically included

perceptual indicators towards the bicycle use for urban mobility that were used to define six bicycle latent variables.

The final model entered two latent variables directly into the bicycle utility function. Forecasting results show that the proposed urban toll to cars produces the highest increases in bicycle share and the highest decreases in car share and therefore it would be the preferred measure. Moreover, the effectiveness of the soft measures related to the latent variables was more limited than those related to the traditional variables time and cost, probably due to weak structural relationships in the MIMIC model. Future research might focus on finding better-supported SEM to improve forecasting power with latent variables.

The rest of the paper is structured as follows. The next section summarises the modelling framework of ICLV models. Third section describes the context and data used. Fourth section includes the modelling specifications and results and shows several forecasting applications of the developed model for testing some potential policy measures for improving cycling use for urban transport. The final section provides a summary of the findings, policy recommendations and further research.

2 Methodological framework

The integrated choice and latent variable (ICLV) model developed herein belongs to the new generation of discrete choice models (DCM) based on the hybrid choice model (HCM) framework (Ben-Akiva et al., 1999; Ben-Akiva et al., 2002a; Ben-Akiva et al., 2002b; Walker and Ben-Akiva, 2002). It allows the proper inclusion of subjective factors, in the form of latent variables, into traditional DCM. Because the latent variables are not directly observed, they are identified –based on observable indicators and exogenous variables– through a latent variable model, and integrated¹ into the choice model.

The **latent variable model** is based on a multiple indicators–multiple causes (MIMIC) structure, based on a structural and measurement part. The structural equations link the observable exogenous variables, such as individuals' characteristics (X_{2n}), with the latent variables (Z_n^*) through linear regression equations. The measurement equations allow the latent variables to describe the observable indicators (I_n) –usually responses to attitudinal or perceptual survey questions–. The equations, for an individual n , are the following (c.f. (Ben-Akiva et al., 2002b)):

$$\text{Structural: } Z_n^* = X_{2n} \gamma + \eta_n \quad N(0, \Sigma_\eta)$$

$$\text{Measurement: } I_n = Z_n^* \alpha + v_n \quad N(0, \Sigma_v)$$

where

Z_n^* = ($L \times 1$) vector of latent variables, where L indicates the number of latent variables;

I_n = ($R \times 1$) vector of R indicators of latent variables associated with individual n ;

X_{2n} = ($1 \times M$) vector of M explanatory variables causing the latent variables;

γ = ($M \times 1$) vector of unknown parameters relating the explanatory variables to the latent variables;

α = ($M \times 1$) vector of unknown parameters relating the latent variables to the indicators;

η_n, v_n = vectors of random disturbance terms;

N = normal distribution;

¹ Integration at the same time (simultaneous estimation) or afterwards (sequential estimation). Integration at the same time (simultaneous estimation) or afterwards (sequential estimation).

$\Sigma_\eta = L_{diag}$ variance–covariance matrix (assuming independent latent variables); and

$\Sigma_v = R_{diag}$ variance–covariance matrix (assuming independent indicators).

Following the utility maximization framework, the equations describing the **DCM including the latent variables**, for an individual n , are the following:

Structural: $U_n = X 1_n \beta_1 + Z_n^* \beta_2 + \varepsilon_n$

Measurement: $y_{\epsilon} = \begin{cases} 1 & \text{if } U_{\epsilon} = \max \{U_{jn}\} \\ 0 & \text{otherwise} \end{cases}$

where

$U_n = (J \times 1)$ vector of utilities, where J indicates the number of alternatives;

$X 1_n = (J \times K)$ matrix, where K is the number of explanatory variables (attributes of the alternatives and characteristics of the decision maker);

$\beta_1 = (K \times 1)$ vector of unknown parameters;

$\beta_2 = (J \times L)$ matrix of unknown parameters associated with the latent variables;

$\varepsilon_n = (J \times 1)$ vector of random disturbance terms associated with utility terms; and

y_{ϵ} = indicator of whether alternative i is chosen by individual n or not.

Because latent variables are not directly observed, the choice probability is obtained by integrating the choice probability without latent variables over the whole space of Z_n^* . The choice probability is the joint probability of the observable variables y_n and I_n , conditional on the exogenous variables Z_n^*

$$P(y_n, I_n | X_n; \alpha, \beta, \gamma, \Sigma_\varepsilon, \Sigma_\eta, \Sigma_v) = \int_{Z_n^*} P(y_n | X_n, Z_n^*; \beta, \Sigma_\varepsilon) f(I_n | X_n, Z_n^*; \alpha, \Sigma_v) g(Z_n^* | X_n; \gamma, \Sigma_\eta) dZ_n^*$$

where X_n is explanatory observed variables $X 1_n$ and $X 2_n$ and f and g are the density functions of the indicators and latent variables respectively.

We use maximum likelihood techniques to estimate the unknown parameters and assume a logit probability kernel ($\varepsilon_n^{iid} EV 1$) which allows the use of maximum simulated likelihood (MSL) estimation. We use the simultaneous approach instead of the sequential one because it uses all the available information jointly and thus it results in both unbiased and efficient parameters, and it avoids severe consequences when transport policies are forecasted or evaluated, as pointed out by Raveau et al. (2010).

3 Context and description of the data

3.1 Vitoria-Gasteiz

Vitoria-Gasteiz is a municipality in northern Spain with a population of 242,924 inhabitants in 2014. The principal urban area is the central city which is compact and has almost completely flat topography. The climate of the area is moderately cold, with damp winters and cool summers.

Local authorities have been implementing a sustainable transport policy during the last decade, following their Mobility and Public Space Plan (Council of Vitoria-Gasteiz, 2007) and

their Cycling Mobility Master Plan (Council of Vitoria-Gasteiz, 2010). Some of the remarkable transport measures implemented during the last years include a new traffic regulation (to legislatively order the circulation of cars, bicycles and pedestrians), pedestrianisation of streets in the city centre, building of bicycle parking and a bicycle lane network, promotion of safe cycling courses, traffic calming in 47 streets of the city centre, an increase in the regulated parking area fees, and camera control to car access to the city centre.

Bicycle use in Vitoria-Gasteiz has increased sharply during the last years, from 3.3% in 2006 to 6.9% in 2011, and to 12.3% in 2014 (Council of Vitoria-Gasteiz, 2015). Nowadays, Vitoria-Gasteiz is the Spanish city with the highest bicycle share of trips, while its sustainable (bicycle and walking) share of trips is the highest of any European medium-size cities (around 250.000 inhabitants), according to EPOMM data (<http://www.epomm.eu>).

3.2 Household travel survey

3.2.1. General characteristics

This paper uses data from a mobility survey designed to fulfil two requirements:

1. Ad-hoc to the TRANSBICI project², in order to collect a large and representative survey with both revealed preference (RP) travel data and perceptions towards bicycle use for transport and,
2. Municipal household travel survey (HTS) to know about the population's trips in a workday of 2014, and comparable with previous municipal HST (2006 and 2011).

Therefore, the survey followed the same methodology than previous municipal HTS and included the specific new questions from the TRANSBICI project. The methodological characteristics were: telephone household survey; stratified random sampling representative of the municipal residents' mobility (older than 9) by transport zone, age group and gender; from Tuesdays to Fridays, during the spring 2014³.

The depurated survey database consisted in a sample of 4,192 individuals, representing 218,515 people in the population⁴ older than 9. The 96.7% of that population travelled the previous day, representing a total of 911,326 trips (4.3 trips per person per day). The mode share of the population trips was: 12.3% by bicycle, 54.4% by walking, 7.6% by public transport (bus and tram), 24.7% by car and motorbike, and 1.1% other modes (taxi, van or truck, school/company bus or coach, railway, public transport on request, and other individual and collective modes).

2 Spanish Research Project 'TRANSBICI-Travel behaviour analysis for modelling the potential use of bicycle: transition to a cycling city'. Spanish Research Project 'TRANSBICI-Travel behaviour analysis for modelling the potential use of bicycle: transition to a cycling city'.

3 A 9% of the sample, especially teenagers, could not be surveyed during that period and they were finally collected in October, after the new beginning of the classes. A 9% of the sample, especially teenagers, could not be surveyed during that period and they were finally collected in October, after the new beginning of the classes.

4 Planned quotes for the strata (by transport zones, age groups and gender) were not completely reached and weights were required for the analysis of the population results. Planned quotes for the strata (by transport zones, age groups and gender) were not completely reached and weights were required for the analysis of the population results.

3.2.2. Survey questions

The novel of the questionnaire comes from the inclusion of bicycle perceptual questions in the usual HTS. The bicycle perceptual questions were designed based on the results of the first part of the TRANSBICI research project, which consisted in a panel survey and included multidisciplinary points of view from transport planners, psychologists and geographers. That panel survey, focused on commuting trips, was conducted in Vitoria-Gasteiz in 2012, 2013 and 2014; and included and tested indicators –perceptions of cycling factors– following the attitudinal Theory of Planned Behavior (TPB) (Ajzen, 1991). The bicycle indicators of the survey were measured using a 7-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7); and were of the following four types (see Table 1 for the detailed indicators of each type):

11. Degree of agreement or disagreement towards several factors related to the (possible) bicycle trip for urban mobility.
12. Degree of limitation provoked by several factors related to the (possible) bicycle trip for urban mobility.
13. Subjective norm (SN): it is one of the TPB's predictors of intention, defined as 'the perceived social pressure to engage or not to engage in a behavior'. As one of the TPB elements, SN is calculated by multiplying the [beliefs](#) linking the behaviour (bicycle use for urban mobility in our case) with their corresponding importances.
14. Global perception of the bicycle use and intentions related to bicycle use.

The usual HTS questions included in the survey were divided in three blocks:

1. Individual and household socioeconomic characteristics and availability of transport modes and type of parking at home (see Table 2).
2. Trips made the previous day: origin, destination, purpose, mode(s), line(s) and ticket(s) (if public transport used), parking at destination (if car driver, motorbike or van/truck used), infrastructure(s) and parking at destination (if bicycle used). For commuting trips, availability of showers and/or lockers at the work/study place was also included.
3. Frequency of bicycle use for different purposes [work, study, non-commuting transport purposes (visiting, going out, going shopping, or going to the doctor/hospital), and doing sport]; and experience riding a bicycle for different purposes.

3.2.3. Modelling sample

Only urban trips (internal to the continuous populated area composed by the city of Vitoria-Gasteiz and the nearby nucleus) were considered. None of the geographically excluded trips had chosen the bicycle as the main mode. All trip purposes except the one 'Without destination or going for a walk⁵' were contemplated. The main⁶ modes considered were bicycle (B), walking (W), public transport (PT) –bus and tram– and car (C) –driver and passenger–, dismissing trips by minor modes such as motorbike, coaches, taxi, and van (2,1% of urban transport trips)

5 Bicycle trips for doing sports were included in this trip purpose. Bicycle trips for doing sports were included in this trip purpose.

6 When more than one mode was used for a trip, a hierarchical organization was applied in order to determine the main mode. When more than one mode was used for a trip, a hierarchical organization was applied in order to determine the main mode.

The final valid modelling sample consisted of 14,406 trips distributed as follows: 13.7% (B); 56.2% (W); 9.3% (PT); 20.8% (C). Weighting those trips to the population (730,044 trips) the distribution is quite similar: 12.4% (B); 58.8% (W); 8.8% (PT); 20.0% (C). Therefore, and to avoid problems related to choice-based sampling, the modelling sample was used as representative of transport urban trips in Vitoria-Gasteiz.

3.2.4. Descriptive statistics

Table 1 summarises the average responses to the perceptual questions (blocks I1, I2, I3 and I4), both for ‘cyclists’ –people who used the bicycle as main mode the previous day– and ‘non-cyclists’. Most of the questions were used as indicator variables for the construction of the latent variables. From the first block, cyclists give similar or more positive values to most indicators than other users, except to indicators related to uncomfortable issues such as weather, sweat and traffic stress, or risk issues (theft or accident). Regarding the second block –of limitations– cyclists perceive fewer limitations than non-cyclists, but for the use of the helmet. For all users, the highest influence from the cycling perspective comes from the family, followed by friends, and co-workers/study colleagues at the last place.

Table 1 Average values of the perceptual questions about the bicycle

	Cyclists	Non-cyclists
Degree of agreement or disagreement towards: the bicycle use for urban mobility is...		
Environmentally friendly	6.8	6.8
Cheap	6.6	6.6
Healthy	6.2	6.5
Time reliable	6.1	5.3
Independent	6.0	5.6
Flexible	5.9	5.7
Relaxing and fun	5.9	4.8
Quick	5.7	5.2
Theft risky	5.4	5.8
Weather dependent	5.2	6.1
Traffic stressful	5.0	5.7
Accident risky	4.3	5.1
Conflicts with pedestrians	4.2	4.5
Sweat	3.9	4.8
Degree of limitation provoked by...		
Ride in the traffic	4.9	5.7
No safe parking	4.4	5.2
No cycleways	4.4	4.9
Fix a puncture	3.9	4.9
Manoeuvring	3.9	4.6
Long distances	3.7	4.7
Helmet use	3.7	3.4
Hilliness	3.4	4.6
No showers/ranks at destination	3.1	4.2
Physical condition	2.7	4.0
Subjective norm		
Family	5.0	4.3
Friends	4.6	3.9
Co-workers/Study colleagues	4.1	3.8
Global perception and intentions		
Global perception about the bicycle use in Vitoria-Gasteiz	5.4	4.9
Intention to increase/start using the bicycle for urban mobility	4.6	3.0
Intention to use a bike-sharing system	3.5	3.1

The global perception about the bicycle use in Vitoria-Gasteiz is quite positive (around five), although slightly higher for cyclists. Intention to start using the bicycle or increase its use for

urban mobility in the city is under the average (3.0) for non-cyclists while it increases to moderately positive (4.6) for current cyclists. Intention to start using a public bike-sharing system is also under the average (around three), with a slightly higher value for cyclists too.

Distribution of the modelling sample according to characteristics related to trips, individual and household socioeconomics, availability of transport modes and type of parking at home are summarised in Table 2. Values are shown for the total sample, and for each of the main transport modes considered: bicycle, walking, public transport and car. The most remarkable data, especially for the bicycle, are the following:

1. The majority of trips had a non-commuting purpose, especially among the walking trips (81%). Among the commuting trip purposes, going to work produced higher percentages of trips than going to studies, for all modes except for the bicycle. This links with the fact that most bicycle trips (58%) were made by young people < 30. While among walking trips half were made by > 49, car and public transport trips were mainly made by people between 30 and 49.
2. Bicycle is the second fastest mode (10.9 min) after car (6.7 min). However, the calculated car time does not take into account the parking time and therefore it might be closer to bicycle time.
3. The average car distance was 3.7 Km which is a high reasonable distance to be made by bicycle, and that was ridden by about the 18% of the cyclists. Therefore, regarding travel distance there is a high potential among car users to change to the bicycle.
4. There were slightly more male bicycle trips (54%) than female bicycle trips (46%). Trips by the rest of modes were mainly made by women. Almost half bicycle trips (48%) were made by workers.
5. The highest percentage of trips by people in households with children below 6 was made by car (26%), while the highest percentage of trips by people in households with elderly (> 64) was walking (32%).
6. Household income was similar among bicycle trips and car trips.
7. Most non-car trips were made by people with car available, especially among bicycle trips (87%). Only 8% of the total trips were made by people who did not know to ride a bicycle, especially people > 64. The majority of non-bicycle trips were made by people who had a bicycle available; percentage which is even higher among car trips.

Table 2 Characteristics of the modelling sample

Variable		Bicycle (14%)	Walking (56%)	Public transport (9%)	Car (21%)	Total
Purpose	Work	23%	11%	19%	32%	18%
	Study	28%	8%	18%	3%	11%
	Non-commuting	49%	81%	63%	65%	72%
Calculated travel time	Mean (min)	10.9	13.1	19.9	6.7	12.1
Calculated travel distance	Mean (Km)	2.5	1.0	3.2	3.7	2.0
Gender	Male	54%	34%	21%	42%	37%
	Female	46%	66%	79%	58%	63%
Age	<30	58%	18%	28%	16%	24%
	30–49	31%	33%	39%	59%	39%
	>49	11%	49%	34%	24%	37%
Nationality	Spanish	94%	97%	93%	97%	97%
	Foreigner	6%	3%	7%	3%	3%
University studies	Yes	27%	29%	24%	33%	29%
	No	73%	71%	76%	67%	71%
Professional situation	Worker	48%	14%	23%	7%	18%
	Student	35%	36%	37%	64%	42%
	Other	17%	51%	40%	29%	41%
Type of schedule	Part-time	16%	11%	13%	18%	13%
	Continuous	54%	28%	34%	39%	34%
	Other	30%	61%	53%	43%	52%
Household situation	Father/Mother	26%	38%	39%	53%	40%
	Son/Daughter	58%	22%	28%	18%	27%
	Other	16%	40%	33%	29%	34%
People in household	Mean	3.4	2.9	3.0	3.1	3.0
Children < 6 in household	Yes	9%	10%	14%	23%	13%
	No	91%	90%	86%	77%	87%
Elderly > 64 in household	Yes	8%	32%	21%	16%	24%
	No	92%	68%	79%	84%	76%
Household income	< 2.000€	44%	54%	59%	45%	51%
	> 2.000€	56%	46%	41%	55%	49%
	N/A	30%	20%	23%	14%	20%
Car license	Yes	53%	69%	59%	94%	71%
	No	47%	31%	41%	6%	29%
Availability of car	Yes	87%	85%	83%	100%	88%
	No	13%	15%	17%	0%	12%
Household's cars	Mean	1.4	1.2	1.2	1.7	1.3
Car parking at home	Inside a building's parking	73%	77%	73%	74%	75%
	Outside (in the street)	27%	23%	27%	26%	25%
Availability of motorbike	Yes	10%	5%	7%	13%	8%
	No	90%	95%	93%	87%	92%
Motorbike parking at home	Inside a building's parking	88%	92%	95%	96%	93%
	Outside (in the street)	12%	8%	5%	4%	7%
Know to ride a bicycle	Yes	100%	90%	89%	95%	92%
	No	0%	10%	11%	5%	8%
Availability of bicycle	Yes	100%	66%	67%	76%	73%
	No	0%	34%	33%	24%	27%
Bicycle parking at home	Inside the household	36%	25%	24%	20%	26%
	Inside the household's building	62%	74%	75%	79%	73%
	Outside (in the street)	2%	1%	0%	0%	1%

4 Empirical analysis

4.1 Modelling

This subsection describes both the construction of the choice set and variables to include in the model –time, cost and latent variables– and the specifications to develop the integrated choice and latent variable (ICLV) model.

4.1.1. Travel times and costs for alternatives modes

Travel times and distances for each trip were calculated for the four alternatives in the model – bicycle, walking, public transport and car–, based on origin and destination addresses from the survey. Since declared travel times are subjective values and a preliminary examination of them showed an important number of errors, calculated times were used both for the chosen and for the alternative modes.

For **car trips** the software Microsoft® MapPoint 2013 and its complement MPMileage 2.4 were used to calculate the quickest point-to-point routes. The complement allowed batching-calculating thousands of routes. Error calculations in a small number of routes by car were solved individually using Google Maps. Fuel costs were calculated by multiplying travel distances by an approximation of average cost of fuel (0.00013€/m). This approximation was estimated considering the distribution of car types in the region –gasoline/gas-oil– (Spanish Directorate-General of Traffic, 2013), average fuel costs in the region in May 2014 (Spanish Ministry of Industry, Energy and Tourism, 2014), and average fuel consumption factors in urban context for Spain, calculated based on the EMEP/EEA guidebook to European emissions (European Monitoring and Evaluation Programme, European Environment Agency, 2013). If trip purpose was different from coming back home and if trip destination was located inside the OTA zone –the regulated parking area in the city centre– an approximation of average parking cost was assigned (1.35€). This approximation was estimated considering the percentage of car users declaring to pay when they park inside the OTA zone and the average rent cost for a garage in the area.

Public transport, walking and bicycle travel times and distances were calculated using an application web to automate queries to the municipal web-router ‘GEO Vitoria-Gasteiz’, based on the open source platform OpenTripPlanner (OTP). Error calculations in a small number of routes by public transport and walking were solved individually using Google Maps. The corresponding errors for some bicycle routes were solved individually with GEO Vitoria-Gasteiz but doing little changes in origin or destination addresses. Public transport fare (0.65€) was calculated as an average between the bus and tram trip fare using the BAT card (general transport ticket for a regular public transport use).

4.1.2. Choice set

To define the availability of the four modes for each trip, several requirements were established:

1. Bicycle requirements: a calculated travel distance less than 9Km; that the individual knows how to ride a bicycle and has a bicycle available; and a moderate (+4) or positive (+5, +6 or +7) intention to start using the bicycle (in a scale from no intention at all (+1) to completely positive intention (+7)).
2. Walking requirements: a calculated travel distance less than 7Km.
3. Public transport requirements: when there is a possible public transport route and therefore there is a calculated travel distance.

4. Car requirements: a calculated travel distance and that the individual has a car available.

Limits in calculated distances were established considering the corresponding maximum distances done by pedestrians (6.7Km) and cyclists (8.4Km) in the modelling sample. The indicator of intention to start using the bicycle for urban mobility was used as an approximation to discard the potential non-cyclists that might never use the bicycle. According to this, there are 45% of potential cyclists among public transport users, 41% among car users and 37% among pedestrians. In this way, the current bicycle share of 13.7% in the modelling sample might increase up to a maximum, but more realistic 42.0% of urban trips.

4.1.3. Latent variables

Most answers to the perceptual questions about the bicycle were used as indicator variables for the construction of the latent variables. Several analyses were applied in order to get a preliminary idea about the structure of the latent variables: an explanatory factor analysis (EFA) with SPSS®v20, and a multiple indicators multiple causes (MIMIC) model with AMOS (SPSS® Amos 22.0). Since the focus of the paper is modelling with discrete choice models, only the structure of the latent variables is reported, but not the details of these analyses. The names of the latent variables were assigned according to their constituent indicators (see Table 3), and considering the existing literature.

Table 3 Relationship between latent variables and indicators

Latent variables	Indicators	Survey questions (see 3.2.2.)
SC - Safety and comfort*	'Low accident risk', 'No traffic stress', 'No conflicts with pedestrian', 'Weather independent', 'No theft risk' and 'No sweat'	Type I1: degree of agreement or disagreement towards several factors related to the (possible) trip by bicycle for urban mobility
DA - Direct advantages	'Relaxing', 'Quick', 'Time reliable', 'Independent' and 'Flexible'	
A - Awareness	'Cheap', 'Environmentally beneficial' and 'Healthy'	
EF - External facilities*	'Ride separate from the traffic', 'Short distance', 'Cycleways', 'Safe parking' and 'Shower at destination'	Type I2: degree of limitation provoked by several factors related to the (possible) trip by bicycle for urban mobility
IC - Individual capacities*¹	'Hilliness', 'Physical condition', 'Fixing a puncture' and 'Manoeuvring'	
SN - Subjective norm	'Family', 'Friends' and 'Co-workers/Study colleagues'	Type I4: perceived social pressure to cycle for urban mobility or not

*: The name and scale values of the original indicators were reversed

¹: The indicator 'Wear a bike helmet' had to be removed.

4.1.4. Model specification

In order to find the best specification that fits with the data and explains mode choice, especially bicycle choice, the authors followed a process by testing: several specifications for the mode-choice model⁷, different types of coefficients (generic and alternative-specific), interactions between variables, and progressively including different types of variables [socioeconomic, alternative-varying and bicycle-specific (such as the latent variables)]. The corresponding tests to choose the most appropriate specification were calculated. This paper presents the results for the best models of each case.

For the traditional discrete choice model (DCM) the utility of choice is a function of alternative-varying variables (travel time and cost, and the interaction between time and age groups), trip-specific variables (purpose), socioeconomics and alternative-specific constants (ASCs) for the alternatives bicycle, walking and public transport.

Based on the aforementioned DCM, the ICLV is developed by progressively including alternative-specific variables for the bicycle –the six bicycle latent variables identified– into its bicycle utility. These latent variables are expected to increase the probability that the bicycle would be chosen. The initial part of the process consisted in calculating the ICLV models sequentially due to the speed in estimation times. Sequential results⁸ anticipated the simultaneous ones and the sequential estimated coefficients were used as starting values for the simultaneous ICLV models, which were calculated afterwards, with very lengthy estimation times.

4.2 Results of model estimation

This subsection presents the estimation results of the choice models developed and discusses their differences and distinctive features, especially for the bicycle choice. Python Biogeme software (Bierlaire, 2003) was used to estimate the models. When needed, the number of draws was set to 1,000.

Table 4 presents the estimation results from a **standard DCM**: a multinomial-logit model without latent variables. ASCs show a clear preference for walking trips over the car, followed bicycle and public transport trips. However, these coefficients for bicycle and public transport should be negative. As expected, the generic coefficient for travel cost and the specific ones for travel times –for bicycle (*bicycle-time*), walking (*walking-time*) and motorised modes (*motorised-time*)– are all negative and statistically significant ($p < 0.05$). The statistically significant (at least $p < 0.10$) interaction⁹ coefficients between travel time and age groups, allowed calculating the corresponding values of time (VOTs) for each subgroup, as shown later. A commuting purpose of the trip shows statistically significant coefficients for all modes, positive for bicycle and public transport and negative for walking.

⁷ Apart from the multinomial-logit, different specifications for mixed logit were also tried. The only coefficient that showed a statistically significant random variation was the time coefficient for walkers. Therefore, the mixed logit was dismissed and the multinomial-logit was the specification finally chosen. Apart from the multinomial-logit, different specifications for mixed logit were also tried. The only coefficient that showed a statistically significant random variation was the time coefficient for walkers. Therefore, the mixed logit was dismissed and the multinomial-logit was the specification finally chosen.

⁸ Results of the sequential models are available upon request. Results of the sequential models are available upon request.

⁹ The interaction term between cost and household income was also tested but resulted statistically insignificant. The interaction term between cost and household income was also tested but resulted statistically insignificant.

In relation to socioeconomic variables we see that only being a *man* and *having children < 6 in the household* have a significant effect on the bicycle choice, positive and negative respectively. Being *foreigner*, *having university studies*, *having elderly people (>64) in the household* or *having a household income < 2.000€/month* do not appear to be statistically significant for the bicycle choice. Regarding results from the variable age group, the bicycle coefficient for an age between 30-49 (compared to >49) is negative (-0.96) and contradicts what happens in reality. The rest of socioeconomic variables from Table 2 were not statistically significant and were not included in the final model.

Table 4 Results for the mode choice model without latent variables

	β	Reference level	MNL	
			Value	P-value
Alternative-specific constants	ASC-bicycle	car	1.25	0.00
	ASC-walking		3.49	0.00
	ASC-public transport		0.34	0.03
	Cost	-	-0.59	0.00
	Bicycle-time	-	-0.17	0.00
	Walking-time	-	-0.13	0.00
	Motorised-time	-	-0.06	0.00
Alternative-varying variables	Bicycle-time*(<30)	>49	0.07	0.00
	Bicycle-time*(30-49)		0.04	0.02
	Walking-time*(<30)		-0.02	0.03
	Walking-time*(30-49)		-0.01	0.05
	Motorised-time*(<30)		0.04	0.00
	Motorised-time*(30-49)		-0.03	0.03
Trip-specific variables	Bicycle-commuting	non-commuting	0.59	0.00
	Walking-commuting		-0.15	0.02
	Public transport-commuting		0.34	0.00
Socioeconomic variables	Bicycle-man	woman	0.30	0.00
	Walking-man		-0.25	0.00
	Public transport-man		-1.01	0.00
	Bicycle-(<30)	>49	0.06	0.80
	Walking-(<30)		0.27	0.13
	Public transport-(<30)		-0.42	0.03
	Bicycle-(30-49)		-0.96	0.00
	Walking-(30-49)		-0.53	0.00
	Public transport-(30-49)		-0.14	0.41
	Bicycle-foreigner	Spanish	0.18	0.40
	Walking-foreigner		0.18	0.31
	Public transport-foreigner		0.53	0.01
	Bicycle-university studies	without university studies	0.06	0.49
	Walking-university studies		-0.10	0.10
	Public transport-university studies		-0.32	0.00
	Bicycle-children<6	without children<6 in the household	-0.56	0.00
	Walking-children<6		-0.43	0.00
	Public transport-children<6		-0.11	0.29
	Bicycle-elderly>64	without elderly>64 in the household	-0.06	0.66
	Walking-elderly>64		0.21	0.01
	Public transport-elderly>64		0.18	0.07
	Bicycle-(<2,000€)	>2,000€/month in the household	-0.02	0.80
	Walking-(<2,000€)		0.13	0.04
	Public transport -(<2.000€)		0.30	0.00
	Bicycle-(N/A)		0.53	0.00
	Walking-(N/A)		0.37	0.00
	Public transport-(N/A)		0.50	0.00
	Final log-likelihood		-9,901.85	
	Likelihood ratio index (p)		0.33	

Several **integrated choice and latent variable (ICLV) models** were developed based on the DCM described in the previous subsection (but omitting the socioeconomic variables due to their low explanatory power for the bicycle alternative and because they are introduced through

the structural equations of the MIMIC model) and testing each of the bicycle latent variables individually. The latent variables ‘Awareness’ and ‘Subjective norm’ did not show statistically significant coefficients. The other four latent variables –‘Safety and comfort’, ‘Direct advantages’, ‘External facilities’ and ‘Individual capacities’– showed positive and statistically significant coefficients and were tested in pairs in six models. The number of latent variables in the final models –only two– was conditioned by convergence difficulties and very lengthy estimation times, related with the simultaneous estimation.

The six developed models were compared with the consistent Akaike information criterion (CAIC). The model with ‘**Direct advantages**’ (DA) and ‘**Individual capacities**’ (IC) showed the lowest CAIC (516,951), indicating the best fit and it was chosen as the final ICLV model (ICLV-1, see Table 5 and upper part of Figure 1). Considering the high importance of safety issues related to the bicycle in the literature, results from a second ICLV including the latent variable ‘Safety and Comfort’ are also shown. Specifically, the one with the lowest CAIC (570,528), that is, the model with the latent variables ‘**Safety and Comfort**’ (SC) and ‘**Individual capacities**’ (IC) (ICLV-2, see Table 5 and the lower part of Figure 1).

ASCs from Table 5 show a clear preference for walking trips over the car and a preference for car trips over bicycle trips, which reflect reality. The specific constant for public transport appears to be the only statistically insignificant coefficient. The rest of coefficients are quite similar to those of the DCM, except the interaction between bicycle-time and (30-49) age group which inverts its sign.

Apart from looking at the estimated coefficients in Table 5, another way to measure the coherence of the results is to look at a preliminary analysis of the VOTs. An aggregated VOT for the motorised modes is around 6€/hour, which is in line with most recent studies reporting VOTs in Spanish contexts: values for the car in the range from 5.69€/h (dell’Olio et al., 2011) to 9.00€/hour (Salas et al., 2009; Shires and De Jong, 2009); and for the bus from 4.75€/h (dell’Olio et al., 2011) to 7.59€/hour (Shires and De Jong, 2009). The interaction coefficients allow disaggregating the VOT as shown at the bottom of Table 5. Bicycle and car users follow the same pattern: the lowest willingness to pay is held by the youngest (<30), then the oldest (>49) and finally the highest willingness to pay is held by the medium age group (30-49). Among pedestrians the highest willingness to pay is also held by the medium age group (30-49)¹⁰, while the lowest is held by the oldest (>49) in this case. VOTs for the bicycle are in line with previous research¹¹ (Börjesson and Eliasson, 2012; Rodríguez and Joo, 2004; Wardman et al., 1997; Wardman et al., 2007) in that non-motorised users would pay more to reduce their travel time than motorised users. Bicycle VOTs go from 1.9 times (for the 30-49 age group) to 2.7 times (for the >49 age group) the values for car/public transport.

Regarding the **latent variables**, all of them enter significantly into the choice model specification with a positive impact in the choice of the bicycle. In the first model (ICLV-1) the highest influence appears from the latent variable **Direct advantages** of the bicycle use –in terms of quickness, time reliability, relax, independency and flexibility– ($\beta=0.93$); while **Individual capacities** of the user –in terms of overcoming hills, manoeuvring, his/her physical condition and the capacity to fix a puncture– appears to play a secondary latent role in the choice of the bicycle ($\beta=0.69$).

10 This group is mainly composed by workers and therefore it is the most sensitive group to transport policies implemented in the city. This group is mainly composed by workers and therefore it is the most sensitive group to transport policies implemented in the city.

11 Only in (dell’Olio et al., 2011) bicycle VOTs are lower than the corresponding for motorised modes. Only in (dell’Olio et al., 2011) bicycle VOTs are lower than the corresponding for motorised modes.

Figure 1 Modelling frameworks of the two models proposed (ICLV-1 and ICLV-2)

In the second model (ICLV-2), both *Individual capacities* and *Safety and comfort* –in terms of low accident and theft risk, no traffic stress, no conflicts with pedestrians, no sweat and weather independent– appear to be influencing in a similar magnitude ($\beta=0.57$ and $\beta=0.59$ respectively). The model results show that the latent variables are the key drivers of bicycle mode choice, although travel time is still statistically significant.

Table 5 Mode choice model results

β		Reference	ICLV-1		ICLV-2		
		level	Value	P-value	Value	P-value	
Alternative-specific constants	ASC-bicycle	car	-7.25	0.00	-3.65	0.00	
	ASC-walking		3.27	0.00	3.28	0.00	
	ASC-public transport		0.05	0.48	0.05	0.52	
Alternative-varying variables	Cost	-	-0.63	0.00	-0.62	0.00	
	Bicycle-time	-	-0.13	0.00	-0.12	0.00	
	Walking-time	-	-0.12	0.00	-0.12	0.00	
	Motorised-time	-	-0.05	0.00	-0.05	0.00	
	Bicycle-time*(<30)	>49	0.06	0.00	0.04	0.00	
	Bicycle-time*(30-49)		-0.05	0.00	-0.05	0.00	
	Walking-time*(<30)		-0.01	0.00	-0.01	0.00	
	Walking-time*(30-49)		-0.04	0.00	-0.04	0.00	
	Motorised-time*(<30)		0.02	0.00	0.02	0.00	
Motorised-time*(30-49)	-0.04		0.00	-0.04	0.00		
Trip-specific variables	Bicycle-commuting	non-commuting	0.80	0.00	0.61	0.00	
	Walking-commuting		-0.14	0.03	-0.14	0.03	
	Public transport-commuting		0.28	0.00	0.28	0.00	
Latent variables	Direct advantages	-	0.93	0.00	-	-	
	Direct advantages - variance	-	0.91	0.00	-	-	
	Individual capacities	-	0.69	0.00	0.57	0.00	
	Individual capacities - variance	-	1.00	0.00	1.00	0.00	
	Safety and comfort	-	-	-	0.59	0.00	
	Safety and comfort - variance	-	-	-	0.87	0.00	
Number of iterations			118		104		
Final log-likelihood			-258,094.66		-284,872.93		
Likelihood ratio index (ρ)			0.90		0.74		
Values of time (€/h)		Age groups			Age groups		
		< 30	30–49	> 49	< 30	30–49	> 49
Bicycle		6.66	16.77	12.15	6.92	15.54	11.17
Walking		12.75	14.96	11.39	12.7	15.19	11.56
					5		
Motorised		2.77	7.93	4.58	2.67	7.98	4.60

As expected, the introduction of latent variables provided better goodness of fit, that is, better predictive modelling capabilities. Comparing the Likelihood Ratio index (ρ) values from Table 4 and Table 5 we can clearly see that the ICLV models have better model fits, especially the ICLV-1. Moreover, Table 6 and Table 7 also show reliability measures of the latent variable model part –referred to the corresponding sequential models– throughout the Squared Multiple Correlation (R^2).

Table 6 presents the estimation results from the structural models. Being the family head (father/mother) or having low household income recognise the **direct benefits** of the bicycle use for urban mobility. Furthermore, men, medium age people and workers do not recognise those direct benefits. With respect to the **individual capacities**, men and people under 49 (especially the youngest) recognise a higher individual capacity related to the bicycle use. However, having low household income show the opposite result. Finally, the **safety and comfort** characteristics are positively recognised by men, workers and fathers/mothers.

Knowing to ride a bicycle and having one available significantly explain the three latent variables. Both the recent (last week) and past (some time in life) cycling experience, for different purposes, are explaining the latent variables. Specifically, commuting bike use last week for safety and comfort; commuting bike use in the past for direct advantages and individual capacities; and non-commuting and sport bike use last week or in the past for all three latent variables.

The use of cycleways only appears to statistically explain the individuals' capacity for bicycle use; and the majority of use of calmed-roads is explaining the individuals' perception of bicycle safety and comfort.

Table 6 Structural models results

Latent variables	ICLV-1				ICLV-2			
	Direct advantages		Individual capacities		Individual capacities		Safety and comfort	
	Estimates (γ)	P-value	Estimates (γ)	P-value	Estimates (γ)	P-value	Estimates (γ)	P-value
Gender (Male)	-0.06	0.00	0.76	0.00	0.75	0.00	0.28	0.00
Age < 30 / > 49	-0.00	1.00	0.32	0.00	0.33	0.00	-0.16	0.00
Age 30-49 / > 49	-0.11	0.00	0.27	0.00	0.27	0.00	-0.20	0.00
Professional situation (Worker)	-0.20	0.00	-0.04	0.35	-0.07	0.15	0.36	0.00
Family status (Father/Mother)	0.26	0.00	-0.04	0.15	-0.04	0.13	0.06	0.01
Income <2,000€/month in the household	0.33	0.00	-0.10	0.00	-0.10	0.00	-0.08	0.00
Know how to ride a bike (Yes)	1.42	0.00	0.84	0.00	0.85	0.00	0.93	0.00
Bicycle availability (Yes)	1.36	0.00	1.04	0.00	1.04	0.00	0.94	0.00
Commuting bike use last week (Yes)	0.03	0.34	0.05	0.18	0.04	0.28	0.16	0.00
Non-commuting bike use last week (Yes)	0.68	0.00	0.44	0.00	0.44	0.00	0.49	0.00
Sport bike use last week (Yes)	0.39	0.00	0.22	0.00	0.22	0.00	0.12	0.00
Commuting bike use in the past (Yes)	0.05	0.03	0.16	0.00	0.17	0.00	-0.02	0.45
Non-commuting bike use in the past (Yes)	0.59	0.00	0.37	0.00	0.38	0.00	0.37	0.00
Sport bike use in the past (Yes)	1.81	0.00	0.97	0.00	0.97	0.00	1.04	0.00
Use of calmed-roads (Yes)	-0.08	0.10	0.11	0.13	0.11	0.16	-0.11	0.13
Use of cycleways (Yes)	0.00	0.96	0.28	0.00	0.26	0.00	0.10	0.16
Mostly using calmed-roads (Yes)	0.10	0.15	0.10	0.42	0.09	0.46	0.23	0.03
Mostly using cycleways (Yes)	0.01	0.92	-0.04	0.64	-0.04	0.59	0.08	0.25
Squared Multiple Correlation (R ²)*		0.15		0.34		0.34		0.23

* Refers to the sequential model.

Table 7 Measurement models results

Indicators	Latent variable	Estimates (α)	P-value	R ²	Variances	P-value
Quick	Direct advantages (ICLV-1)	1.00	na	0.29	1.35	0.00
Time reliable		1.03	0.00	0.22	1.26	0.00
Relaxing		0.96	0.00	0.41	1.53	0.00
Independent		1.08	0.00	0.20	1.50	0.00
Flexible		1.08	0.00	0.14	1.36	0.00
Hilliness	Individual capacities (ICLV-1) & (ICLV-2)	1.00	na	0.50	1.38	0.00
Manoeuvring		0.95	0.00	0.29	1.50	0.00
Physical condition		1.16	0.00	0.43	1.51	0.00
Fixing a puncture		0.90	0.00	0.32	1.77	0.00
No sweat	Safety and comfort (ICLV-2)	1.00	na	0.15	1.63	0.00
No conflicts with pedestrian		1.07	0.00	0.21	1.74	0.00
No traffic stress		0.76	0.00	0.29	1.55	0.00
Weather independent		0.63	0.00	0.19	1.2	0.00
Low accident risk		0.94	0.00	0.40	1.28	0.00
No theft risk		0.69	0.00	0.15	1.39	0.00

* Refers to the sequential model.

With regard to the measurement part, Ben-Akiva normalisation was applied to fix the scale of the latent variables, by fixing the coefficient for indicators 'Quick', 'Hilliness' and 'No sweat'

to 1. The rest of coefficients and variances from the measurement equations are shown in Table 7. First, a higher perception of the **direct benefits** of the bicycle lead to recognise mostly the independence, flexibility, time reliability and quickness that bicycle use provides, and finally the relaxing character of the bicycle use. Second, the latent variable **Individual capacities** is mainly explaining the perceptions of the own physical condition and of the ability to overcome hills. To a lesser extent this latent variable is explaining the perception of manoeuvring when riding the bicycle and the ability to fix punctures. Third, the latent variable **Safety and comfort** mainly explains the safety perceptions of the bicycle related to pedestrians or motorised traffic. The lowest coefficient refers to the comfortability issue related to the weather influence to the bicycle use.

4.3 *Forecasting the impact of policy measures*

The final estimated ICLV model (ICLV-1)¹², intended to properly catch bicycle trips –by the proper inclusion of bicycle latent variables–, was used as a tool to predict the impact on choice behaviour of different types of potential transport measures. Four measures were related to the traditional variables time and cost –some fostering bicycle use and others punishing car use– and to the choice set. Some of these measures continue the initiated path of the local transport policy, and others have been successfully implemented in other cities. Three other measures were related to the latent variables, trying to change the perceptions of users by changing the variables in the structural model¹³. These three soft measures generalise the already implemented measure of promotion of safe cycling courses. Moreover, the combined effect of measures fostering bicycle use and others punishing car use were also tested. The individual measures were the following:

- **Related to time and cost and to the choice set (hard measures)**

1. **Cycling network extension.** Provision of cycleways and improvement of the bicycle network connectivity so that bicycle travel times in the mode choice model reduce by 10% in all trips. This would mean the continuation of a measure which has been progressively implemented since 2007.
2. **Extension of the traffic calming area**, so that car travel times in the mode choice model increase by 10% in all trips. This would mean the extension of the current traffic calming area (transport zones 1-6 and 9) to the entire city centre (transport zones 1-9, 15-21 and 25-27).
3. **Urban toll to cars** travelling within the central part of the city. This would increase in the mode choice model the variable ‘Cost’ for the car for trips with origin or destination inside the charging area in 1.80€¹⁴. This measure has been implemented in several European cities to reduce traffic congestion and to improve air quality and noise.

¹² This was chosen as the final model because it showed the lowest CAIC and therefore it had the best fit. This was chosen as the final model because it showed the lowest CAIC and therefore it had the best fit.

¹³ For forecasting there is no need for the latent variable measurement model. For forecasting there is no need for the latent variable measurement model.

¹⁴ According to an average of charging schemes in non-capital cities in Europe. According to an average of charging schemes in non-capital cities in Europe.

4. **Public bike-share system**, so that the whole population would have access to a bicycle for urban mobility. This scenario is not a true forecasting exercise, since alternatives' attributes do not change. However, it is an approximation exercise to test a popular cycling measure in Spain, which was planned to be implemented in Vitoria-Gasteiz in 2012, but was finally rejected because of financial problems.
- **Related to the latent variables (soft measures)**
5. **Commuting cycling programmes in companies** to try the commuting bicycle experience, such as the 'Bike to work days'. This would change in the structural model the variable 'Commuting bike use in the past (Yes)' in all trips made by workers.
 6. **Non-commuting cycling programmes for the general public** to try the bicycle experience for urban mobility. This would change in the structural model the variable 'Non-commuting bike use in the past (Yes)' in all trips.
 7. **Sport cycling programmes for the general public** to promote the use of the bicycle as a leisure activity. This would change in the structural model the variable 'Sport bike use in the past (Yes)' in all trips.

Table 8 presents the observed market shares, the estimated baseline scenario (simulated market shares) and the market share changes predicted by the final ICLV-1 model for each of the transport measures and some of their combinations. Obviously, the results show that under all initiatives the bicycle mode share increases. Moreover, car mode share decreases in all scenarios.

The proposed **urban toll to cars** produces the highest increases in bicycle share and the highest decreases in car share –without taking into account the public bike-share system– with the additional positive effect of increasing walking and public transport shares. The **cycling network extension** would be the second most preferred measure, according to the bicycle share increase. The **extension of the traffic calming** would produce a similar car share decrease than the aforementioned measure, although the impact on bicycle share would be very limited.

The effectiveness of the measures related to the latent variables is more limited than the previous ones, especially the one related programmes such as the 'Bike to work days'. **Non-commuting cycling programmes for the general public** would be most effective for the bicycle share, drawing principally from public transport and car trips.

The combined effect of the measure fostering bicycle use –**cycling network extension (1)**– and the preferred measure punishing car use –**urban toll to cars (3)**– shows with respect to scenario (8) a moderately increase in bicycle share and a moderately decrease in the rest of mode shares. The addition of measure (6) tinges previous results in the same direction.

Table 8 Policy scenarios and market shares with ICLV-1 model: predicted values and changes

Policy measures			Bicycle	Walking	Public transport	Car
Observed market share		value	13.69%	56.21%	9.27%	20.84%
0. Baseline scenario		value	14.48%	55.80%	9.14%	20.58%
Related to time and cost and to the choice set	1. Cycling network extension (↓ 10% bicycle travel time)	value <i>change</i> _{0−1}	15.25% 5.33%	55.52% -0.49%	9.01% -1.52%	20.22% -1.74%
	2. Extension of the traffic calming (↑ 10% car travel time)	value <i>change</i> _{0−2}	14.56% 0.52%	55.99% 0.35%	9.27% 1.37%	20.18% -1.92%
	3. Urban toll to cars	value <i>change</i> _{0−3}	15.52% 7.14%	59.58% 6.79%	11.08% 21.21%	13.82% -32.86%
	4. Public bike-share system	value <i>change</i> _{0−4}	25.86% 78.55%	50.25% -9.93%	7.32% -20.00%	16.57% -19.46%
Related to the latent variables	5. Bike to work days	value <i>change</i> _{0−5}	14.54% 0.41%	55.76% -0.07%	9.14% -0.09%	20.57% -0.06%
	6. Non-commuting cycling programmes for the general public	value <i>change</i> _{0−6}	15.04% 3.88%	55.49% -0.54%	9.06% -0.88%	20.40% -0.87%
	7. Sport cycling programmes for the general public	value <i>change</i> _{0−7}	14.96% 3.30%	55.52% -0.50%	9.06% -0.89%	20.46% -0.58%
Combined scenarios	Cycling network extension (1) & Urban toll to cars (3)	value <i>change</i> _{0−13}	16.31% 12.60%	59.25% 6.20%	10.90% 19.15%	13.54% -34.19%
	Cycling network extension (1) & Urban toll to cars (3) & Non-commuting cycling programmes for the general public (6)	value <i>change</i> _{0−136}	16.93% 16.92%	58.89% 5.550%	10.78% 17.84%	13.40% -34.87%

5 Conclusions

The empirical output of this paper is to present the first ICLV travel demand model that considers the bicycle option, including several bicycle latent variables (LVs) –using simultaneous estimation– and considering forecasting issues to test several potential transport measures. Different from other ICLV models considering the bicycle, data for the model building comes from an important RP sample (14,406 trips) representative of the urban mobility in the city of Vitoria-Gasteiz (Spain) in 2014. Perceptual indicators towards the bicycle use for urban mobility were used to define six bicycle LVs that were introduced individually and directly into the bicycle utility function.

The study revealed the importance of the LVs –‘**Direct advantages**’, ‘**Safety and comfort**’, ‘**External facilities**’ and ‘**Individual capacities**’– which played a significant role in the bicycle choice process. Although with a lower number of indicators, these LVs were also identified and appeared to be significant in other applications. However, the LVs ‘Awareness’ and ‘Subjective norm’ did not show statistically significant coefficients.

The final ICLV model including two of the significant latent variables, –‘**Direct advantages**’ and ‘**Individual capacities**’– was chosen to test several potential transport measures. In particular, the inclusion of the latent variables allowed testing three real-world soft measures related to bicycle experience that cannot be tested with traditional DCM. These soft measures were expected to change some of the causal variables defining the latent variables, which in turn would change the latent variables –thorough the structural equations in the MIMIC model– and finally the mode choice behaviour. This method is different from the one referring to a certain change in a latent variable directly targeted by a policy intervention [which is done in Maldonado-Hinarejos et al. (2014)] and a less problematic way of using any ICLV model for the derivation of transport policies, as pointed by Chorus and Kroesen (2014).

Forecasting results showed that the urban toll to cars would be the preferred measure, not only because it produced the highest increase in bicycle share but also because this measure also decreased car share the most. Moreover, the effectiveness of the soft measures related to the latent variables was more limited than those related to the traditional variables time and cost. The tested combination of hard and soft measures –some fostering bicycle use and others punishing car use– shows an additive increase in bicycle share, drawing trips only from the car, as opposed to the solely other forecasting application in Maldonado-Hinarejos et al. (2014)

Although the soft measures tested were affected by estimated coefficients larger than those of time and cost, the limited effectiveness of the soft measures might be explained by weak structural relationships in the MIMIC model (see R^2 values from Table 6). Therefore, future research might focus on finding better-supported SEM to improve forecasting power with latent variables. In this regard, it is also worth mentioning the absence of a methodology to test soft measures affecting indicators from the latent variable measurement model, since for forecasting only structural equations in the MIMIC model are needed. Finally, although the simultaneous approach is preferred over the sequential approach, the very lengthy estimation times of the models associated to the simultaneous full likelihood estimation, was the second limitation of the present study.

Finally, it is worth mentioning that future research with the present data might develop specific models for different trips purposes, focusing specially on commuting trips and comparing the strength of other latent variables, such as cycling habit for non-commuting trips, with the corresponding in previous bicycle commuting studies (see e.g. Heinen et al., 2011; Muñoz et al., 2013; Muñoz et al. 2016).

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5 Conclusions and future research

This chapter includes a summary of the main findings and conclusions, and suggests further follow up research.

5.1 Overview of results and conclusions

This section is a summary of the results and contributions from the papers presented in the previous chapters.

5.1.1 From chapter 2

The special characteristics of the bicycle as a transport mode make it difficult to explain utilitarian bicycling with the traditional trade-off between time and cost –traditionally the key explanatory factor for motorised demand. This makes it even more necessary to promote advanced models with the explicit inclusion of psychological factors, quantitatively modelled as latent variables, among other aspects. Considerable data and multidisciplinary technical skills are required to build these models, which creates certain difficulties in modelling development but can be compensated for with a clearer understanding of the explanatory variables and methodologies used in previous studies. Therefore, chapter 2 includes a comprehensive survey (54 studies) of the modelling literature on the choice of the bicycle for utilitarian purposes, and summarises and assesses the evolution of the explanatory variables and methodologies used. Considering the potential explanatory power of psychological latent variables in bicycle mode choice models, the survey focuses on both the evolution of the incorporation of latent variables and the critical role they play.

Regarding modelling issues, the **main results** are the following:

- All aggregate models in the review come from the transport field and most of them use linear regressions. Logistic regression studies are used more or less to the same extent in the fields of health, travel behaviour and transport planning. Structural equation model (SEM) studies are insignificant when modelling the bicycle mode choice problem, with only one study. Discrete choice models (DCM) bicycle experiences are used solely in the fields of travel behaviour and transport planning, and most of these studies use specifications based on logit formulations. The extended version of DCM was not applied to bicycle mode choice until recently and has only been reported in five studies until now.

- All the studies in the review use cross-sectional data. Details of the construction of the availability of modes and times and costs for the non-chosen alternatives are usually omitted in the RP studies.
- The majority of the studies focus on bicycle commuting trips. Some of the studies contain questions on non-cyclists' reasons for currently not bicycling. A large number of studies consider samples of students, faculty and staff at universities or colleges. Interest in modelling bicycle choices among teenagers has increased in recent years.
- Some studies model the bicycle mode choice separately for different groups of users, according to the current transport mode, socioeconomic and housing characteristics, bicycling experience, trip purpose or spatial parameters (zones or ranges of distance).
- Forecasting is not extensive.
- Only nine of the studies in the review use an aggregate approach. Most aggregate models do not consider psychological indicators or latent variables. The vast majority of studies (45) use a disaggregate approach due to the importance of considering individual differences. The tendency to include psychological indicators and latent variables in the models also explains the focus on individual, disaggregate choices.

Regarding explanatory variables, the **main result** is the identification of three chronological stages –early, intermediate, and late– in modelling development according to the different ways of introducing psychological constructs into bicycling demand models: psychological indicators directly in the utility function (early), sequential estimation based on constructing latent variables and then including them in the utility function (intermediate), and the hybrid choice modelling framework (late).

1. Studies in the **early stage** (9 studies from mid-1990s to mid-2000s) basically neglected psychological constructs. The initial focus was on policy-oriented variables such as time and environment characteristics.
2. Studies in the **intermediate stage** (30 studies from mid-2000s to the present day) progressively recognised the potential explanatory power of the latent variables. In addition to latent variables, it is worth noting the attention paid to environment characteristics in this stage. Whereas trip length and topography are seen as significant variables, other environment characteristics do not appear to have a high influence on bicycling. These results are even clearer when both objective and perceived environmental variables are introduced at the same time.
3. The integrated choice and latent variable (ICLV) model from the hybrid choice modelling framework re-emerged during the last decade in transport choice modelling. This, and a sole SEM on the bicycle mode choice problem, has enabled authors in the **late stage** (6 studies from the last three years) to consider latent variables as the core of the model.

The review highlights the increase in the incorporation of latent variables in bicycle choice models in the last decade, with the progressive use of more sophisticated methodologies until the arrival of complex models that explicitly and properly treat psychological latent variables. Therefore, the role of latent variables in bicycle choice models has evolved from a marginal role to being recognised as the main driver explaining bicycle demand.

Chapter 2 also includes comprehensive tables highlighting key variables (appendix 1) and main characteristics of the papers (appendices 2, 3 and 4) that might help future research in the topic:

- Appendix 1 shows the complete list of the variables used in bicycle mode choice research, highlighting those that are reported to be statistically significant in each of the studies in the review. A classification in which subjective variables are also divided according to whether the variable has an equivalent objective variable is proposed.
- Appendix 2 provides a summary containing focus, whether latent variables are considered, data reduction method if appropriate, trip purpose, and context (city/area and country).
- Appendix 3 summarises the methodology adopted by describing the type of model, specification, dependent variable, choice set, source of data [revealed preference (RP)/stated preference (SP)] and sample size.
- Appendix 4 includes inference (provision of elasticities or forecasting) and goodness of fit.

Based on all the indicators reviewed, and included in Table 2.1., a set of questions is proposed as a uniform measurement scale for identifying attitudes towards bicycling. This comprehensive list of indicators might be adopted by other studies to enable a systematic comparison across different spatial and temporal contexts.

Recommendations for future research are also presented. They are summarised as follows:

1. Inclusion of bicycle-related questions, both objective and subjective (attitudes and perceptions), in RP surveys to further develop modelling frameworks with cycling latent variables.
2. Use of advances in technology (GPS, sensors, cameras, trip-planning software and apps) to make it easier to collect richer data that can be exploited in new bicycle-route-choice and level-of-service models and to ease the process of constructing time and cost attributes for the non-chosen modes.
3. Development of more solid market segmentation approaches when using SEM and hybrid choice models (HCMs) in order to improve targeting policies and programs and encourage bicycling. A closer look at the experience, attitudes and perceptions of the different segments will provide policy-relevant insights into the preferences and motivations for adopting active transport as a lifestyle. In particular, the group of people who will never use the bicycle no matter what the circumstances should be explicitly considered as a key segment to be modelled.
4. Development of random parameter models (such as mixed logit, mixed probit or latent class) as the kernel of a hybrid choice specification and consideration of interactions between the latent and objective variables.

5. Reconsideration of forecasting processes with better-supported SEM, necessary to improve forecasting power with latent variables.
6. Development of before-and-after studies and attitudinal change models to represent and forecast future bicycle adoption levels under different policy scenarios.

Table 5.1. Summary of the main findings and recommendations from paper I

Paper	Contributions	Recommendations	
			Future research
(I)	<p>Identification of the increasing role of latent variables in modelling bicycle mode choice.</p> <ul style="list-style-type: none"> ▪ Increase in the incorporation of latent variables in bicycle choice models in the last decade. ▪ Identification of three chronological stages –early, intermediate, and late– in modelling development, according to the different ways of introducing psychological constructs into bicycling demand models. ▪ Evolution in the role of latent variables in bicycle choice models: from a marginal role to a main role. 		
	<p>Summary and assessment of the evolution of methodologies in bicycle mode choice models.</p> <ul style="list-style-type: none"> ▪ The vast majority of studies use a disaggregate approach. ▪ The majority of the studies focus on bicycle commuting trips. ▪ Some studies model the bicycle mode choice separately for different groups of users. ▪ Most aggregate models use linear regressions. ▪ Logistic regression studies are used more or less to the same extent in the fields of health and in travel behaviour and transport planning. ▪ Most of the studies using discrete choice models (DCMs) use specifications based on logit formulations. ▪ Structural equation model (SEM) studies are insignificant ▪ The extended version of DCM was not applied to bicycle mode choice until recently and has only been reported in five studies until now. ▪ Forecasting is not extensive. ▪ All the studies use cross-sectional data. ▪ Necessity to move forward advanced models. 	<ul style="list-style-type: none"> ▪ Development of more solid market segmentation approaches in order to improve targeting policies and programs and encourage bicycling. ▪ Development of random parameter models (such as mixed logit, mixed probit or latent class) as the kernel of a hybrid choice specification and consideration of interactions between the latent and objective variables. ▪ Reconsideration of forecasting processes with better-supported SEM, necessary to improve forecasting power with latent variables. ▪ Development of before-and-after studies and attitudinal change models to represent and forecast future bicycle adoption levels under different policy scenarios. ▪ Use of advances in technology (GPS, sensors, cameras, trip-planning software and apps) to make it easier the collection of richer data. 	
	<p>Development of comprehensive tables highlighting key variables (appendix 1) and main characteristics of the papers (appendices 2, 3 and 4) that might help future research in the topic.</p>		
	<p>Proposal of a set of questions as a uniform measurement scale for identifying attitudes towards bicycling.</p>	<ul style="list-style-type: none"> ▪ Inclusion of bicycle-related questions –both objective and subjective (attitudes and perceptions)– in RP surveys to further develop modelling frameworks with cycling latent variables. 	

5.1.2 From chapter 3

Because psychological factors have been identified as particularly influential in the decision to cycle for urban transport, and specifically for commuting, chapter 3 measures and examines perceptions of cycling characteristics and bicycle latent variables and their association with, and influence on, bicycle commuting.

The proposed methodology is not excessively demanding from the data and computational perspectives. Although the two studies are cross-sectional, they can be useful to be applied by practitioners to orient bicycle local policies. Moreover, they can also be useful for researchers as a first approach to the phenomenon before the development of more complex models and also to suggest policy recommendations.

In *paper II*, perceptions were measured following the framework of the TPB –Theory of Planned Behavior (Ajzen, 1991): attitudinal beliefs, subjective norm, descriptive norm beliefs and perceived behavioral control (PBC) beliefs. This is the first application of the TPB model with disaggregated measures of subjective norm, descriptive norm and PBC. Cycling habit was also included as part of the research, following the response frequency measure established by Verplanken et al. (1994). **Statistical differences** in the perceptions between groups were determined: according to the commuting mode –between cycling commuters and other mode commuters–, and according to the bicycle experience –amongst commuter cyclists, sport/leisure cyclists and non-cyclists. This approach made it possible to identify the indicators especially valued by specific groups, thus directing the following multivariate analysis. The univariate analysis also identified the main barriers to commuting by bicycle. **Exploratory factor analysis** (EFA) and summated scales were carried out to identify and define the main underlying structures –latent variables– among the perceptions. A binary **logistic regression** was developed based on the abovementioned factors and scales (or latent variables) in order to determine the key psychological factors influencing bicycle commuting. Based on all results, **recommendations for cycling policies** were suggested, for the context of Madrid (Spain).

Regarding differences among groups, the **main results** are the following:

- For the total sample:
 - The top-two scores among **attitudinal** beliefs correspond to *Environmental benefits* and *Health benefits*. The lowest means correspond to *Weather independent* and *Traffic safety*.
 - *Safe parking at home* is the **PBC** belief with the highest average score, followed by *Physical fitness*. This means that respondents show fewer difficulties in relation to these factors. However, *Traffic aggression* has the lowest value; hence it is the largest barrier to overcome.
 - *Family* is the social group with the most positive influence on the decision to commute by bicycle (highest perceived social pressure or **subjective norm**), followed by *Friends*, and *Co-workers/fellow students*.
 - The respondents consider that *Young people* are the group that is increasing its use of the bicycle the most (**descriptive norm**). In contrast, respondents' *Family members* are seen as the group that has increased their bicycle use the least.

- The cycling habit –for non-commuting trip purposes, except sport– in the sample is extremely low.
- Statistical differences between all groups are statistically significant for:
 - All attitudinal indicators, except *Health benefits*, *Environmental benefits*, *Quality of life*, *Cheap*, *Available*, *Image prestige* and *Easy to park*.
 - Descriptive norm scale.
 - All PBC indicators, except *Facilities at destination*, *Safe parking at destination*, *Safe parking at home* and *Traffic aggression*.
 - Cycling habit
- As expected, cycling commuters value all attitudinal indicators more positively than non-cycling commuters. Moreover, cycling commuters value most PBC indicators –except those related to the bicycle parking– more positively, meaning that their difficulties in using the bicycle to commute are lower than the corresponding difficulties for non-cycling commuters.
- As bicycle experience (including sport) increases, valuations of attitudinal indicators increase and those of barriers to commuting by bicycle decreases.
- *Traffic safety* is the worst perceived attitudinal indicator for cycling commuters and the second worst for other commuters. Moreover, all respondents show more difficulties in relation to *Traffic aggression* (PBC indicator).
- Car/motorbike commuters are the most strongly opposed to cycling commuters, showing the greatest differences, both for attitudinal and PBC perceptions.

Regarding EFA and regression analysis, the **main results** are the following:

- Two underlying structures (factors or latent variables) are identified among the attitudinal variables: '**Direct Benefits**' and '**Long-term benefits**'. As for PBC indicators, three other structures are relevant: '**Physical conditions**', '**External facilities**' and '**Individual capacities**'.
- Choosing the bicycle as a commuting mode is mainly defined by the existence of bicycle habit for non-commuting trips. Attitudes related to direct benefits in terms of reliability, comfort and time are influential on the choice of the bicycle as a commuting mode, but to a lesser extent than habit.

Based on the results, the **main findings and policy recommendations** are the following:

- Differences between car/motorbike commuters and cycling commuters suggest that negative perceptions from car/motorbike commuters (the bicycle is slow, unreliable, uncomfortable, inflexible, weather dependent, stressful and boring), and their barriers (*Distance*, *Topography*, *Physical fitness* and *Cycling in traffic*) might be improved by policies that allow non-cycling commuters to experience cycling more easily, for example, measures that allow easy daily access to bicycles (public bike sharing), free availability of bicycles in companies for employees, tax discounts when buying a bicycle and integration with public transport.

- Results from the indicators *Traffic safety* and *Traffic aggression* highlights a real problem in the relationship between bicycles and motorised traffic in the congested city centre of Madrid. This work suggests that this problem cannot be solved simply by increasing the cyclist commuting experience. It is also necessary to provide dedicated cycle lanes, restrict car access and implement traffic calming in certain areas.
- Results regarding problems related to bicycle facilities (lack of showers or bike racks at destination, lack of safe parking at home or at destination) also suggest the impossibility to be resolved through the cycling experience. These variables should therefore be included as measures in the cycling mobility strategy of local administrations and organisations.
- Regarding subjective and descriptive norm results, cycling publicity campaigns could have a twofold objective: to encourage families to support more bicycle use, and to dispel the image of bicycles as being only for young people.
- Modelling results represents the case of a city with low bicycle use, which is in contrast with cases where cycling is a normal practice. In cycling cities, both habit and TPB factors (attitudinal direct benefits and PBC) show a significant influence on cycling commuting (Heinen et al., 2011). In other words, when the bicycle is considered to be a real transport mode in the city, the importance of attitudes, norms and PBC is likely to increase, as bicycle use is less dependent on habit. The social and physical context, as well as the method of measuring the PBC (disaggregated in several items in the present study) might explain the different results. Some of the aforementioned policies could foster non-commuters to start experiencing cycling, and then to develop their habit for non-commuting trips and finally for commuting. Thus Park et al. (2011) point out that 57% of commuter cyclists began as leisure-cyclists. However, the increase in the number of commuting trips would be better to come from motorised trips in order to maintain high levels of pedestrians and public transport users.

Table 5.2. Summary of the main findings and recommendations from paper II

Paper	Contributions	Recommendations	
		Policy measures	
(III)	<p>First application of the TPB model:</p> <ul style="list-style-type: none">▪ With disaggregated measures of subjective norm, descriptive norm and PBC.▪ In a context with low bicycle use.		
	<p>Identification of the main barriers to commuting by bicycle.</p> <ul style="list-style-type: none">▪ Car/motorbike commuters are the most strongly opposed to cycling commuters, <p>(1)</p> <ul style="list-style-type: none">▪ <i>Traffic aggression</i> is the largest barrier to overcome to all respondents▪ <i>Traffic safety</i> is the worst perceived attitudinal indicator for cycling commuters and the second worst for other commuters.▪ There is a real problem in the relationship between bicycles and motorised traffic in the congested city centre of Madrid which cannot be solved simply by increasing the cyclist commuting experience. <p>(2)</p> <ul style="list-style-type: none">▪ Negative perceptions from car/motorbike commuters (the bicycle is slow, unreliable, uncomfortable, inflexible, weather dependent, stressful and boring), and their barriers (Distance, Topography, Physical fitness and Cycling in traffic) might be improved by policies that allow non-cycling commuters to experience cycling more easily. <p>(3)</p> <ul style="list-style-type: none">▪ Problems related to bicycle facilities (lack of showers or bike racks at destination, lack of safe parking at home or at destination) cannot be solved through the cycling experience. <p>(4)</p> <ul style="list-style-type: none">▪ Family is the social group with the most positive influence on the decision to commute by bicycle (subjective norm).▪ The group ‘Young people’ is the one that is increasing its use of the bicycle the most (descriptive norm).	<p>(1)</p> <p>To provide dedicated cycle lanes, restrict car access and implement traffic calming in certain areas.</p> <p>(2)</p> <p>Public bike sharing, free availability of bicycles in companies for employees, tax discounts when buying a bicycle and integration with public transport.</p> <p>(3)</p> <p>Specific measures related to bicycle facilities to be included in the cycling mobility strategy of local administrations and organisations.</p> <p>(4)</p> <p>Cycling publicity campaigns could have a twofold objective: to encourage families to support more bicycle use, and to dispel the image of bicycles as being only for young people.</p>	
	<p>Identification of the key psychological factors influencing bicycle commuting (in a context with low bicycle use).</p> <ul style="list-style-type: none">▪ Choosing the bicycle as a commuting mode is mainly defined by the existence of bicycle ‘Habit for non-commuting trips’ and ‘Direct benefits’ in terms of reliability, time and comfort.▪ Other bicycle latent variables –‘Long-term benefits’, ‘Physical conditions’, ‘External facilities’ and ‘Individual capacities’– do not appear to be statistically significant for bicycle commuting in a context of city with low bicycle use.	<ul style="list-style-type: none">▪ Some of the aforementioned policies could foster non-commuters to start experiencing cycling and then to develop their habit for non-commuting trips and finally for commuting.	

Paper III proposes cycling-related indicators based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) for their inclusion in mobility surveys and evaluates the structure of bicycle latent variables using exploratory factor analysis (EFA). Cycling indicators –defined as perceptions of cycling characteristics– included attitudes, subjective norm, descriptive norm beliefs and PBC beliefs (addressed both by controllability and self-efficacy indicators). The questionnaire was designed by a multidisciplinary research team of transport planners, geographers and psychologists. This well-executed TPB survey included not only questions related to beliefs but also importances, and therefore provided a more accurate measurement of attitudes and subjective norm. As a consequence the following analyses of the latent variables identified had a sound basis. This application also included the habit, obtained through the self-reported frequency of past behaviour (Verplanken et al., 2005). **Statistical differences** and **regression analysis** were applied with the cycling latent variables. The study also includes several analyses (categorical techniques and tests of equality for column or row proportions) to find the relationship between objective factors and bicycle commuting. This methodology was applied to the ‘starter cycling city’ of Vitoria-Gasteiz (Spain), which is a context in transition to a cyclable city. A set of customised policy initiatives is recommended in the light of the research findings.

Regarding analyses over the objective factors, the **main results** are the following:

- Socioeconomic and household characteristics (*Gender, Age group, Family status and Professional situation*), mode availability (*Car licence, Bicycle availability and Bicycle parking at home*) and trip characteristics (*Travel time and Travel distance*) were associated with bicycle commuting, albeit all with minor size effects.
- The **bicycle commuter (BC) profile** identified in Vitoria-Gasteiz is the following:
 - The majority of BCs are men (72%).
 - The proportion of BCs aged 16-24 (47%) is significantly higher than for other modes (19%).
 - Almost half the BCs (45%) are children (both male and female) aged >16 years, still living with their parents.
 - Although the representative sample shows among BCs a higher percentage of employed people (58%) than students (42%), the latest use the bicycle for commuting three times more (27%) than workers (9%).
 - The majority of BCs have a car license (66%), have a car available (80%) and do not park the bicycle inside home (61%).
 - Vitoria-Gasteiz is a medium-size and compact city; and most bicycle commuters therefore ride a distance of between 1 and 5 km (98%) and make trips with duration of between 10-30 min (69%).

Regarding analyses over the subjective factors, the **main results** are the following:

- The EFA identified four attitudinal latent variables –**Lifestyle, Safety and comfort, Awareness** and **Direct disadvantages**; another –**Subjective norm**– related to

psychological support for using the bicycle to commute; and a final variable –**Individual capabilities**– referring to the respondents’ ability to cope with certain cycling circumstances. The study also calculated a seventh latent variable –**Non-commuting cycling habit**– for the habit of using the bicycle for non-commuting trips. All these cycling latent variables were significantly associated with the commuting mode, with medium and large effects, unlike the objective factors.

- Safety and comfort issues are not the main deterrents for all commuters, although more progress needs to be made to normalise cycling.

Based on the results, the **main findings and policy recommendations** are the following:

- The results for **Non-commuting cycling habit** show the greatest difference between bicycle and non-bicycle commuters. This latent variable appears to be the strongest latent predictor of bicycle commuting. One potential strategy to change this that could be considered by the city authorities is the launch of *marketing campaigns* to encourage non-bicycle commuters to increase their bicycle use for going out, shopping, running errands and so on. It should however be noted that habit may not be easy to change. For this reason, and because **Subjective Norm** is another latent variable influencing bicycle commuting, it may be more positive to target bicycle measures to social groups rather than individuals. We suggest prioritising marketing campaigns and other infrastructure investments (cycleways and bicycle parking) around leisure zones and social and cultural centres/associations to maximise the significant influence of friends on bicycle commuter behaviour. The second most important social group to target is co-workers and classmates, suggesting measures in work/study environments.
- Further efforts could also be made to foster the speed and time reliability of the bicycle (**Direct advantages** for bicycle commuters) –especially in the case of public transport or car users– through policies aimed at encouraging people to experience the cycling trip. Some 59% of these commuters have never tried commuting by bicycle and 67% of them make trips of less than five km. A lack of experience in this area may impact the results of this latent variable (Rondinella et al., 2012). One positive measure would be to launch bicycle-specific programmes such as *Bike-to-work days*. There is encouraging evidence from other places of the effect of this type of programmes on cycling (Pucher et al., 2010; Yang et al., 2010).
- **Safety and comfort** is another important predictor for bicycle commuting, although only for car commuters, for whom this is probably seen as a deterrent due to their lack of experience. Safety and comfort issues are not major barriers to bicycle commuting for non-car commuters. The recent policy in Vitoria-Gasteiz of providing cycleways and improving bicycle network connectivity appears to be effective.
- Regarding to the latent variable **Individual capabilities**, the extension of measures such as cycling courses (how to ride safely on the proper infrastructures and near cars, how to fix a puncture and repair/maintain the bicycle and so forth) would benefit non-bicycle commuters and especially pedestrians and public transport users.

Table 5.3. Summary of the main findings and recommendations from paper III

Paper	Contributions	Recommendations	
		Policy measures	
(III)	Well-executed TPB survey including not only questions related to beliefs but also importances (attitudes and subjective norm), designed by a multidisciplinary research team of transport planners, geographers and psychologists.		
	<p>Identification of the key psychological factors influencing bicycle commuting (<u>in a context in transition towards a cyclable city</u>).</p> <p>(1)</p> <ul style="list-style-type: none"> ▪ 'Non-commuting cycling habit' appears to be the strongest latent predictor of bicycle commuting. <p>(2)</p> <ul style="list-style-type: none"> ▪ The latent variable 'Subjective Norm', related to the psychological support for using the bicycle to commute, also influences bicycle commuting. <p>(3)</p> <ul style="list-style-type: none"> ▪ 'Safety and comfort' is another important predictor for bicycle commuting, although only for car commuters, for whom this is probably seen as a deterrent due to their lack of experience. <p>(4)</p> <ul style="list-style-type: none"> ▪ The latent variable 'Direct advantages' in terms of time reliability and speed, also influences bicycle commuting. ▪ Further efforts could also be made to foster the speed and of the bicycle (Direct advantages for bicycle commuters) –especially in the case of public transport or car users. <p>(5)</p> <ul style="list-style-type: none"> ▪ Other bicycle latent variables –'Individual capabilities', 'Awareness', and 'Life style'– do not appear to be statistically significant for bicycle commuting in a context in transition towards a cyclable city. 	<p>(1)</p> <ul style="list-style-type: none"> ▪ To launch marketing campaigns to encourage non-bicycle commuters to increase their bicycle use for going out, shopping, running errands and so on, in order to normalise cycling. <p>(2)</p> <ul style="list-style-type: none"> ▪ To target bicycle measures to social groups rather than individuals: to prioritise marketing campaigns and other infrastructure investments (cycleways and bicycle parks) around leisure zones and social and cultural centres/associations and in work/study environments. <p>(3 & 4)</p> <ul style="list-style-type: none"> ▪ Policies aimed at encouraging people to experience the cycling trip, e.g. bicycle-specific programmes such as Bike-to-work days. 	

5.1.3 From chapter 4

Chapter 2 recognised the main role of latent variables in explaining bicycle demand and the consequent necessity to move forward advanced models –that allow both the proper inclusion of the latent variables and the forecasting use. Moreover, also included is the limited number of studies –only five up to now– using extended discrete choice models for analysing the bicycle choice. Considering all previous points, chapter 4 develops the first ICLV travel demand model that considers the bicycle option, including several bicycle latent variables –using simultaneous estimation– and considering forecasting issues to test several potential transport measures.

Four measures are related to the traditional variables time and cost, such as the reduction of bicycle travel times, the increase in car travel time or economic sanctions to car use. A scenario with the implementation of a public bike-share system is also tested. The inclusion of the latent variables in the model allows testing three real-world soft measures related to bicycle experience that cannot be tested with traditional discrete choice models. These soft measures are expected to change some of the causal variables defining the latent variables, which in turn will change the latent variables –through the structural equations in the latent variable model– and finally the mode choice behaviour. This method is different from the one referring to a certain change in a latent variable directly targeted by a policy intervention [which is done in Maldonado-Hinarejos et al. (2014)] and a less problematic way of using any ICLV model for the derivation of transport policies, as pointed by Chorus and Kroesen (2014).

Regarding the modelling process, the **main results** are the following:

- Six bicycle latent variables are identified and estimated individually and simultaneously in the ICLV model. The latent variables –‘**Safety and comfort**’, ‘**Direct advantages**’, ‘**External facilities**’ and ‘**Individual capacities**’– show positive and statistically significant coefficients and suggest a significant role in the bicycle choice process. However, the latent variables ‘Awareness’ and ‘Subjective norm’ do not show statistically significant coefficients.
- The model with ‘**Direct advantages**’ and ‘**Individual capacities**’ (directly included into the bicycle utility function) shows the best fit and is chosen for the forecasting application.

Regarding the forecasting application, the **main results and policy recommendations** are the following:

- The proposed **urban toll to cars** produces the highest increases in bicycle share and the highest decreases in car share with the additional positive effect of increasing walking and public transport shares.
- The proposed **reduction of 10% on the bicycle travel time** would be the second most preferred measure, according to the bicycle share increase. The **extension of the traffic calming** would produce a similar car share decrease than the aforementioned measure, although the impact on bicycle share would be very limited.

- The effectiveness of the measures related to the latent variables is more limited than those related to time and cost.
- Non-commuting cycling programmes for the general public would be the most effective for the bicycle share, drawing principally from public transport and car trips.
- The combined effect of measures fostering bicycle use –**cycling network extension** and **non-commuting cycling programmes for the general public**– and the preferred measure punishing car use –**urban toll to cars**– shows an additive increase in bicycle share, drawing trips only from the car.

Table 5.4. Summary of the main findings and recommendations from paper IV

Paper	Contributions	Recommendations
		Policy measures
(IV)	Data gathering of a HTS sample (RP) representative of the urban mobility in the city of Vitoria-Gasteiz (Spain) in 2014, including perceptual indicators towards the bicycle use for urban mobility.	
	<p>Identification of the key psychological factors influencing general bicycle use (<u>in a context in transition towards a cyclable city</u>).</p> <ul style="list-style-type: none"> ▪ Four significant latent variables: <ol style="list-style-type: none"> 1. 'Direct advantages' 2. 'Safety and comfort' 3. 'External facilities' 4. 'Individual capacities' ▪ Other bicycle latent variables –'Awareness' and 'Subjective norm'– do not appear to be statistically significant for general bicycle use in a context in transition towards a cyclable city. 	
	<p>First ICLV model with simultaneous estimation and two bicycle LVs –'Direct advantages' and 'Individual capacities'– and used for policy analysis.</p> <ul style="list-style-type: none"> ▪ Soft measures related to bicycle experience can be tested. ▪ Soft measures are expected to change some of the causal variables defining the latent variables, which in turn will change the latent variables –thorough the structural equations in the MIMIC model– and finally the mode choice behaviour. 	<ul style="list-style-type: none"> ▪ To combine the effect of measures fostering bicycle use –'cycling network extension' and 'non-commuting cycling programmes for the general public'– with measures punishing car use –'urban toll to cars'– to produce the highest increases in bicycle share and the highest decreases in car share.

5.2 Discussion of results

This section includes a discussion on the contribution of this thesis and that are set in the context of research findings from other papers.

Chapter 2 (*paper I*) focuses on the review of the key variables, following reviews from previous studies [see e.g. (Goldsmith, 1992; Dill and Carr, 2003; Rietveld and Daniel, 2004; Fernández-Heredia et al., 2014; Fernández-Heredia et al., 2016)] or from specific literature review papers [see e.g. the comprehensive one by Heinen et al. (2010) or some partial ones (Saelens et al., 2003; Parkin et al., 2007; Lorenc et al., 2008; Sirard and Slater, 2008; Reynolds et al., 2009; Panter and Jones, 2010; and Willis et al., 2015)]. The important systematization in the review process in chapter 2 made it possible to prepare comprehensive tables highlighting key variables and main characteristics of the papers that might help future research in the topic. Moreover, chapter 2 moves forward in the literature review of the determinants of bicycle use because it also summarises and assesses the evolution of methodologies in bicycle mode choice models. Although Maldonado-Hinarejos et al. (2014) included a very limited review in this sense; chapter 2 widens it and covers the whole literature on bicycle mode choice modelling. Finally, the main novelty of chapter 2 lies in analysing both the evolution of the incorporation of latent variables in bicycle mode choice models and the critical role they play. This is a new perspective which had not been studied before.

Chapter 3 (*paper II* and *paper III*) is focused on determining the key psychological variables affecting commuting by bicycle in two different cycling contexts. On the one hand, the study in Madrid (*paper II*) is the first application of the TPB model in a context with low bicycle modal share. This research can therefore be used as a case study, since it is likely to be highly comparable to other locations in the early stages. On the other hand, Vitoria-Gasteiz is an example of city where cycling has only recently become the subject of promotion. The results of the study in *paper III* correspond to an intermediate stage and could help shed light on the process of so-called cities in transition towards a cyclable city. Chapter 4 (*paper IV*) widens the purpose of the bicycle use under investigation to all trip purposes in Vitoria-Gasteiz. It also moves forward in the development of advanced models for modelling bicycle mode choice and in their forecasting use.

Contrary to common thinking that cyclists ride bicycles mainly because they are concerned with the environment and so forth, bicycle commuting both in Madrid and in Vitoria-Gasteiz is not affected by the latent variable related to environmental benefits, health benefits, etc. (called 'Long term benefits' in *paper II* and 'Awareness' in *paper III*). The same is shown by Heinen et al. (2011) for distances shorter than 5Km. This latent variable is not significant for bicycle mode choice in general either (also called 'Awareness' in *paper IV*). However, these green issues do influence in bicycle commuting in other contexts and target segments of people, such as in a University Campus in Madrid (Spain) in Fernández-Heredia, et al. (2016); and among teenagers in Cyprus in Kamargianni and Polydoropoulou (2013) and in Kamargianni et al. (2015). In the case of Maldonado-Hinarejos et al. (2014) this latent variable appears to be significant because it is mixed with practical travel issues.

Vitoria-Gasteiz shares with Madrid the importance of the latent variable **Non-commuting cycling habit** and more progress is thus needed to normalise the bicycle as a mode of transport. The importance of habit diminishes the influence of other latent variables such as

Individual capabilities (PBC), which appears to be significant in more cyclable contexts such as the Netherlands (Heinen et al., 2011).

Apart from the latent variable 'Non-commuting cycling habit' –from *papers II* and *III*– the main latent predictors of bicycle commuting are practical travel issues, some of them related to time and cost but capturing other perspectives. For example, quickness and time reliability (called 'Direct benefits' in *paper II*, 'Direct disadvantages' in *paper III* and 'Direct advantages' in *paper IV*) or comfort and traffic safety (called 'Safety and comfort' in *paper III* and *IV* and part of 'Direct benefits' in *paper II*). Although with a lower number of indicators, these latent variables are also identified and appear to be significant in other applications: 'Direct advantages' is called 'Convenience' in Fernández-Heredia, et al. (2016); 'Safety and comfort' is identified as 'Safety consciousness' in the city of Toronto (Canada) in Habib et al. (2014) and throughout two latent variables –'Context' and 'Stress'– in London (England) in Maldonado-Hinarejos et al., (2014).

The main difference between Madrid and Vitoria-Gasteiz is related to the safety issue, since it is not the main barrier to bicycle commuting for non-car commuters in Vitoria-Gasteiz, while it is a clear barrier for all commuters in Madrid. Moreover, social pressure is not an influential factor in Madrid, neither in Vitoria-Gasteiz for general bicycle use.

For general bicycle use in *paper IV*, the latent variables 'Individual capacities' and 'External facilities' do appear to be statistically significant for the bicycle option. These latent variables are also present in Fernández-Heredia, et al (2016) as 'External restrictions' and 'Physical determinants'; and in Habib et al. (2014) as 'Perceptions towards bikeability of the city'.

Considering all the differences on the results depending on the context, policy recommendations must be ad-hoc. As chapter 4 has shown, the most effective way to promote bicycle use is to combine the implementation of bicycle measures (hard and soft measures) with measures punishing car use.

5.3 Future research

This section is a commentary on the further developments presented in chapter 2 that could be addressed in future research. On the one hand, some of the recommendations were addressed –at least partially– by the empirical applications, but suggests more research; and others were out of the scope of the thesis. On the other hand, some of the recommendations can take advantage of the databases of the TRANSBICI project and therefore could be more direct; and others might need future research projects.

First, it is shown in chapter 2 that all the studies in the modelling literature on the choice of the bicycle for utilitarian purposes use cross-sectional data. Development of **longitudinal studies** –before-and-after studies and attitudinal change models– are needed to find more solid conclusions on the causality between cycling and its determinants, and to better represent and forecast future bicycle adoption levels under different policy scenarios. In the case of bicycle commuting, the panel mobility survey from the TRANSBICI project could be used to model the effect of the implementation of the traffic calming in 47 streets of the city centre of Vitoria-Gasteiz (Spain), both in perceptions and mode behaviour.

Second, this thesis is based on traditional data collection methods, such as face-to-face and telephone interviews, which are very money demanding. Future research might **take**

advantage of the technology progress in data collection, that allows for example adding trip satisfaction and other attitudinal questions to smartphone trip-planning apps, while time-consuming revealed preference questions are collected passively. This trend will make it easier to collect rich data that allow objective attributes to be accurately measured and in which the role of latent factors will become even more central.

Third, in this thesis is shown a way to include bicycle-related questions –both objective and subjective (attitudes and perceptions)– in a Household Travel Survey (HTS), that many cities and metropolitan areas conduct to monitor modal share and other mobility characteristics. This has allowed the development of a modelling framework with cycling latent variables and could be an interesting starting point to generalise the inclusion of bicycle-related questions in HTS for many other cities and metropolitan areas that are keen to encourage bicycle use. Since the research on cycling is still limited (compared to other transport modes), it seems essential to **investigate the factors of bicycle use in different contexts** and compare them.

Fourth, the modelling applications in this thesis have focused exclusively on psychological factors. For example, perceptions of bicycle facilities and how these facilities affect individual attitudes have offered some insights into how the bicycle facilities affect the individual. However, the direct inclusion of both objective and subjective bicycle facilities variables has not been modelled. The HTS used in chapter 4 contained both types of these variables, but the characteristics of the developed model were unable to include objective variables related to bicycle facilities. Therefore, further research with the available data could focus on the **specific analyses of both objective and subjective variables related to cycling facilities**, or to other environmental variables, for cyclists. Moreover, chapter 4 included the investigation of bicycle use for urban mobility, in general. However, **specific models for different trip purposes** could be analysed, looking at the strength of the factors in each case.

Fifth, in this thesis were explored attitudes and perceptions towards bicycle use among different types of commuters, in two different cycling contexts. However, **more solid market segmentation analyses** –using SEMs, HCMs or other methodologies such as decision tree analysis– could be developed to improve targeting policies and programs and encourage bicycling. Moreover, although the modelling applications in chapter 4 have considered the group of people who will never use the bicycle no matter what the circumstances, it might be explicitly considered as a key segment to be modelled.

Finally, in chapter 4 was developed a forecasting application within the hybrid choice modelling framework, but with weak structural relationships to explain the formation of the latent constructs. Therefore, future applications might **reconsider forecasting processes**, due to their notably absent from hybrid choice modelling, but with better-supported SEM, necessary to improve forecasting power with latent variables. From an econometric perspective, **random parameter models** (such as mixed logit, mixed probit or latent class) should be adopted as the kernel of a hybrid choice specification. **Interactions between the latent and objective variables** –e.g. interactions between latent variables and socio-economic variables– might also be included in the modelling specification. This way, their results could orient the following market segmentation analyses. Improvements in computer calculation times might help the development of these issues, following the initiated modelling path developed in this thesis.

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Appendices

Appendix A – Bicycle share of trips in different cities worldwide

Country	Range of bicycle share	Cities
Australia	0%-9%	Brisbane-North
Canada	0%-9%	Calgary; Edmonton; Montreal; Ottawa; Quebec City; Toronto; Vancouver; Winnipeg
United States	0%-9%	Cleveland; Sacramento
Ireland	0%-9%	Cork; Dublin; Galway; Limerick; Waterford
Portugal	0%-9%	Almada; Aveiro; Braga; Funchal; Lisbon; Olhão; Oporto; Vila Nova de Gaia; Agueda
Spain	10%-19%	Vitoria-Gasteiz
	0%-9%	Barcelona; Bilbao; Burgos; Córdoba; Donostia-San Sebastián; Leganés; León; Málaga; Murcia; Pamplona; Sevilla (Agglomeration); Tarragona; Valencia
England	10%-19%	Bristol; Norwich; York
	0%-9%	Aberdeen; Blackpool; Blackburn with Darwen; City of London - Municipality; Doncaster; Dundee; Edinburgh; Exeter; Gloucester; Greater Manchester; Ipswich; Leeds; Leicester; Liverpool; London; Milton Keynes; Newcastle; Nottingham; Peterborough; Plymouth; Portsmouth; Preston; Sheffield; Southampton; Stoke-on-Trent; Swindon; Thurrock; Watford; West Midlands; West Yorkshire; Worcester; Wrexham (County Borough)
France	0%-9%	Aix; Amiens; Annemasse; Bas-Rhin; Bayonne; Beaujolais; Besançon; Bethune; Bordeaux; Bouches-du-Rhône; Brest; Chambéry; Clermont-Ferrand; Dunkerque; Elbeuf; Genevois Fancais; Grenoble; Grenoble Agglo; Istres; Le Havre; Le Mans; Lens; Lille; Limoges; Lorient; Lyon; Marseille; Maubeuge; Metropole Savoie; Montpellier; Nancy; Nantes; Nice; Paris; Pau; Pointe-à-Pitre; Reims; Rennes; Rouen; Rouen Agglo; Rouen-Elbeuf; Saint Quentin en Yvelines; Saint-Étienne; Strasbourg; Toulon; Toulouse; Tours; Vienne
Italy	20%-29%	Bolzano; Ferrara; Pavia
	10%-19%	Pisa; Ravenna; Reggio Emilia
	0%-9%	Bergamo; Bologna; Brescia; Cuneo; Firenze; Foggia; Livorno; Messina; Monopoli; Parma; Torino; Venezia; Verona; Savona; Bari
Switzerland	20%-29%	Basel
	10%-19%	Bern
	0%-9%	Lausanne; Zürich
Estonia	0%-9%	Tallinn; Tartu
Norway	0%-9%	Bergen; Drammen; Fredrikstad; Kristiansand; Oslo; Porsgrunn; Sandnes; Sarpsborg; Skien; Stavanger; Tromsø; Trondheim
Austria	20%-29%	Salzburg
	10%-19%	Feldkirch; Graz; Innsbruck; Leoben; St. Pölten; Vorarlberg (Land/Region)
	0%-9%	Hartberg; Judenburg; Linz; Wien
Latvia	0%-9%	Riga
Belgium	20%-29%	Antwerp; Ghent
	10%-19%	Genk; Hasselt
	0%-9%	Brussels; Charleroi; Liege; Namur
Finland	20%-29%	Kotka; Oulu
	10%-19%	Helsinki; Hyvinkää; Jyväskylä; Lahti; Tampere; Turku
	0%-9%	Espoo; Vantaa

Country	Range of bicycle share	Cities
Sweden	20%-29%	Linköping; Lund; Malmö; Örebro; Uppsala
	10%-19%	Eskilstuna; Gävle; Norrköping; Umeå; Västerås
	0%-9%	Gothenburg; Stockholm
Germany	≥30%	Emden; Münster
	20%-29%	Bamberg; Bremen; Coswig/Radebeul; Cottbus; Dessau; Dessau-Roßlau; Freiburg; Göttingen; Greifswald; Großenhain; Heidelberg; Karlsruhe; Konstanz; Ludwigsfelde; Oldenburg; Oranienburg; Potsdam
	10%-19%	Aachen; Augsburg; Berlin; Bernau bei Berlin; Bielefeld; Bonn; Braunschweig; Darmstadt; Dortmund; Dresden; Duisburg; Düsseldorf; Eberswalde; Eichwalde/Zeuthen; Erlangen; Falkensee/Dallgow/Wustermark; Frankfurt; Frankfurt am Main; Halle; Halle (Saale); Hamburg; Hamm; Hannover; Heidenau; Herford; Hildesheim; Jena; Kirchheim unter Teck; Köln; Krefeld; Leipzig; Lemgo; Lübeck; Ludwigsburg; Ludwigshafen; Magdeburg; Mainz; Mannheim; Munich; Neuss; Nürnberg; Osnabrück; Paderborn; Passau; Pirna; Radeberg; Ratingen; Reutlingen; Riesa; Rosenheim; Rostock; Schweinfurt; Spremberg; Strausberg; Teltow/Stahnsdorf/Kleinmachnow; Ulm/Neu-Ulm; Villingen Schwenningen
	0%-9%	Bochum; Castrop-Rauxel; Chemnitz; Dippoldiswalde; Erfurt; Essen; Freital/Tharandt; Fürth; Gera; Heilbronn; Kaiserslautern; Kamen; Kassel; Koblenz; Meißen; Moenchengladbach; Oberhausen; Offenbach am Main; Pforzheim; Rüdersdorf bei Berlin; Saarbrücken; Schwerin; Solingen; Stuttgart; Trier; Ulm; Wiesbaden; Witten; Wuppertal; Zwickau
Bulgaria	10%-19%	Kavarna
	0%-9%	Antonovo; Balchik; Burgas; Gabrovo; Haskovo; Kardjali; Montana; Pazardjik; Plevn; Razlog; Ruse; Sofia; Stara Zagora; Varna; Veliko Tarnovo; Vratza
Denmark	20%-29%	Copenhagen; Gladsaxe; Odense
	10%-19%	Ballerup; Greve; Helsingør (Elsinore); Hoeje Taastrup; Naestved; Norddjurs; Roskilde
	0%-9%	Syddjurs
Netherlands	≥30%	Eindhoven; Groningen; Houten; Leiden; Oss; Region North-East Brabant; Zwolle
	20%-29%	Almere; Amersfoort; Amsterdam; Apeldoorn; Breda; Dordrecht; Ede; Emmen; Enschede; Haarlem; Maastricht; Nijmegen; Tilburg; Utrecht; Zaanstad
	10%-19%	Arnhem; Den Haag; Haarlemmermeer; Parkstad Limburg; Rotterdam; 's-Hertogenbosch; Zoetermeer

Appendix B – Summary of surveys' characteristics

Surveys Characteristics	Commuting survey for bicycle analysis in two corridors of the city centre of Madrid	Commuting survey for bicycle analysis in Vitoria-Gasteiz	Household travel survey including bicycle indicators in Vitoria-Gasteiz
Study	Municipal study to analyse the mobility demand and social impacts before the construction of bicycle lanes	First phase of the TRANSBICI project	Second phase of the TRANSBICI project
Area	Two axis of the city centre of Madrid	The municipality of Vitoria-Gasteiz	The municipality of Vitoria-Gasteiz
Focus	Commuting mobility	Commuting mobility	General mobility
Bicycle use	Commuting: - General: 0.6% (2009)	Commuting: 10.9% (2011) General: 6.8% (2011)	Commuting: 21.4% (2014) General: 12.3% (2014)
Typology	Crossectional	Crossectional (1 st wave of a 3 waves panel survey)	Crossectional
Period	20 th , 21 st and 22 nd of September 2011	From the 27 th of April to the 18 th of May 2012	<ul style="list-style-type: none"> From the 1st week of May to the 3rd week of June In October (9% of the total sample, mainly teenagers)
Typology	Face-to-face on-street	Telephone	Telephone
Selection of respondents	Direct personal approach in sidewalks and squares, parking entrances, bus stops and metro stations	Asking permission to employers and instructors at work/study places	Random selection of the household telephone number
Universe	Municipal residents moving around the area	Employees and students, aged from 16 to 64, and commuting in Vitoria-Gasteiz	Municipal residents > 9
Time length	15 min	15 min	21 min
Survey takers	Civil Engineer Master students	Company: Append Investigación de Mercados	Company: Quor
Tasks developed by the author of the thesis	<ul style="list-style-type: none"> Questionnaire design Coordination of the survey progress Supervision of the survey takers' work in situ Development of surveys 	<ul style="list-style-type: none"> Questionnaire design Coordination of the survey progress Supervision of the survey takers' work by monitoring some surveys 	<ul style="list-style-type: none"> Coordination of the stakeholders Questionnaire design Other survey preparations Training and pilot surveys Coordination of the survey progress Supervision of the survey takers' work by monitoring some surveys and correction of errors Depuration process and (preliminar) analyses Presentation of results
Incentives	No	Raffle of 3 gift cards of 100€	Raffle of a digital pad
Designed sample distribution	40% cyclists, 20% pedestrians, 20% public transport users, 20% car/motorbike users	'Bicycle + walking + public transport' (58%) and 'car + motorbike + other modes' (42%)	12.3% by bicycle, 54.4% walking, 7.6% by public transport, 24.7% by car and motorbike and 1.1% by other modes
Survey sample	321 individuals	736 individuals	4,192 individuals
Analysis sample	224 individuals	654 individuals	14,406 trips
Questionnaire	Paper	CATI*-system	CATI*-system

Surveys Characteristics	Commuting survey for bicycle analysis in two corridors of the city centre of Madrid	Commuting survey for bicycle analysis in Vitoria-Gasteiz	Household travel survey including bicycle indicators in Vitoria-Gasteiz
Traditional questions	<ul style="list-style-type: none"> • Respondents' daily transport mode and intention to change it • Socioeconomic questions • Availability of transport modes • Mobility habits 	<ul style="list-style-type: none"> • Socio-economic and household data • Availability of transport modes • Commuting trip characteristics (mode and address + time of the origin-destination) • Frequency of bicycle use for different purposes. 	<ul style="list-style-type: none"> • Individual and household socioeconomic characteristics • Availability of transport modes and type of parking at home • Trips made the previous day (origin, destination, purpose, mode(s), line(s) and ticket(s), parking at destination, infrastructure(s) used, availability of showers and/or lockers at the work/study place) • Frequency of bicycle use for different purposes • Experience riding a bicycle for different purposes
Perceptual questions	<ul style="list-style-type: none"> • Perceptions of bicycle use: <ul style="list-style-type: none"> - Attitudinal beliefs - Perceived behavioural control beliefs - Subjective norm (beliefs and importances) - Descriptive norm beliefs • Perceptions of bicycle facilities in the area 	<ul style="list-style-type: none"> • Attitudes (beliefs and importances) • Subjective norm (beliefs and importances) • Descriptive norm beliefs • Perceived behavioural control beliefs: controllability and self-efficacy • Social identity 	<ul style="list-style-type: none"> • Degree of agreement or disagreement towards several factors related to the (possible) trip by bicycle for urban mobility • Degree of limitation provoked by several factors related to the (possible) trip by bicycle for urban mobility • Subjective norm (beliefs and importances) • Global perception of the bicycle use for urban mobility in Vitoria-Gasteiz • Degree of intention to (start using) increase the bicycle use for urban mobility • Degree of intention to use a possible public-bike sharing system
Likert scales for perceptual questions	<ul style="list-style-type: none"> • 4-point Likert scale: nothing, few, quite and many • 11-point Likert scale: from completely disagree-unimportant (+0) to completely agree-important (+10) 	<ul style="list-style-type: none"> • 7-point Likert scale: from completely disagree-unimportant (+1) to completely agree-important (+7) 	<ul style="list-style-type: none"> • 7-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7)

* CATI: computer-assisted telephone interviewing

Appendix C – Questionnaire of the commuting survey for bicycle analysis in two corridors of the city centre of Madrid

ENCUESTA EJES CENTRO PDMC

ÁREA DE GOBIERNO
DE MEDIO AMBIENTE
Y MOVILIDAD

Entrevistador _____	Fecha _____/9/2011	Lugar _____
Nº cuestionario _____	Hora _____ : _____	Modo principal ☐ CM ☐ TP ☐ P ☐ B

1 **Sexo** ☐_1 Hombre ☐_2 Mujer

2 **¿Turista?** ☐_1 Sí ☐_2 No

3 **Origen** ☐_1 España ☐_2 Otro país: _____

4 **¿Dispone de permiso de conducir coche?** ☐_1 Sí ☐_2 No

5 **¿Dispone de coche para realizar sus desplazamientos?** ☐_1 Sí ☐_2 No

8 **¿Dispone de permiso de conducir moto?** ☐_1 Sí ☐_2 No

9 **¿Dispone de moto para realizar sus desplazamientos?** ☐_1 Sí ☐_2 No

12 **¿Sabe montar en bicicleta?** ☐_1 Sí ☐_2 No

13 **¿Dispone de bicicleta para realizar sus desplazamientos?** ☐_1 Sí ☐_2 No

16 **¿Dispone de abono de transporte?** ☐_1 Sí ☐_2 No

6 **En el hogar hay:** _____ coches

7 **El coche que utiliza con más frecuencia lo aparca:**
☐_1 En parking o plaza en el edificio de residencia
☐_2 En parking o plaza en otro edificio en las inmediaciones
☐_3 En la calle

10 **En el hogar hay:** _____ motos

11 **La moto que utiliza con más frecuencia la aparca:**
☐_1 En parking o plaza en el edificio de residencia
☐_2 En parking o plaza en otro edificio en las inmediaciones
☐_3 En la calle

14 **En el hogar hay:** _____ bicicletas

15 **La bicicleta que utiliza con más frecuencia la aparca:**
☐_1 Dentro de la vivienda
☐_2 Trastero, deposito, parking, en el edificio de residencia
☐_3 Otro estacionamiento seguro: _____
☐_4 En la calle

17 **¿Cuántos viajes hace al día con el abono durante los días laborables?** _____ viajes

Pensando en sus desplazamientos habituales, ¿qué modo de transporte utiliza con mayor frecuencia al realizar cada una de las siguientes actividades? [Si utiliza varios modos de transporte indique con el que recorre más distancia. Una sola casilla por fila]

	COCHE	MOTO	AUTOBÚS	METRO/ TREN	TAXI	BICICLETA	A PIE	NO PROCEDE
18 Ir al lugar de trabajo	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8
19 Ir al lugar de estudio	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8
20 Hacer la compra diaria (alimentación, higiene, etc.)	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8
21 Comprar ropa o complementos	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8
22 Llevar o recoger niños, ancianos, etc.	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8
23 Salir de ocio (restaurante, cine, etc.)	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8
24 Visitar a familiares / amigos	☐ _1	☐ _2	☐ _3	☐ _4	☐ _5	☐ _6	☐ _7	☐ _8

Pensando en sus desplazamientos a su lugar de trabajo o estudio, ¿con qué frecuencia utiliza los siguientes modos de transporte? [Si compagina estudios y trabajo, haga referencia a la actividad con mayor número de desplazamientos semanales]

	DIARIA, o casi todos los días laborales (> 3 usos/semana)	SEMANAL, o casi semanal (> 3 usos/mes)	OCASIONAL (> 3 usos/año)	NO USUARIO (<= 3 usos/año)
25 Coche	☐ ₁	☐ ₃	☐ ₄	☐ ₅
26 Moto	☐ ₁	☐ ₃	☐ ₄	☐ ₅
27 Autobús	☐ ₁	☐ ₃	☐ ₄	☐ ₅
28 Metro/Tren	☐ ₁	☐ ₃	☐ ₄	☐ ₅
29 Taxi	☐ ₁	☐ ₃	☐ ₄	☐ ₅
30 A pie	☐ ₁	☐ ₃	☐ ₄	☐ ₅

¿Con qué frecuencia utiliza la bicicleta para realizar cada una de las siguientes actividades? [Una sola casilla por fila]

	DIARIA, independiente de las condiciones climáticas (>3 usos/semana)	DIARIA, solo con buen tiempo (>3 usos/semana)	SEMANAL, o casi semanal (> 3 usos/mes)	OCASIONAL (> 3 usos/año)	NO USUARIO (<= 3 usos/año)
31 Trabajo	☐ ₁	☐ ₂	☐ ₃	☐ ₄	☐ ₅
32 Estudios	☐ ₁	☐ ₂	☐ ₃	☐ ₄	☐ ₅
33 Gestiones, médico, compras, visitas, etc.	☐ ₁	☐ ₂	☐ ₃	☐ ₄	☐ ₅
34 Ocio, paseo, turismo, etc.	☐ ₁	☐ ₂	☐ ₃	☐ ₄	☐ ₅
35 Deporte	☐ ₁	☐ ₂	☐ ₃	☐ ₄	☐ ₅

37 ¿Su uso de la bicicleta con respecto al año pasado es? ☐₁ Mayor ☐₂ Igual ☐₃ Menor

38 ¿De 0 a 10, en qué medida le gustaría (le gusta si ya la utiliza) utilizar la bicicleta para ir a su lugar de trabajo/estudio? _____ 10 = mucho
0 = por nada

39 ¿Cree que su uso de la bicicleta aumentará en los próximos 12 meses? ☐₁ Seguro que no ☐₂ Prob. no ☐₃ Prob. sí ☐₄ Seguro que sí

¿Hasta qué punto cree que estarían (están si ya la utiliza) de acuerdo las siguientes personas con que usted se desplazara (desplaza) en bicicleta al lugar de trabajo o estudio? [Escala de 0 a 10: Totalmente en desacuerdo - Totalmente de acuerdo]

40 Familiares cercanos (padre, madre, hermanos, pareja)	_____
41 Amigos	_____
42 Compañeros de trabajo o estudio	_____

¿Hasta qué punto es importante para usted la opinión de esas personas respecto a desplazarse al lugar de trabajo o estudio en bicicleta? [Escala de 0 a 10: Nada importante - Muy importante]

43 Familiares cercanos (padre, madre, hermanos, pareja)	_____
44 Amigos	_____
45 Compañeros de trabajo o estudio	_____

46 En su situación actual, ¿qué grado de dificultad tiene en utilizar la bicicleta para desplazarse a su lugar de trabajo o estudio? ☐₁ Mucha ☐₂ Bastante ☐₃ Poca ☐₄ Ninguna

Entrevistador _____

Nº cuestionario _____

En su situación actual, ¿cuánto influyen los siguientes factores en la dificultad de utilizar la bicicleta para desplazarse a su lugar de trabajo o estudio? [Una sola casilla por fila]

		Mucho	Bastante	Poco	Nada
47	Las distancias que debo recorrer son muy largas	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
48	En mi camino hay demasiadas cuestas, desniveles, subidas	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
49	Tengo una condición física insuficiente	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
50	Tengo miedo a que me roben/dañen la bicicleta	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
51	No tengo duchas o taquillas en destino	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
52	No tengo aparcamiento seguro en destino	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
53	No tengo aparcamiento seguro en casa	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
54	No me siento suficientemente capacitado a conducir en el tráfico	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
55	Tengo que transportar objetos	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
56	Tengo que transportar otras personas (acompañar niños o mayores)	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
57	La lluvia, El frío, El calor lo dificultan	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
58	Tengo miedo a accidentes o caídas	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
59	En mi camino el tráfico es demasiado rápido, agresivo	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
60	Me siento más expuesto/a a la contaminación del tráfico	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
61	No puedo (o no me gusta) llegar sudado/a	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Nada
62	¿Qué nivel de impacto podría tener la habilitación de carriles bici en disminuir estas dificultades?	☐ 1 Mucho	☐ 2 Bastante	☐ 3 Poco	☐ 4 Ninguno
63	¿Cuál es su opinión sobre los proyectos de habilitación de carriles bici en el centro de Madrid?	☐ 1 Muy buena ☐ 5 Muy mala	☐ 2 Buena ☐ 6 No se bastante para valorar	☐ 3 Regular ☐ 7 NS/NC	☐ 4 Mala
64	¿Cuáles serán los efectos de los proyectos para la zona?	☐ 1 Serán positivos (+) ☐ 2 Serán negativos (-) ☐ 3 Ambiguos (+ y -) ☐ 4 Nulo/sin cambios ☐ 5 NS/NC			
65	¿De dónde se debería extraer el espacio necesario para los carriles bici del centro de Madrid? [En el primer caso elegir un conjunto de porcentajes que sumen 100%] ☐ 1 De las aceras: _____ % + Del aparcamiento: _____ % + Del carril de circulación: _____ % = 100% ☐ 2 No se debería extraer espacio para segregar las bicis ☐ 3 NS/NC				
66	Nº de personas que viven en el hogar	_____ personas			
67	Situación en el hogar	☐ 1 Padre/Madre ☐ 2 Hijo/a ☐ 3 Cónyuge o pareja sin hijos (o con estos fuera del hogar) ☐ 4 No lazos familiares ☐ 5 Otras situaciones			
68	Edad	_____ años			
69	Situación profesional	☐ 1 Ocupado ☐ 2 Estudiante ☐ 3 Ambos (trabaja y estudia) ☐ 4 Labores del hogar ☐ 5 Pensionista ☐ 6 Desempleado ☐ 7 Otra situación _____			
70	Nivel de estudios terminados	☐ 1 Ninguno ☐ 2 EGB/Graduado Escolar ☐ 3 Bachillerato superior/BUP/COU ☐ 4 Formación profesional ☐ 5 Estudios Universitarios ☐ 6 No indica			
71	¿Puede decirme el rango de ingresos mensuales medios en el hogar?	☐ 1 < 1.000€ ☐ 2 1.000 - 2.000€ ☐ 3 2.000 - 3.000€ ☐ 4 2.000 - 3.000€ ☐ 5 > 4.000€			

PREGUNTAS OPCIONALES

Teniendo en cuenta las características de la bicicleta como modo de transporte, evalúe hasta qué punto está de acuerdo con las siguientes frases. [Utilice una escala de 0 a 10, en la que 0 indica "Totalmente en desacuerdo" con la frase y en la que 10 indica "Totalmente de acuerdo" con la frase. Elija el punto de la escala que mejor refleje su opinión, tratando de distinguir todo lo posible entre las diferentes cuestiones.]

72	Es rápido, ahorro tiempo	_____	80	Me proporciona independencia (puerta a puerta, elección de ruta, detenerse libremente, etc.)	_____
73	Beneficia al medio ambiente	_____			
74	Es relativamente barato	_____	81	Se ve poco afectado por la climatología	_____
75	Cuando lo necesito está disponible	_____	82	Es relajante	_____
76	Es seguro, sin accidentes	_____	83	Es divertido	_____
77	Es fiable, me garantiza llegar a tiempo	_____	84	Está bien visto, es moderno, da buena imagen, etc.	_____
78	Resulta bueno para mi salud	_____	85	Es fácil de aparcar	_____
79	Es confortable	_____	86	Es una forma de mejorar mi ciudad	_____

¿Hasta qué punto cree que se ha incrementado el uso de la bici en Madrid entre los siguientes grupos de personas? [Escala de 0 a 10: Nada - Mucho]

87	Las personas en general	_____	90	Mis amigos	_____
88	Los jóvenes	_____	91	Mis compañeros de trabajo o estudio	_____
89	Mis familiares	_____			

Contacto:

Comentarios:

Appendix D – Questionnaire of the commuting survey for bicycle analysis in Vitoria-Gasteiz

p. 1/8

TRANSBICI - Comportamiento y modelización de la demanda ciclista:
transición hacia una ciudad ciclable

Encuesta Panel (EP1_VG): Cuestionario OLA1

Cartoncito con la Escala 0-6 entregado a las personas contactadas con el cuestionario de CAPTACIÓN

Encuesta telefónica sobre aspectos relacionados con la movilidad urbana en Vitoria-Gasteiz ○ ● ● ● ● ● ● ●

La encuesta se compone de **TRES llamadas telefónicas** en los siguientes meses (duración 10-15 minutos):
 ☎ abril de 2012
 ☎ octubre de 2012
 ☎ marzo/abril de 2013

CONSERVE ESTE CUPÓN durante las tres fases de la encuesta, anotando el número que le comunicaremos. En caso de resultar agraciado, le servirá para recoger el premio.

CUPÓN nº: _____

Entre los que contesten se sortearán los siguientes **PREMIOS**, en cheques regalo de El Corte Inglés:
 • 3 cheques de **100 €** tras la 1ª llamada
 • 5 cheques de **120 €** tras la 2ª llamada
 • 10 cheques de **150 €** tras la 3ª llamada

De acuerdo con la Ley de Protección de Datos y el código CCI ESOMAR, toda la información que nos facilite en las entrevistas telefónicas será tratada exclusivamente con fines estadísticos no pudiendo ser utilizada de forma nominal ni facilitada a terceros.

Le rogamos tenga a mano este cupón en el momento de las llamadas. Le vamos a pedir que exprese su opinión en base a la siguiente escala de 0 a 6:

nada	moderadamente			totalmente		
○	○	○	○	○	○	○
0	1	2	3	4	5	6

Los responsables de la investigación y el Ayuntamiento de Vitoria-Gasteiz, le agradecen sinceramente su participación

INICIO

Buenos días/tardes, soy _____, entrevistador/a de un proyecto de investigación de la Universidad Politécnica de Madrid en convenio con el Ayuntamiento de Vitoria, financiado por el Ministerio de Economía y Competitividad, sobre aspectos relacionados con la movilidad urbana.

De acuerdo con la LEY DE PROTECCIÓN DE DATOS y el código CCI ESOMAR, toda la información que nos facilite en este cuestionario será tratada exclusivamente con fines estadísticos no pudiendo ser utilizada de forma nominal ni facilitada a terceros.

En el cuestionario **NO HAY RESPUESTAS VERDADERAS NI FALSAS**, conteste siempre la respuesta que usted considere que refleja mejor sus opiniones o gustos.

NOTAS para el Encuestador

1. En caso de requerir más información del proyecto dirijase al 91 336 6657 (dar esta información solo a quien la requiera).
2. Las preguntas 0, P2 y P4 sirven para verificar que la persona se desplaza **AL MENOS UN DÍA A LA SEMANA** a su lugar habitual de trabajo o estudio. Si esta condición no se realiza, terminar la encuesta, pues no es válida.

Hábito + Caracterización espacial del desplazamiento habitual (CAP_auto, EPx)

(Son las mismas preguntas realizadas en el cuestionario de captación, repetidas en OLA2 y OLA3)

P0. ¿Tiene delante el Cupón que se le entregó, con la escala 0-6? 1. Sí 2. No	
P1. ¿Cuál es su situación profesional? <i>(leer)</i> 1. Menor de 16 años <i>(no válido)</i> 2. Ocupado 3. Estudiante 4. Ambos (trabaja y estudia) 5. Otras situaciones <i>(no válido)</i>	<div style="border: 1px solid black; padding: 5px;"> Si (0 = 2, 3, 4) se continúa la encuesta. Si (0 = 1 o 5) se finaliza. </div>
Pensando en sus desplazamientos habituales, P2. Si (0= 2 o 0= 4) ¿Cuántos días a la semana se desplaza a su lugar de trabajo? <i>(leer)</i> _____ días <i>[numero: 0-7]</i>	
P3. Si ((0= 2 o 0= 4) y 0>0) ...¿y qué modo de transporte utiliza habitualmente para desplazarse al trabajo? <i>(leer)</i> <i>[Si utiliza varios modos de transporte indique con el que recorre más distancia]</i> 1. Coche 2. Moto 3. Autobús urbano / Tranvía 4. Autobús interurbano 5. Taxi 6. Bicicleta 7. A pie 8. Otro: _____	
P4. Si (0= 3 o 0= 4) ¿Cuántos días a la semana se desplaza a su lugar de estudio? <i>(leer)</i> _____ días <i>[numero: 0-7]</i>	<div style="border: 1px solid black; padding: 5px;"> Si (0=0 y P4=0) se finaliza. </div>
P5. Si ((0= 3 o 0= 4) y P4>0) ¿Qué modo de transporte utiliza habitualmente para desplazarse al lugar de estudio? <i>(leer)</i> <i>[Si utiliza varios modos de transporte indique con el que recorre más distancia]</i> 1. Coche 2. Moto 3. Autobús urbano / Tranvía 4. Autobús interurbano 5. Taxi 6. Bicicleta 7. A pie 8. Otro: _____	
P6. Si (P3=1) ... y el aparcamiento de su coche en el lugar de trabajo/estudio lo realiza en... <i>(leer)</i> <i>[Si compagina estudios y trabajo, referirse a la actividad que realiza con mayor frecuencia]</i> 1. Parking Gratuito Centro Comercial 2. Zona Azul/ OTA 3. Garaje/Parking propio o alquilado 4. Parking por horas 5. No aparca - dobles filas 6. En la calle – libre 7. Le acompañan	

<p>P7. Si (P3=6) ... y el aparcamiento de su bicicleta en el lugar de trabajo/estudio lo realiza en... (leer) <i>[Si compagina estudios y trabajo, referirse a la actividad que realiza con mayor frecuencia]</i></p> <ol style="list-style-type: none"> 1. Atada a mobiliario urbano 2. Atada a aparca-bicis regulado 3. Bajo llave (trastero, deposito, parking) 4. Dentro del lugar de trabajo/estudio 5. Otro: _____
<p>P8. Pensando en el desplazamiento habitual a su lugar de trabajo/estudios, ¿puede indicar origen y destino del mismo? (leer) <i>[Si compagina estudios y trabajo, haga referencia a la actividad con mayor número de desplazamientos semanales. Indique calle y portal aproximativo (ej. "calle de Burgos 20" si Ud. Vive en calle de Burgos 16)]</i></p> <p>- ORIGEN (dirección de su Hogar): _____ Nº _____ Código postal: _____</p> <p>- DESTINO (dirección de su lugar de trabajo/estudios): _____ Nº _____ Código postal: _____</p>
<p>P9. ¿Cuál es su hora aproximada de salida y llegada al lugar de trabajo/estudio? (leer) <i>[Por favor, intente ser lo más preciso posible]</i></p> <p>- Salida _____:____ horas</p> <p>- Llegada _____:____ horas</p>
<p>P8b Indique por favor una de las siguientes posibilidades:</p> <ol style="list-style-type: none"> 1. El desplazamiento ES DIRECTO, no realizo otras actividades 2. El desplazamiento NO ES DIRECTO, realizo otras actividades antes de llegar al destino (acompañamientos, visitas, compras, etc.) <p>P8c ¿Qué tipo de jornada realiza?</p> <ol style="list-style-type: none"> 1. Jornada partida 2. Jornada continuada 3. Sin horarios fijos

Disponibilidad de modos (EPx_tel)

P10. ¿Dispone Ud. de permiso de conducir? (leer)	-a: Coche (B) 1. Sí 2. No -b: Moto (A1/A2/A) 1. Sí 2. No
P11. ¿Dispone Ud. de coche para desplazarse a su lugar de trabajo/estudio? (Preguntar aunque no tenga permiso, adaptar) (leer)	1. Propietario/conductor 2. Acompañante 3. Usuario no propietario 4. No dispone 5. No indica
P12. Si (P11=1, 2, 3) El lugar de aparcamiento en el hogar del coche que tiene disponible es... (leer)	1. En parking o plaza en el edificio de residencia 2. En parking o plaza en otro edificio en las inmediaciones 3. En la calle 4. No indica
P13. ¿Sabe montar en bicicleta? (leer)	1. Sí 2. No
P14. Si (P13=1) ¿Dispone usted de bicicleta para desplazarse a su lugar de trabajo/estudio? (leer)	1. Bicicleta propia 2. Bicicleta de un familiar/amigo 3. Bicicleta pública 4. No dispone 5. No indica
P15. Si (P13=1 y P14=1, 2, 3) El lugar de aparcamiento en el hogar de la bicicleta que tiene disponible es ... (leer)	1. Dentro de la vivienda 2. En un trastero, deposito, parking, en el edificio de residencia 3. En otro estacionamiento seguro 4. En la calle 5. No indica

Intención/Hábito de conducta ciclista (EPx_tel)

P16. Pensando en el desplazamiento habitual a su lugar de trabajo/estudios,	
NO usa bici	Si (P3<>6 o P5<>6) ¿con cuál de las siguientes frases está más de acuerdo? (leer)
SÍ, usa bici	Si (P3=6 o P5=6) ¿con cuál de las siguientes frases está más de acuerdo? (leer)
SÍ	P17. Si (P3=6 o P5=6) ¿Desde cuándo va en bicicleta a su lugar de trabajo/estudio?
	abierta, por codificar después del piloto

P18. Si (P13=1 y P14 = 1, 2, 3) Pensando en otras actividades distintas al desplazamiento habitual a su lugar de trabajo/estudios, ¿con qué frecuencia ha utilizado la bicicleta? (leer)				
- para ocio (paseo, turismo, salir...)	1. siempre	2. casi siempre	3. de vez en cuando	4. nunca
- para hacer deporte	1. siempre	2. casi siempre	3. de vez en cuando	4. nunca
- para ir a hacer gestiones, al médico, de compras, visitas...	1. siempre	2. casi siempre	3. de vez en cuando	4. nunca

De ahora en adelante todas las preguntas que le haré serán con respecto a su desplazamiento habitual al lugar de trabajo/estudios

Mire ahora al Cupón que le entregamos. Le pedimos que exprese su opinión en base a la escala de 0 a 6 que está a la vuelta del Cupón

Actitud hacia la conducta (EPx_tel)

NO bici	A*. Si (P3<>6 o P5<>6) Teniendo en cuenta la posibilidad de utilizar la bicicleta para trasladarse a su lugar de trabajo o estudio, indique hasta qué punto estaría de acuerdo o en desacuerdo con las siguientes afirmaciones:
SÍ bici	A+. Si (P3=6 o P5=6) Pensando en su desplazamiento habitual a su lugar de trabajo/estudios, indique hasta qué punto está de acuerdo o en desacuerdo con las siguientes afirmaciones:

15

¿hasta qué punto está de acuerdo o en desacuerdo con las siguientes afirmaciones?

	Nada de acuerdo	Moderadamente de acuerdo				Totalmente de acuerdo	
	0	1	2	3	4	5	6
A7	Me desplazaría/ <i>desplazo</i> con rapidez	☐	☐	☐	☐	☐	☐
A1	Sabría/ <i>Se</i> cuánto voy a tardar en llegar a mi destino	☐	☐	☐	☐	☐	☐
A8	Me costaría/ <i>cuesta</i> transportar personas	☐	☐	☐	☐	☐	☐
A9	Me costaría/ <i>cuesta</i> transportar objetos	☐	☐	☐	☐	☐	☐
A2	Tendría/ <i>Tengo</i> libertad, al no depender de ningún otro modo de transporte	☐	☐	☐	☐	☐	☐
A4	Ahorraría/ <i>Ahorro</i> respecto a otros modos de transporte	☐	☐	☐	☐	☐	☐
A3	Tendría/ <i>Tengo</i> un riesgo elevado de sufrir un accidente	☐	☐	☐	☐	☐	☐
A5	Haría/ <i>Hago</i> ejercicio físico	☐	☐	☐	☐	☐	☐
A10	Aparcaría/ <i>Aparco</i> con facilidad	☐	☐	☐	☐	☐	☐
A11	Tendría un riesgo elevado de que me robaran o dañaran la bici / <i>Tengo un riesgo elevado de que me roben o dañen la bici</i>	☐	☐	☐	☐	☐	☐
A6	Contaminaría/ <i>Contamino</i> menos el medio ambiente	☐	☐	☐	☐	☐	☐
A19	Respiraría/ <i>Respiro</i> aire contaminado	☐	☐	☐	☐	☐	☐
A12	Causaría/ <i>Causo</i> molestias a los peatones	☐	☐	☐	☐	☐	☐
A13	Dependería/ <i>Dependo</i> mucho de la climatología	☐	☐	☐	☐	☐	☐
A14	Podría/ <i>Puedo</i> vestir con ropa adecuada para mis actividades	☐	☐	☐	☐	☐	☐
A15	Causaría/ <i>Causo</i> una buena impresión a los demás	☐	☐	☐	☐	☐	☐
A16	Llegaría/ <i>Llego</i> estresado a mi destino	☐	☐	☐	☐	☐	☐
A17	Me divertiría/ <i>divierto</i> por el camino	☐	☐	☐	☐	☐	☐
A18	Llegaría/ <i>Llego</i> sudado a mi destino	☐	☐	☐	☐	☐	☐
A20	Me relajaría/ <i>relajo</i> durante el trayecto	☐	☐	☐	☐	☐	☐

B. Y hasta qué punto es importante para Ud. en sus desplazamientos al lugar trabajo o estudio...

		Nada importante		Moderadamente importante			Totalmente importante	
		0	1	2	3	4	5	6
B7	Desplazarme con rapidez	☐	☐	☐	☐	☐	☐	☐
B1	Saber cuánto voy a tardar en llegar a mi destino	☐	☐	☐	☐	☐	☐	☐
B8	Poder transportar personas	☐	☐	☐	☐	☐	☐	☐
B9	Poder transportar objetos	☐	☐	☐	☐	☐	☐	☐
B2	Tener libertad, no depender de ningún modo de transporte	☐	☐	☐	☐	☐	☐	☐
B4	Ahorrar respecto a otros modos de transporte	☐	☐	☐	☐	☐	☐	☐
B3	Minimizar el riesgo de sufrir un accidente	☐	☐	☐	☐	☐	☐	☐
B5	Hacer ejercicio físico	☐	☐	☐	☐	☐	☐	☐
B10	Aparcar con facilidad	☐	☐	☐	☐	☐	☐	☐
B11	Minimizar el riesgo de que roben o dañen mi modo de transporte	☐	☐	☐	☐	☐	☐	☐
B6	Contaminar menos el medio ambiente	☐	☐	☐	☐	☐	☐	☐
B19	No respirar aire contaminado	☐	☐	☐	☐	☐	☐	☐
B12	No causar molestias a los peatones	☐	☐	☐	☐	☐	☐	☐
B13	No depender mucho de la climatología	☐	☐	☐	☐	☐	☐	☐
B14	Vestir con ropa adecuada para mis actividades	☐	☐	☐	☐	☐	☐	☐
B15	Causar una buena impresión a los demás	☐	☐	☐	☐	☐	☐	☐
B16	No llegar estresado a mi destino	☐	☐	☐	☐	☐	☐	☐
B17	Divertirme durante el camino	☐	☐	☐	☐	☐	☐	☐
B18	No llegar sudado a mi destino	☐	☐	☐	☐	☐	☐	☐
B20	Relajarme durante el trayecto	☐	☐	☐	☐	☐	☐	☐

Norma descriptiva, validación social (EPx_tel)

G. ¿Hasta qué punto cree que los siguientes grupos de personas utilizan la bicicleta para desplazarse al lugar de trabajo/estudio en Vitoria-Gasteiz?

		No se utiliza nada o casi nada		Se utiliza moderadamente			Se utiliza mucho	
		0	1	2	3	4	5	6
G1	Los jóvenes	☐	☐	☐	☐	☐	☐	☐
G2	Mis familiares	☐	☐	☐	☐	☐	☐	☐
G3	Mis amigos	☐	☐	☐	☐	☐	☐	☐
G4	Mis compañeros del lugar de trabajo o estudio	☐	☐	☐	☐	☐	☐	☐
G6	Los inmigrantes	☐	☐	☐	☐	☐	☐	☐

H. ¿Hasta qué punto le parece adecuado utilizar la bicicleta para desplazarse al lugar de trabajo o estudio?

Nada adecuado		Moderadamente adecuado			Totalmente adecuado	
0	1	2	3	4	5	6
☐	☐	☐	☐	☐	☐	☐

Norma subjetiva (EPx_tel)

NO bici

**C. Imagínese que decidiera desplazarse en bici a su lugar de trabajo/estudio...
¿En qué grado se mostrarían de acuerdo los siguientes grupos de personas?**

SÍ bici

**Respecto a su decisión de desplazarse en bici a su lugar de trabajo/estudio...
¿En qué grado se muestran de acuerdo los siguientes grupos de personas?**

5

¿En qué grado se muestran de acuerdo los siguientes grupos de personas?

		Nada de acuerdo		Moderadamente de acuerdo		Totalmente de acuerdo		
		0	1	2	3	4	5	6
C1	Mi familia	☐	☐	☐	☐	☐	☐	☐
C2	Mis amigos	☐	☐	☐	☐	☐	☐	☐
C4	Los compañeros de mi lugar de trabajo o estudio	☐	☐	☐	☐	☐	☐	☐

D. Y, ¿cómo valora la opinión de estas personas a este respecto? La considero...

		Nada importante		Moderadamente importante		Muy importante		
		0	1	2	3	4	5	6
D1	La de mi familia	☐	☐	☐	☐	☐	☐	☐
D2	La de mis amigos	☐	☐	☐	☐	☐	☐	☐
D4	La de los compañeros de mi lugar de trabajo o estudio	☐	☐	☐	☐	☐	☐	☐

Control conductual percibido – Controlabilidad (EPx_tel)**E. Indique hasta qué punto está Ud. de acuerdo con las siguientes afirmaciones:**

		Nada de acuerdo		Moderadamente de acuerdo				Totalmente de acuerdo	
		0	1	2	3	4	5	6	
E1	Las infraestructuras existentes a lo largo de mi trayecto al lugar de trabajo/estudio (carriles, pistas y aceras bici) facilitarían/facilitan mi desplazamiento en bici	☐	☐	☐	☐	☐	☐	☐	
E2	En mi lugar de trabajo o estudio podría/puedo aparcar la bicicleta con seguridad	☐	☐	☐	☐	☐	☐	☐	
E3	En mi casa podría/puedo aparcar la bicicleta con seguridad	☐	☐	☐	☐	☐	☐	☐	
E5	En mi trayecto al lugar de trabajo/estudio hay cuestas, desniveles, subidas, que dificultarían/dificultan el uso habitual de la bicicleta	☐	☐	☐	☐	☐	☐	☐	
E6	La distancia que tendría/tengo que recorrer para mi trayecto al lugar de trabajo/estudio es adecuada para ir en bicicleta	☐	☐	☐	☐	☐	☐	☐	
E7	El tráfico a lo largo de mi trayecto al lugar de trabajo/estudio me permitiría/permite desplazarme en bicicleta por la calzada junto a los coches	☐	☐	☐	☐	☐	☐	☐	

Control conductual percibido – Autoeficacia (EPx_tel)**F. Indique hasta qué punto se consideraría /considera Ud. capaz de realizar las siguientes tareas:**

		Nada capaz		Moderadamente capaz				Totalmente capaz	
		0	1	2	3	4	5	6	
F1	Conducir su bicicleta a través del tráfico	☐	☐	☐	☐	☐	☐	☐	
F2	Aparcar su bicicleta de forma segura para evitar robos	☐	☐	☐	☐	☐	☐	☐	
F3	Realizar controles periódicos de la bicicleta para mantenerla en buen estado.	☐	☐	☐	☐	☐	☐	☐	
F4	Arreglar un pinchazo en una rueda de la bicicleta	☐	☐	☐	☐	☐	☐	☐	
F5	Utilizar elementos de protección personal	☐	☐	☐	☐	☐	☐	☐	
F6	Realizar las maniobras en bicicleta con seguridad	☐	☐	☐	☐	☐	☐	☐	
F7	Subir cuestas o desniveles con la bicicleta	☐	☐	☐	☐	☐	☐	☐	
F8	Planificar la ruta para desplazarse	☐	☐	☐	☐	☐	☐	☐	
F9	Interpretar las señales de circulación y la normativa vial	☐	☐	☐	☐	☐	☐	☐	

Identidad social (EPx_tel)**S. Por favor, señale su grado de acuerdo respecto a las siguientes afirmaciones:**

		Nada de acuerdo		Moderadamente de acuerdo				Totalmente de acuerdo	
		0	1	2	3	4	5	6	
S1	Me identifico con “los ciclistas”	☐	☐	☐	☐	☐	☐	☐	
S2	Me veo a mí mismo como “ciclista”	☐	☐	☐	☐	☐	☐	☐	
S3	Creo que tengo cosas en común con “los ciclistas”	☐	☐	☐	☐	☐	☐	☐	

Preguntas socio-económicas

S1. Sexo: 1. Hombre 2. Mujer
S2. Edad: _____
S3. Nacionalidad: 1. Estado español 2. Otra: _____
S4. Nº de personas que viven en su hogar (incluyendo Usted): _____ personas (incluyendo Usted)
S5a. Situación en la vivienda <i>(leer)</i> 0. Padre/Madre 1. Hijo/a 2. Cónyuge o pareja sin hijos o con estos fuera del hogar 3. Sin lazos familiares (ej. solo/a, piso compartido, etc.) 4. Otras situaciones: _____
S5b. Si (5a=1); ¿tiene hijos menores de 12 años? 1. Sí 2. No
S6. ¿Cuál es su nivel de estudios terminados? <i>(leer)</i> 1. Ninguno 2. EGB/GRADUADO escolar 3. Bachillerato superior/BUP/COU 4. Formación profesional 5. Estudios Universitarios
S7. ¿Puede decirme el rango de ingresos mensuales medios en el hogar? (solo en EP3_tel) 1. < 1.000€ 2. 1.000 - 2.000€ 3. 2.000 - 3.000€ 4. 3.000 - 4.000€ 5. > 4.000€ 6. Ns/Nc
S8. ¿Tendría algún comentario que hacer?: _____(transcripción rápida)
S9. ¿Estaría disponible a ser contactado directamente por los investigadores de la Universidad Politécnica de Madrid para una entrevista personal a lo largo de este año? 1. Sí 2. No

Le comunico el número del Cupón para que lo apunte en él y así poder participar en la extracción de premios. El número del cupón es: *número asignado*

Muchas gracias por su colaboración.

Recordar 2ª y 3ª ola...
FIN

Comentarios entrevistador: _____

Appendix E – Questionnaire of the household travel survey including bicycle indicators in Vitoria-Gasteiz

ESTUDIO DE MOVILIDAD URBANA – VITORIA-GASTEIZ MAYO 2014																															
<p>Buenos/as días/tardes, soy _____, entrevistador/a del Ayuntamiento de Vitoria-Gasteiz. Le llamamos desde nuestro Call Center de Salburua, y estamos realizando una encuesta para un estudio sobre movilidad urbana. Con sus respuestas contribuiría a mejorar la planificación de la movilidad de la ciudad. Además le informamos de que entre los participantes en esta encuesta se sorteará un Tablet o caja regalo de estancia de fin de semana. ¿Podría atenderme unos minutos? En caso de requerir más información sobre la veracidad del proyecto diríjase al 010 de información municipal.</p> <p>Como ya sabe, de acuerdo con la LEY DE PROTECCIÓN DE DATOS y el código CCI ESOMAR, toda la información que nos facilite en este cuestionario será tratada exclusivamente con fines estadísticos no pudiendo ser utilizada de forma nominal ni facilitada a terceros.</p> <p>En el cuestionario NO HAY RESPUESTAS VERDADERAS NI FALSAS, conteste siempre la respuesta que considere que refleja mejor sus opiniones o gustos.</p>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> GRUPOS DE PREGUNTAS: G – Preguntas GENERALES S – Preguntas SOCIOECONÓMICAS M – Preguntas DISPONIBILIDAD DE MODOS B – Preguntas sobre BICICLETA P – Preguntas del DIARIO DE VIAJES </div> <div style="border: 1px solid black; padding: 5px; text-align: center;"> VG = Vitoria-Gasteiz </div>																														
<p>Variables automáticas (G1-G6)</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 15%; border: 1px solid black;">G1</td> <td style="width: 45%; border: 1px solid black;">Nº Encuesta</td> <td style="width: 10%; border: 1px solid black;"></td> <td style="width: 10%; border: 1px solid black;"></td> <td style="width: 10%; border: 1px solid black;"></td> <td style="width: 10%; border: 1px solid black;"></td> </tr> <tr> <td style="border: 1px solid black;">G2</td> <td style="border: 1px solid black;">Día de la encuesta</td> <td style="border: 1px solid black;"></td> <td style="border: 1px solid black;"></td> <td style="border: 1px solid black;"></td> <td style="border: 1px solid black;"></td> </tr> <tr> <td style="border: 1px solid black;">G3</td> <td style="border: 1px solid black;">Dirección de residencia</td> <td style="border: 1px solid black;"></td> <td colspan="3" style="border: 1px solid black; text-align: center;">Verificar la dirección, si no coincide (no vive en lugar al que se llama): NO VÁLIDO</td> </tr> <tr> <td style="border: 1px solid black;">G4</td> <td style="border: 1px solid black;">Distrito</td> <td style="border: 1px solid black;"></td> <td colspan="3" rowspan="3" style="border: 1px solid black; padding: 5px; text-align: center;"> AUTOMÁTICOS a partir de la dirección de residencia y la equivalencia CALLEJERO: (Distritos/Secciones Y Zonas de transporte) </td> </tr> <tr> <td style="border: 1px solid black;">G5</td> <td style="border: 1px solid black;">Sección</td> <td style="border: 1px solid black;"></td> </tr> <tr> <td style="border: 1px solid black;">G6</td> <td style="border: 1px solid black;">Zona de transporte</td> <td style="border: 1px solid black;"></td> </tr> </table>		G1	Nº Encuesta					G2	Día de la encuesta					G3	Dirección de residencia		Verificar la dirección, si no coincide (no vive en lugar al que se llama): NO VÁLIDO			G4	Distrito		AUTOMÁTICOS a partir de la dirección de residencia y la equivalencia CALLEJERO: (Distritos/Secciones Y Zonas de transporte)			G5	Sección		G6	Zona de transporte	
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SOCIOECONÓMICAS															
MIEMBRO SELECCIONADO															
<p>S1. Sexo (no preguntar, anotar)</p> <p>1. Hombre 2. Mujer</p>															
<p>S2. EDAD. Edad _____ (numérico) S2 (grupo de edad)</p> <p>Menor de 6 años: NO VÁLIDO</p> <p>Si la persona NO interesa por cumplimiento de cuotas, pero ya ha accedido a ser encuestada preguntar resto de SOCIOECONÓMICAS, para que no sea muy brusco.</p>															
<p>S3. ¿Cuál es su situación profesional?</p> <p>Si la persona estudia y trabaja a la vez que indique la actividad principal (la que realice más días a la semana) (leer)</p> <table border="1"> <tr> <td>Si S2 <65</td> <td>Si S2 mayor o igual a 65</td> </tr> <tr> <td>1. Estudiante</td> <td>4. Jubilado/a o pensionista</td> </tr> <tr> <td>2. Ocupado/a</td> <td>2. Ocupado/a</td> </tr> <tr> <td>3. Desempleado/a</td> <td>1. Estudiante</td> </tr> <tr> <td>4. Jubilado/a o pensionista</td> <td>5. Trabajo doméstico</td> </tr> <tr> <td>5. Trabajo doméstico</td> <td>3. Desempleado/a</td> </tr> <tr> <td>6. Otras situaciones</td> <td>6. Otras situaciones</td> </tr> </table>		Si S2 <65	Si S2 mayor o igual a 65	1. Estudiante	4. Jubilado/a o pensionista	2. Ocupado/a	2. Ocupado/a	3. Desempleado/a	1. Estudiante	4. Jubilado/a o pensionista	5. Trabajo doméstico	5. Trabajo doméstico	3. Desempleado/a	6. Otras situaciones	6. Otras situaciones
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<p>S3_OT (especificación de otras situaciones)</p> <p>Si S3 = 2</p> <p>S4. Por su profesión, ¿se ve obligado a viajar constantemente en coche, furgoneta o camión propio o de la empresa?</p> <p>Si toda la jornada conduciendo ininterrumpidamente o paros técnicos (fin de la encuesta, no se le pregunta por trayectos) Tampoco resulta computable a efectos de muestra, quedaría apartada.</p> <p>1. Sí 2. No</p>															
<p>S4_1 (en blanco por un filtro)</p>															

DISPONIBILIDAD DE MODOS		
<p>M1. ¿Tiene permiso de conducir coche?</p> <p>1. Sí 2. No</p>	<p>M5. ¿Dispone de moto?</p> <p>1. Sí (Propietario/conductor, Acompañante, Usuario no propietario)</p> <p>2. No</p> <p>Si M5 = 1</p> <p>M6. ¿Dónde aparca la moto en su lugar de residencia? (si tiene varias hablamos siempre de la moto que más utiliza) (leer)</p> <p>1. En garaje (En el edificio de residencia o en otro de las inmediaciones)</p> <p>2. En la calle</p>	<p>M7. ¿Sabe montar en bicicleta?</p> <p>1. Sí 2. No</p> <p>M8. ¿Dispone de bicicleta? (preguntar aunque no sepa montar, adaptar)</p> <p>1. Sí 2. No</p> <p>Si M8 = 1</p> <p>M9. ¿Dónde aparca la bicicleta en su lugar de residencia? (si tiene varias hablamos siempre de la bicicleta que más utiliza) (leer)</p> <p>1. Dentro de la vivienda</p> <p>2. En un cuarto de bici, garaje o trastero en el edificio de residencia (preguntar que concrete)</p> <p>2.1. A nivel de calle</p> <p>2.2. En otra planta</p> <p>3. En otro estacionamiento seguro</p> <p>4. En la calle</p> <p>M9_1: A nivel de calle o en otra planta</p>

FRECUENCIA Y EXPERIENCIA DE USO POR DIFERENTES MOTIVOS				BICICLETA		NORMA SOCIAL	
Si M7 = 1 Y M8 = 1 ¿Cuántas veces utilizó la bicicleta en la última semana y en el último mes para realizar cada una de las siguientes actividades? (leer) B1 (variable interna de filtros)						Si O (B1a=0 Y B2a=0; B1b=0 Y B2b=0; B1c=0 Y B2c=0; B1d=0 Y B2d=0): UTILIZA LA BICICLETA COMO MODO DE TRANSPORTE Valore si los siguientes grupos de personas se muestran de acuerdo o no respecto al uso que usted hace de la bicicleta como modo de transporte (sin contar el uso por deporte o paseo), siendo 0 nada de acuerdo y 6 totalmente de acuerdo. Si Y (B1a=0 Y B2a=0; B1b=0 Y B2b=0; B1c=0 Y B2c=0; B1d=0 Y B2d=0): NO UTILIZA LA BICICLETA COMO MODO DE TRANSPORTE Valore si los siguientes grupos de personas se mostrarían de acuerdo o no respecto al posible uso que usted podría hacer de la bicicleta como modo de transporte (sin contar el uso por deporte o paseo), siendo 0 nada de acuerdo y 6 totalmente de acuerdo.	
Última semana (numérico) B1a Si S3 = 2 Ir al trabajo B1b Si S3 = 1 Ir a lugar de estudio B1c Gestiones, médico, compras, visitas, quedar con amigos, ir al cine... B1e Hacer deporte o pasear				Último mes (numérico) B2a B2b B2c B2e		Nada de acuerdo 0 1 2 3 4 5 6 Totalmente de acuerdo	
B0: sumatorio de todas las B1 y B2 menos las "e" Si M7 = 1 Y M8 = 1 Y O (B1a=0 Y B2a=0; B1b=0 Y B2b=0; B1c=0 Y B2c=0; B1d=0 Y B2d=0; B1e=0 Y B2e=0) Ó Si M7 = 1 Y M8 = 2							
¿Ha utilizado alguna vez la bicicleta, aunque sea hace tiempo, para (adaptar y leer) B3A_1/B3B_1 Si Y [S3 = 2; (B1a=0; B2a=0)] Ir al trabajo B3A_2/B3B_2 Si Y [S3 = 1; (B1b=0; B2b=0)] Ir a lugar de estudio B3A_3/B3B_3 Si Y (B1c=0; B2c=0) Gestiones, médico, compras, visitas, quedar con amigos, ir al cine... B3A_4/B3B_4 Si Y (B1e=0; B2e=0) Hacer deporte o pasear				1. No, nunca 2. Si, alguna vez 3. Si, con regularidad 1. No, nunca 2. Si, alguna vez 3. Si, con regularidad 1. No, nunca 2. Si, alguna vez 3. Si, con regularidad 1. No, nunca 2. Si, alguna vez 3. Si, con regularidad		INSISTIR PARA QUE SEA EL ENCUESTADO EL QUE DE UN NÚMERO No lo apoyan nada o nada No lo ven nada bien Le apoyan mucho Lo ven muy bien Totalmente de acuerdo Poco de acuerdo Moderadamente de acuerdo Bastante de acuerdo Totalmente de acuerdo (Que considere bien el número) Le apoyan muy poco Lo ven bastante bien Le apoyan bastante	
¿... y qué importancia le da usted a la opinión de estas personas? En una escala de 0 a 6... (La opinión de estas personas sobre que el encuestado use o pueda usar la bicicleta)				Nada de importante 0 1 2 3 4 5 6 Muy importante		INSISTIR PARA QUE SEA EL ENCUESTADO EL QUE DE UN NÚMERO Le da comportamente igual o que opina Valora esa opinión más o menos Valora esa opinión mucho Valora esa opinión poco Nada importante Moderadamente importante Muy importante Poco importante Bastante importante Totalmente importante (Que considere bien el número) Valora esa opinión poco Valora esa opinión bastante	

PERCEPCIONES																															
<p>BICICLETA (contestar solo a 1 de las 2 columnas)</p> <p>[MISMO FILTRO QUE PARA LA B4, cuando (UTILIZA LA BICICLETA COMO MODO DE TRANSPORTE)]</p> <p>B6A Pensando en sus desplazamientos habituales en bicicleta (sin contar el uso por deporte o paseo), indique hasta qué punto está de acuerdo o en desacuerdo con las siguientes afirmaciones:</p> <p>RECORDAR que la escala va de 0 a 6 siendo:</p> <ul style="list-style-type: none"> - 1 Me desplazo con rapidez - 2 Llego sudado a mi destino - 3 Sé cuánto tardar en llegar - 4 Hay conflictos con los peatones - 5 El trayecto en bici me relaja y divierte - 6 No dependo de autobuses ni tranvías - 7 Me estresa circular con los coches - 8 Contamino menos el medio ambiente - 9 Me condiciona mucho la climatología - 10 Hago ejercicio físico - 11 Tengo mucho riesgo de sufrir un accidente - 12 Es más barato que otros modos de transporte - 13 Tengo flexibilidad de horarios y rutas - 14 Temo que me roben o dañen la bici <p>INSISTIR PARA QUE SEA EL ENCUESTADO EL QUE DE UN NÚMERO</p> <table border="1"> <tr> <td>COMPLETAMENTE NO</td> <td>MÁS O MENOS</td> <td>COMPLETAMENTE SÍ</td> </tr> <tr> <td>Nada de acuerdo</td> <td>Moderadamente de acuerdo</td> <td>Totalmente de acuerdo</td> </tr> <tr> <td>0</td> <td>1 2 3 4 5 6</td> <td></td> </tr> <tr> <td>Poco de acuerdo (Que concreten ellos el número)</td> <td>Bastante de acuerdo (Que concreten ellos el número)</td> <td></td> </tr> <tr> <td>UN POCO SÍ</td> <td>BASTANTE SÍ</td> <td></td> </tr> </table>	COMPLETAMENTE NO	MÁS O MENOS	COMPLETAMENTE SÍ	Nada de acuerdo	Moderadamente de acuerdo	Totalmente de acuerdo	0	1 2 3 4 5 6		Poco de acuerdo (Que concreten ellos el número)	Bastante de acuerdo (Que concreten ellos el número)		UN POCO SÍ	BASTANTE SÍ		<p>B6B Teniendo en cuenta la posibilidad de utilizar la bicicleta como modo de transporte (no para hacer deporte o paseo), indique hasta qué punto está de acuerdo o en desacuerdo con las siguientes afirmaciones:</p> <p>RECORDAR que la escala va de 0 a 6 siendo:</p> <ul style="list-style-type: none"> - 1 Me desplazaría con rapidez - 2 Llegaría sudado a mi destino - 3 Sabría cuánto tardaría en llegar - 4 Habría conflictos con los peatones - 5 El trayecto en bici me relajaría y divertiría - 6 No dependería de autobuses ni tranvías - 7 Me estresaría circular con los coches - 8 Contaminaría menos el medio ambiente - 9 Me condicionaría mucho la climatología - 10 Haría ejercicio físico - 11 Tendría mucho riesgo de sufrir un accidente - 12 Sería más barato que otros modos de transporte - 13 Tendría flexibilidad de horarios y rutas - 14 Temería que me robaran o dañasen la bici <p>INSISTIR PARA QUE SEA EL ENCUESTADO EL QUE DE UN NÚMERO</p> <table border="1"> <tr> <td>COMPLETAMENTE NO</td> <td>MÁS O MENOS</td> <td>COMPLETAMENTE SÍ</td> </tr> <tr> <td>Nada de acuerdo</td> <td>Moderadamente de acuerdo</td> <td>Totalmente de acuerdo</td> </tr> <tr> <td>0</td> <td>1 2 3 4 5 6</td> <td></td> </tr> <tr> <td>Poco de acuerdo (Que concreten ellos el número)</td> <td>Bastante de acuerdo (Que concreten ellos el número)</td> <td></td> </tr> <tr> <td>UN POCO SÍ</td> <td>BASTANTE SÍ</td> <td></td> </tr> </table>	COMPLETAMENTE NO	MÁS O MENOS	COMPLETAMENTE SÍ	Nada de acuerdo	Moderadamente de acuerdo	Totalmente de acuerdo	0	1 2 3 4 5 6		Poco de acuerdo (Que concreten ellos el número)	Bastante de acuerdo (Que concreten ellos el número)		UN POCO SÍ	BASTANTE SÍ	
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<p>B7A En qué grado los siguientes aspectos limitan sus desplazamientos habituales en bicicleta (sin contar el uso por deporte o paseo)?</p> <p>RECORDAR que la escala va de 0 a 6 siendo:</p> <ul style="list-style-type: none"> - 1 La carencia de vías ciclistas o bidegorris - 2 Distancias largas - 3 No tener aparcamiento seguro - 4 Cuestas o desniveles - 5 Conducir su bicicleta en medio del tráfico - 6 No tener duchas o taquillas - 7 Realizar las maniobras ciclistas con seguridad - 8 Su condición física - 9 Arreglar un pinchazo de la bicicleta - 10 El uso del casco <p>Valore las siguientes afirmaciones:</p> <p>RECORDAR que la escala va de 0 a 6 siendo:</p> <p>B8A. En los próximos 6 meses tengo intención de <u>incrementar</u> mi uso de la bicicleta para mis desplazamientos habituales (sin contar deporte o paseo)</p> <ul style="list-style-type: none"> - B9_1 Desplazarse en bicicleta en Vitoria-Gasteiz es eficiente, cómodo y seguro - B9_2 Si instalasen un sistema de bicicletas públicas en Vitoria-Gasteiz, me abonaría 	<p>B7B En qué grado los siguientes aspectos <u>limitarían</u> su posible desplazamiento en bicicleta (sin contar el uso por deporte o paseo)?</p> <p>RECORDAR que la escala va de 0 a 6 siendo:</p> <ul style="list-style-type: none"> - 1 La carencia de vías ciclistas o bidegorris - 2 Distancias largas - 3 No tener aparcamiento seguro - 4 Cuestas o desniveles - 5 Conducir su bicicleta en medio del tráfico - 6 No tener duchas o taquillas - 7 Realizar las maniobras ciclistas con seguridad - 8 Su condición física - 9 Arreglar un pinchazo de la bicicleta - 10 El uso del casco <p>Valore las siguientes afirmaciones:</p> <p>RECORDAR que la escala va de 0 a 6 siendo:</p> <p>B8B. En los próximos 6 meses tengo intención de <u>comenzar a utilizar</u> la bicicleta para mis desplazamientos habituales (sin contar deporte o paseo)</p> <ul style="list-style-type: none"> - B9_1 Desplazarse en bicicleta en Vitoria-Gasteiz es eficiente, cómodo y seguro - B9_2 Si instalasen un sistema de bicicletas públicas en Vitoria-Gasteiz, me abonaría 																														

P0. Hemos acabado con las valoraciones. Ahora comentaremos los desplazamientos que hizo ayer. Empezamos por el primero....

1. Sí 2. No
Si P0 = 1, continuar
Si P0 = 2, saltar a S6

P0_ Observaciones. En caso de no realizar ningún trayecto ayer pedir motivo...

- Insistir en caso necesario en que SOLO los del día de ANTERIOR
- Anotar todos los desplazamientos del día anterior **LABORABLE** a la realización de la encuesta.
- Sólo se especifican los movimientos urbanos dentro de Vitoria. Por ejemplo, si va a Bilbao, no nos interesan los desplazamientos una vez llegue a Bilbao.
- Por cada desplazamiento se considerarán hasta 3 modos de transporte distintos hasta llegar al destino final por 1 MISMO motivo.

Variable automática	G7	Día de los desplazamientos	1. Lunes	2. Martes	3. Miércoles	4. Jueves
Sólo encuestar MARTES, MIÉRCOLES, JUEVES Y VIERNES (automática a partir del día de encuesta)						

P153 (variable interna de filtros)

Nº DEL VIAJE	DIRECCIÓN EXACTA		MOTIVO DEL VIAJE EN ORIGEN Y EN DESTINO	MODOS DE TRANSPORTE UTILIZADOS		MODOS DE TRANSPORTE DISPONIBLES										
EN ORDEN CORRELATIVO	¿El lugar del que salió estaba en Vitoria-Gasteiz?	<div> <div>1. SI</div> <div>2. No</div> </div>	<div> <div>1. Casa/ hogar/ residencia habitual</div> <div>2. Trabajo</div> <div>3. Estudios</div> <div>4. Compras</div> <div>5. Médico/hospital</div> <div>6. Visita amigo/familiar</div> <div>7. Acompañar personas/llevar colegio</div> <div>8. Diversión, comida/cena fuera de casa</div> <div>9. Gestiones de trabajo</div> <div>10. Gestiones personales</div> <div>11. Sin destino fijo o paseo</div> <div>12. 2ª residencia</div> </div>	<p>P13 ¿Qué modos de transporte utilizó para ir a ese lugar? Escuchar respuesta libre. Si no contesta leer listado de modos. Clickar los modos que correspondan</p> <table border="1"> <tr> <td>INDIVIDUALES</td> <td> <div>P13-1. A pie</div> <div>P13-2. Bicicleta</div> <div>P13-3. Taxi</div> <div>P13-4. Coche conductor</div> <div>P13-5. Coche acompañante</div> <div>P13-6. Moto</div> <div>P13-7. Camión o furgoneta</div> <div>P13-8. Bus urbano (TUVISA)</div> <div>P13-9. Tranvía</div> <div>P13-10. Bus escolar, de empresa o autocar</div> <div>P13-11. Autobús interurbano</div> <div>P13-12. Ferrocarril</div> <div>P13-13. Transporte colectivo bajo demanda</div> <div>P13-14. Otros individuales</div> <div>P13-15. Otros colectivos</div> </td> <td>0/1</td> </tr> <tr> <td>COLECTIVOS</td> <td></td> <td></td> </tr> <tr> <td>OTROS _</td> <td></td> <td></td> </tr> </table>		INDIVIDUALES	<div>P13-1. A pie</div> <div>P13-2. Bicicleta</div> <div>P13-3. Taxi</div> <div>P13-4. Coche conductor</div> <div>P13-5. Coche acompañante</div> <div>P13-6. Moto</div> <div>P13-7. Camión o furgoneta</div> <div>P13-8. Bus urbano (TUVISA)</div> <div>P13-9. Tranvía</div> <div>P13-10. Bus escolar, de empresa o autocar</div> <div>P13-11. Autobús interurbano</div> <div>P13-12. Ferrocarril</div> <div>P13-13. Transporte colectivo bajo demanda</div> <div>P13-14. Otros individuales</div> <div>P13-15. Otros colectivos</div>	0/1	COLECTIVOS			OTROS _			<p>P17_JERARQUIA. AUTOMÁTICA INTERNA:</p> <ul style="list-style-type: none"> Si de P13.1 a P13.15 se han clickado 1 modo: P17 = P13 (correspondiente) Si de P13.1 a P13.15 se han clickado 2 o más modos: P17 = Modo de transporte principal según jerarquía de modos (1-15) <div>Jerarquía de modos de transporte</div>	
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COLECTIVOS																
OTROS _																
<p>VIAJE 1 Tantas filas hasta que NO haya más viajes</p>	<div> <div>1. SI</div> <div>2. No</div> </div>	<div> <div>1. SI</div> <div>2. No</div> </div>	<p>Si sólo responde un modo (1-7 ó 14) MODOS INDIVIDUALES + OTROS individuales</p> <ul style="list-style-type: none"> ¿Utilizó algún otro modo de transporte para ese mismo desplazamiento? Preguntar tantas veces hasta que conteste NO 1. SI → ¿Me puede indicar cuál fue? Clickar en la tabla anterior 2. No <p>Si sólo responde un modo (7-13 ó 15) MODOS COLECTIVOS + OTROS colectivos</p> <ul style="list-style-type: none"> ¿Cómo accedió a la parada/estación? Clickar en la tabla anterior Y al bajarse del transporte público ¿Qué modo de transporte utilizó para llegar a su destino? Clickar en la tabla anterior <p>Si de P13.1 a P13.14 se han clickado 2 o más modos ¿Me puede indicar el orden de los modos que utilizó? PROGRAMAR para que no pase de pregunta hasta que se hayan seleccionado en esta pregunta tantos modos como los clickados en P13. Que aparezcan AUTOMÁTICAMENTE tantas filas como modos clickados en P13</p> <div> <div>Nº y NOMBRE</div> <div>Listado desplegable</div> </div> <table border="1"> <tr> <td>P14A 1ª</td> <td>Desplegable</td> <td>P15A</td> <td></td> </tr> <tr> <td>P14B 2ª</td> <td>Desplegable</td> <td>P15B</td> <td></td> </tr> <tr> <td>P14C 3ª</td> <td>Desplegable</td> <td>P15C</td> <td></td> </tr> </table>		P14A 1ª	Desplegable	P15A		P14B 2ª	Desplegable	P15B		P14C 3ª	Desplegable	P15C	
P14A 1ª	Desplegable	P15A														
P14B 2ª	Desplegable	P15B														
P14C 3ª	Desplegable	P15C														

Nº DEL VIAJE	SI P17 = O (4; 6; 7)		SI O (P13-7; P13-8) = 1		SI O P13-2= 1		PARA TODOS LOS MODOS				
	TRANSPORTE PRIVADO		TRANSPORTE PÚBLICO (BUS O TRANVÍA EN VITORIA)		BICICLETA						
APARCAMIENTO EN DESTINO			TÍTULO DE TRANSPORTE		USO DE LAS INFRAESTRUCTURAS URBANAS		APARCAMIENTO EN DESTINO				
¿Cómo aparcó su vehículo en su lugar de destino? (leer)			¿Qué tipo de billete utilizó? (leer)		Indique por dónde discurrió en su desplazamiento en bicicleta... (leer)		¿Cómo aparcó su bicicleta en su lugar de destino? (leer)				
EN ORDEN CORRELATIVO			1. Parking Gratuito / Centro Comercial 2. Zona Azul/ OTA 3. Parking propio o alquilado 4. Parking por horas 5. Doble fila 6. En la calle - libre		1. Billete sencillo, pago en efectivo 2. Billete sencillo, ida vuelta, pago en efectivo 3. Tarjeta BAT 4. BAT 30 días 5. BAT berezi 6. Otros: _____ (transcripción rápida)		1. Candeada a aparcabici 2. Candeada a mobiliario urbano 3. En un cuarto de bici, garaje o trastero 4. Dentro del lugar de destino (preguntar que concrete) 4.1. A nivel de calle 4.2. En otra planta				
								Señalar sólo 1 (la mayoritaria)			
								P21a	Por la calzada normal con los coches	Si/No	P22
								P21	Por calles con velocidad reducida o carril bici pintado	Si/No	
								P21	Por bidegorri o vía ciclista	Si/No	
VIAJE 1			Que aparezcan AUTOMÁTICAMENTE tantas filas como modos (P14a, P14b, P14c....) = (7 ó 8)		¿Y cuál en mayor medida?		P24. <input type="text"/>				
Tantas filas hasta que NO haya más viajes			<div>P19. <input type="text"/></div> <div>P20A <input type="text"/> P20A_OT <input type="text"/> P20B <input type="text"/> P20B_OT <input type="text"/> P20C <input type="text"/> P20C_OT <input type="text"/></div>				P25. <div>1. Si <input type="text"/> 2. No <input type="text"/></div>				

F100 (variable interna de filtros)

P26. Y el siguiente desplazamiento.... Preguntar tantas veces hasta que conteste NO

1. Si

2. No

P27. ¿Se correspondió con la vuelta del anterior que nos ha descrito?
(No preguntar en caso de que el anterior desplazamiento fuera de vuelta)

1. Si Reanudar por P4 (hora salida), P9 (hora llegada), P13 (modo) en adelante

2. No Reanudar por P1

OTRAS	
Para finalizar,	
G8. ¿Tendría algún comentario que hacer? _____ (transcripción rápida) (Los comentarios tienen que estar relacionados con los modos de transporte de Vitoria-Gasteiz)	
<p>Por último, agradecerle su participación y comentarle que nos gustaría informarle de los resultados de la encuesta por haber participado en ella. Además, como le dijimos, participará en un sorteo de un Tablet o caja regalo de estancia de fin de semana.</p> <p>Para comunicarle ambas cosas le agradeceríamos...</p>	
G9. ... nos facilitase su correo electrónico _____ Se lo repito... (En caso de que no disponga de email, solicitar el de algún familiar o persona de confianza)	
Si la persona reusa a participar en el sorteo, clicar G10. ☐	
G11. ¿Tendría inconveniente en que le contactáramos de nuevo para completar esta información en caso necesario? 1. Sí 2. No	

Appendix F – Summary of sequential ICLV models

ICLV models with 1 LV

Coefficients	Value	p-value
ASC-bicycle	-0.99	0.00
ASC-walking	3.26	0.00
ASC-public transport	0.04	0.62
ASC-car		
Cost	-0.61	0.00
Bicycle-time	-0.12	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.51	0.00
Walking-commuting	-0.13	0.04
Public transport-commuting	0.29	0.00

Coefficients	Value	p-value
ASC-bicycle	-4.99	0.00
ASC-walking	3.25	0.00
ASC-public transport	0.04	0.57
ASC-car		
Cost	-0.61	0.00
Bicycle-time	-0.14	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.06	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.02	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.70	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.29	0.00

200a_LV: Safety and comfort	1.01	0.00
300b_Sigma safety and comfort		
Gender (Male)	0.27	0.00
Age < 30 / > 49	0.02	0.60
Age 30-49 / > 49	-0.07	0.00
Professional situation (Worker)	0.23	0.00
Family status (Father/Mother)	-0.05	0.00
Income < 2000	-0.12	0.00
Know how to ride a bike (Yes)	0.16	0.00
Bicycle availability (Yes)	0.30	0.00
Commuting bike use last week (Yes)	0.14	0.00
Non-commuting bike use last week (Yes)	0.13	0.00
Sport bike use last week (Yes)	-0.02	0.31
Experience_commuting (Yes)	0.07	0.00
Experience_non-commuting (Yes)	0.15	0.00
Experience_sport (Yes)	0.06	0.07
Use of calmed roads (Yes)	-0.09	0.10
Use of cycleways (Yes)	0.10	0.02
Mostly using calmed roads (Yes)	0.15	0.03
Mostly using cycleways (Yes)	0.05	0.30
401a_No sweat		
401b_No conflicts with pedestrian	1.29	0.00
401c_No traffic stress	1.37	0.00
401d_Weather independent	0.85	0.00
401e_Low accident risk	1.42	0.00
401f_No theft risk	0.85	0.00

200b_LV: Direct advantages	1.47	0.00
300b_Sigma direct advantages		
Gender (Male)	0.01	0.80
Age < 30 / > 49	0.20	0.00
Age 30-49 / > 49	-0.01	0.52
Professional situation (Worker)	-0.25	0.00
Family status (Father/Mother)	0.06	0.01
Income < 2000	0.19	0.00
Know how to ride a bike (Yes)	0.08	0.02
Bicycle availability (Yes)	0.46	0.00
Commuting bike use last week (Yes)	0.16	0.00
Non-commuting bike use last week (Yes)	0.14	0.00
Sport bike use last week (Yes)	0.14	0.00
Experience_commuting (Yes)	0.24	0.00
Experience_non-commuting (Yes)	0.30	0.00
Experience_sport (Yes)	0.01	0.85
Use of calmed roads (Yes)	0.03	0.63
Use of cycleways (Yes)	0.19	0.00
Mostly using calmed roads (Yes)	0.14	0.13
Mostly using cycleways (Yes)	0.01	0.83
401a_Quick		
401b_Time reliable	0.79	0.00
401c_Relaxing	1.35	0.00
401d_Independent	0.87	0.00
401e_Flexible	0.63	0.00

Final log-likelihood:	-9,976
Rho bar for the init. model:	0.32
Sample size:	14,406
Number of estimated parameters:	17
CAIC:	20,131

Final log-likelihood:	-9,875
Rho bar for the init. model:	0.33
Sample size:	14,406
Number of estimated parameters:	17
CAIC:	19,930

INTEGRATING BICYCLE OPTION IN MODE CHOICE MODELS THROUGH LATENT VARIABLES

Coefficients	Value	p-value
ASC-bicycle	1.34	0.00
ASC-walking	3.25	0.00
ASC-public transport	0.04	0.62
ASC-car		
Cost	-0.60	0.00
Bicycle-time	-0.13	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.06	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.65	0.00
Walking-commuting	-0.13	0.04
Public transport-commuting	0.29	0.00

Coefficients	Value	p-value
ASC-bicycle	-1.15	0.00
ASC-walking	3.27	0.00
ASC-public transport	0.04	0.56
ASC-car		
Cost	-0.61	0.00
Bicycle-time	-0.13	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.59	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

200_LV: Awareness	-0.08	0.30
300b_Sigma awareness		
Gender (Male)	-0.17	0.00
Age $< 30 / > 49$	0.11	0.00
Age 30-49 / > 49	0.01	0.72
Professional situation (Worker)	-0.22	0.00
Family status (Father/Mother)	0.06	0.00
Income < 2000	0.10	0.00
Know how to ride a bike (Yes)	0.04	0.09
Bicycle availability (Yes)	0.05	0.01
Commuting bike use last week (Yes)	-0.03	0.25
Non-commuting bike use last week (Yes)	-0.03	0.15
Sport bike use last week (Yes)	0.08	0.00
Experience_commuting (Yes)	0.03	0.06
Experience_non-commuting (Yes)	-0.01	0.46
Experience_sport (Yes)	0.09	0.00
Use of calmed roads (Yes)	0.13	0.00
Use of cycleways (Yes)	0.07	0.09
Mostly using calmedroads (Yes)	-0.05	0.41
Mostly using cycleways (Yes)	-0.09	0.03
Healthy		
Cheap	0.97	0.00
Environmentally beneficial	0.72	0.00

200d_LV: External facilities	0.76	0.00
300b_Sigma external facilities		
Gender (Male)	0.65	0.00
Age $< 30 / > 49$	0.09	0.03
Age 30-49 / > 49	0.09	0.00
Professional situation (Worker)	0.17	0.00
Family status (Father/Mother)	-0.10	0.00
Income < 2000	-0.07	0.00
Know how to ride a bike (Yes)	0.27	0.00
Bicycle availability (Yes)	0.35	0.00
Commuting bike use last week (Yes)	0.17	0.00
Non-commuting bike use last week (Yes)	0.18	0.00
Sport bike use last week (Yes)	0.08	0.01
Experience_commuting (Yes)	0.10	0.00
Experience_non-commuting (Yes)	0.17	0.00
Experience_sport (Yes)	0.12	0.02
Use of calmed roads (Yes)	0.13	0.08
Use of cycleways (Yes)	0.23	0.00
Mostly using calmedroads (Yes)	0.04	0.71
Mostly using cycleways (Yes)	-0.09	0.20
401a_Cycleways		
401b_Short distance	1.05	0.00
401c_Safe parking	0.90	0.00
401d_Ride separate from the traffic	0.97	0.00
401e_Shower at destination	0.92	0.00

Final log-likelihood:	-10,151
Rho bar for the init. model:	0.31
Sample size:	14,406
Number of estimated parameters:	17
CAIC:	20,481

Final log-likelihood:	-9,920
Rho bar for the init. model:	0.32
Sample size:	14,406
Number of estimated parameters:	17
CAIC:	20,021

Coefficients	Value	p-value
ASC-bicycle	-1.53	0.00
ASC-walking	3.27	0.00
ASC-public transport	0.04	0.56
ASC-car		
Cost	-0.62	0.00
Bicycle-time	-0.12	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.05	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.66	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

Coefficients	Value	p-value
ASC-bicycle	0.92	0.00
ASC-walking	3.25	0.00
ASC-public transport	0.04	0.62
ASC-car		
Cost	-0.60	0.00
Bicycle-time	-0.13	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.06	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.65	0.00
Walking-commuting	-0.13	0.04
Public transport-commuting	0.29	0.00

200e_LV:Individual capacities	0.66	0.00
300b_Sigma individual capacities		
Gender (Male)	0.91	0.00
Age < 30 / > 49	0.33	0.00
Age 30-49 / > 49	0.33	0.00
Professional situation (Worker)	-0.03	0.56
Family status (Father/Mother)	-0.16	0.00
Income < 2000	-0.19	0.00
Know how to ride a bike (Yes)	0.35	0.00
Bicycle availability (Yes)	0.73	0.00
Commuting bike use last week (Yes)	0.11	0.02
Non-commuting bike use last week (Yes)	0.23	0.00
Sport bike use last week (Yes)	0.12	0.00
Experience_commuting (Yes)	0.28	0.00
Experience_non-commuting (Yes)	0.27	0.00
Experience_sport (Yes)	0.24	0.00
Use of calmed roads (Yes)	0.15	0.08
Use of cycleways (Yes)	0.28	0.00
Mostly using calmedroads (Yes)	0.05	0.69
Mostly using cycleways (Yes)	-0.07	0.39
401a_Hilliness		
401b_Manoeuvring	0.79	0.00
401c_Physical condition	1.35	0.00
401d_Fixing a puncture	0.87	0.00

200_LV:Subjective norm	0.02	0.29
300b_Sigma subjective norm		
Gender (Male)	-0.11	0.00
Age < 30 / > 49	0.51	0.00
Age 30-49 / > 49	0.18	0.00
Professional situation (Worker)	-0.06	0.32
Family status (Father/Mother)	0.09	0.01
Income < 2000	0.15	0.00
Know how to ride a bike (Yes)	0.18	0.00
Bicycle availability (Yes)	0.49	0.00
Commuting bike use last week (Yes)	0.08	0.14
Non-commuting bike use last week (Yes)	-0.06	0.17
Sport bike use last week (Yes)	0.19	0.00
Experience_commuting (Yes)	0.27	0.00
Experience_non-commuting (Yes)	0.34	0.00
Experience_sport (Yes)	0.29	0.00
Use of calmed roads (Yes)	-0.06	0.59
Use of cycleways (Yes)	-0.06	0.53
Mostly using calmedroads (Yes)	0.07	0.63
Mostly using cycleways (Yes)	0.25	0.01
Family		
Friends	1.09	0.00
Coworkers/Classmates	0.54	0.00

Final log-likelihood:	-9,899
Rho bar for the init. model:	0.33
Sample size:	14,406
Number of estimated parameters:	17
CAIC:	19,977

Final log-likelihood:	-10,151
Rho bar for the init. model:	0.31
Sample size:	14,406
Number of estimated parameters:	17
CAIC:	20,481

ICLV models with 2 LVs

Coefficients	Value	p-value
ASC-bicycle	-6.83	0.00
ASC-walking	3.26	0.00
ASC-public transport	0.04	0.57
ASC-car		
Cost	-0.62	0.00
Bicycle-time	-0.13	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.03	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.57	0.00
Walking-commuting	-0.13	0.03
Public transport-commuting	0.28	0.00

200a_LV:Safety and comfort	0.98	0.00
300b_Sigma safety and comfort		
Gender (Male)	0.27	0.00
Age $< 30 / > 49$	0.02	0.60
Age 30-49 / > 49	-0.07	0.00
Professional situation (Worker)	0.23	0.00
Family status (Father/Mother)	-0.05	0.00
Income < 2000	-0.12	0.00
Know how to ride a bike (Yes)	0.16	0.00
Bicycle availability (Yes)	0.30	0.00
Commuting bike use last week (Yes)	0.14	0.00
Non-commuting bike use last week (Yes)	0.13	0.00
Sport bike use last week (Yes)	-0.02	0.31
Experience_commuting (Yes)	0.07	0.00
Experience_non-commuting (Yes)	0.15	0.00
Experience_sport (Yes)	0.06	0.07
Use of calmed roads (Yes)	-0.09	0.10
Use of cycleways (Yes)	0.10	0.02
Mostly using calmedroads (Yes)	0.15	0.03
Mostly using cycleways (Yes)	0.05	0.30
401a_No sweat		
401b_No conflicts with pedestrian	1.29	0.00
401c_No traffic stress	1.37	0.00
401d_Weather independent	0.85	0.00
401e_Low accident risk	1.42	0.00
401f_No theft risk	0.85	0.00

200b_LV: Direct advantages	1.45	0.00
300b_Sigma direct advantages		
Gender (Male)	0.01	0.80
Age $< 30 / > 49$	0.20	0.00
Age 30-49 / > 49	-0.01	0.52
Professional situation (Worker)	-0.25	0.00
Family status (Father/Mother)	0.06	0.01
Income < 2000	0.19	0.00
Know how to ride a bike (Yes)	0.08	0.02
Bicycle availability (Yes)	0.46	0.00
Commuting bike use last week (Yes)	0.16	0.00
Non-commuting bike use last week (Yes)	0.14	0.00
Sport bike use last week (Yes)	0.14	0.00
Experience_commuting (Yes)	0.24	0.00
Experience_non-commuting (Yes)	0.30	0.00
Experience_sport (Yes)	0.01	0.85
Use of calmed roads (Yes)	0.03	0.63
Use of cycleways (Yes)	0.19	0.00
Mostly using calmedroads (Yes)	0.14	0.13
Mostly using cycleways (Yes)	0.01	0.83
401a_Quick		
401b_Time reliable	0.79	0.00
401c_Relaxing	1.35	0.00
401d_Independent	0.87	0.00
401e_Flexible	0.63	0.00

Final log-likelihood:	-9,726
Rho bar for the init. model:	0.34
Sample size:	14,406
Number of estimated parameters:	18
CAIC:	19,643

Coefficients	Value	p-value
ASC-bicycle	-1.69	0.00
ASC-walking	3.27	0.00
ASC-public transport	0.04	0.57
ASC-car		
Cost	-0.61	0.00
Bicycle-time	-0.12	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.53	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

200a_LV:Safety and comfort	0.55	0.00
300b_Sigma safety and comfort		
Gender (Male)	0.27	0.00
Age $< 30 / > 49$	0.02	0.60
Age 30-49 / > 49	-0.07	0.00
Professional situation (Worker)	0.23	0.00
Family status (Father/Mother)	-0.05	0.00
Income < 2000	-0.12	0.00
Know how to ride a bike (Yes)	0.16	0.00
Bicycle availability (Yes)	0.30	0.00
Commuting bike use last week (Yes)	0.14	0.00
Non-commuting bike use last week (Yes)	0.13	0.00
Sport bike use last week (Yes)	-0.02	0.31
Experience_commuting (Yes)	0.07	0.00
Experience_non-commuting (Yes)	0.15	0.00
Experience_sport (Yes)	0.06	0.07
Use of calmed roads (Yes)	-0.09	0.10
Use of cycleways (Yes)	0.10	0.02
Mostly using calmedroads (Yes)	0.15	0.03
Mostly using cycleways (Yes)	0.05	0.30
401a_No sweat		
401b_No conflicts with pedestrian	1.29	0.00
401c_No traffic stress	1.37	0.00
401d_Weather independent	0.85	0.00
401e_Low accident risk	1.42	0.00
401f_No theft risk	0.85	0.00

200d_LV:External facilities	0.57	0.00
300b_Sigma external facilities		
Gender (Male)	0.65	0.00
Age $< 30 / > 49$	0.09	0.03
Age 30-49 / > 49	0.09	0.00
Professional situation (Worker)	0.17	0.00
Family status (Father/Mother)	-0.10	0.00
Income < 2000	-0.07	0.00
Know how to ride a bike (Yes)	0.27	0.00
Bicycle availability (Yes)	0.35	0.00
Commuting bike use last week (Yes)	0.17	0.00
Non-commuting bike use last week (Yes)	0.18	0.00
Sport bike use last week (Yes)	0.08	0.01
Experience_commuting (Yes)	0.10	0.00
Experience_non-commuting (Yes)	0.17	0.00
Experience_sport (Yes)	0.12	0.02
Use of calmed roads (Yes)	0.13	0.08
Use of cycleways (Yes)	0.23	0.00
Mostly using calmedroads (Yes)	0.04	0.71
Mostly using cycleways (Yes)	-0.09	0.20
401a_Cyleways		
401b_Short distance	1.05	0.00
401c_Safe parking	0.90	0.00
401d_Ride separate from the traffic	0.97	0.00
401e_Shower at destination	0.92	0.00

Final log-likelihood:	-9,886
Rho bar for the init. model:	0.33
Sample size:	14,406
Number of estimated parameters:	18
CAIC:	19,962

Coefficients	Value	p-value
ASC-bicycle	-2.14	0.00
ASC-walking	3.27	0.00
ASC-public transport	0.04	0.56
ASC-car		
Cost	-0.62	0.00
Bicycle-time	-0.12	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.04	0.00
Bicycle-time*(30-49)	-0.05	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.58	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

200a_LV: Safety and comfort	0.58	0.00
300b_Sigma safety and comfort		
Gender (Male)	0.27	0.00
Age $< 30 / > 49$	0.02	0.60
Age 30-49 / > 49	-0.07	0.00
Professional situation (Worker)	0.23	0.00
Family status (Father/Mother)	-0.05	0.00
Income < 2000	-0.12	0.00
Know how to ride a bike (Yes)	0.16	0.00
Bicycle availability (Yes)	0.30	0.00
Commuting bike use last week (Yes)	0.14	0.00
Non-commuting bike use last week (Yes)	0.13	0.00
Sport bike use last week (Yes)	-0.02	0.31
Experience_commuting (Yes)	0.07	0.00
Experience_non-commuting (Yes)	0.15	0.00
Experience_sport (Yes)	0.06	0.07
Use of calmed roads (Yes)	-0.09	0.10
Use of cycleways (Yes)	0.10	0.02
Mostly using calmedroads (Yes)	0.15	0.03
Mostly using cycleways (Yes)	0.05	0.30
401a_No sweat		
401b_No conflicts with pedestrian	1.29	0.00
401c_No traffic stress	1.37	0.00
401d_Weather independent	0.85	0.00
401e_Low accident risk	1.42	0.00
401f_No theft risk	0.85	0.00

200e_LV: Individual capacities	0.52	0.00
300b_Sigma individual capacities		
Gender (Male)	0.91	0.00
Age $< 30 / > 49$	0.33	0.00
Age 30-49 / > 49	0.33	0.00
Professional situation (Worker)	-0.03	0.56
Family status (Father/Mother)	-0.16	0.00
Income < 2000	-0.19	0.00
Know how to ride a bike (Yes)	0.35	0.00
Bicycle availability (Yes)	0.73	0.00
Commuting bike use last week (Yes)	0.11	0.02
Non-commuting bike use last week (Yes)	0.23	0.00
Sport bike use last week (Yes)	0.12	0.00
Experience_commuting (Yes)	0.28	0.00
Experience_non-commuting (Yes)	0.27	0.00
Experience_sport (Yes)	0.24	0.00
Use of calmed roads (Yes)	0.15	0.08
Use of cycleways (Yes)	0.28	0.00
Mostly using calmedroads (Yes)	0.05	0.69
Mostly using cycleways (Yes)	-0.07	0.39
401a_Hilliness		
401b_Manoeuvring	0.79	0.00
401c_Physical condition	1.35	0.00
401d_Fixing a puncture	0.87	0.00

Final log-likelihood:	-9,855
Rho bar for the init. model:	0.33
Sample size:	14,406
Number of estimated parameters:	18
CAIC:	19,900

Coefficients	Value	p-value
ASC-bicycle	-5.99	0.00
ASC-walking	3.26	0.00
ASC-public transport	0.04	0.54
ASC-car		
Cost	-0.62	0.00
Bicycle-time	-0.13	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.06	0.00
Bicycle-time*(30-49)	-0.04	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.65	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

200b_LV: Direct advantages	1.28	0.00
300b_Sigma direct advantages		
Gender (Male)	0.01	0.80
Age $< 30 / > 49$	0.20	0.00
Age 30-49 / > 49	-0.01	0.52
Professional situation (Worker)	-0.25	0.00
Family status (Father/Mother)	0.06	0.01
Income < 2000	0.19	0.00
Know how to ride a bike (Yes)	0.08	0.02
Bicycle availability (Yes)	0.46	0.00
Commuting bike use last week (Yes)	0.16	0.00
Non-commuting bike use last week (Yes)	0.14	0.00
Sport bike use last week (Yes)	0.14	0.00
Experience_commuting (Yes)	0.24	0.00
Experience_non-commuting (Yes)	0.30	0.00
Experience_sport (Yes)	0.01	0.85
Use of calmed roads (Yes)	0.03	0.63
Use of cycleways (Yes)	0.19	0.00
Mostly using calmedroads (Yes)	0.14	0.13
Mostly using cycleways (Yes)	0.01	0.83
401a_Quick		
401b_Time reliable	0.79	0.00
401c_Relaxing	1.35	0.00
401d_Independent	0.87	0.00
401e_Flexible	0.63	0.00

200d_LV: External facilities	0.57	0.00
300b_Sigma external facilities		
Gender (Male)	0.65	0.00
Age $< 30 / > 49$	0.09	0.03
Age 30-49 / > 49	0.09	0.00
Professional situation (Worker)	0.17	0.00
Family status (Father/Mother)	-0.10	0.00
Income < 2000	-0.07	0.00
Know how to ride a bike (Yes)	0.27	0.00
Bicycle availability (Yes)	0.35	0.00
Commuting bike use last week (Yes)	0.17	0.00
Non-commuting bike use last week (Yes)	0.18	0.00
Sport bike use last week (Yes)	0.08	0.01
Experience_commuting (Yes)	0.10	0.00
Experience_non-commuting (Yes)	0.17	0.00
Experience_sport (Yes)	0.12	0.02
Use of calmed roads (Yes)	0.13	0.08
Use of cycleways (Yes)	0.23	0.00
Mostly using calmedroads (Yes)	0.04	0.71
Mostly using cycleways (Yes)	-0.09	0.20
401a_Cycleways		
401b_Short distance	1.05	0.00
401c_Safe parking	0.90	0.00
401d_Ride separate from the traffic	0.97	0.00
401e_Shower at destination	0.92	0.00

Final log-likelihood:	-9,731
Rho bar for the init. model:	0.34
Sample size:	14,406
Number of estimated parameters:	18
CAIC:	19,653

INTEGRATING BICYCLE OPTION IN MODE CHOICE MODELS THROUGH LATENT VARIABLES

Coefficients	Value	p-value
ASC-bicycle	-6.12	0.00
ASC-walking	3.26	0.00
ASC-public transport	0.04	0.55
ASC-car		
Cost	-0.62	0.00
Bicycle-time	-0.13	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.05	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.70	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

Coefficients	Value	p-value
ASC-bicycle	-1.81	0.00
ASC-walking	3.27	0.00
ASC-public transport	0.04	0.55
ASC-car		
Cost	-0.62	0.00
Bicycle-time	-0.12	0.00
Walking-time	-0.12	0.00
Motorised-time	-0.05	0.00
Bicycle-time*(<30)	0.05	0.00
Bicycle-time*(30-49)	-0.05	0.00
Walking-time*(<30)	-0.01	0.00
Walking-time*(30-49)	-0.04	0.00
Motorised-time*(<30)	0.02	0.00
Motorised-time*(30-49)	-0.03	0.00
Bicycle-commuting	0.63	0.00
Walking-commuting	-0.14	0.03
Public transport-commuting	0.28	0.00

200b_LV: Direct advantages	1.24	0.00
300b_Sigma direct advantages		
Gender (Male)	0.01	0.80
Age $< 30 / > 49$	0.20	0.00
Age 30-49 / > 49	-0.01	0.52
Professional situation (Worker)	-0.25	0.00
Family status (Father/Mother)	0.06	0.01
Income < 2000	0.19	0.00
Know how to ride a bike (Yes)	0.08	0.02
Bicycle availability (Yes)	0.46	0.00
Commuting bike use last week (Yes)	0.16	0.00
Non-commuting bike use last week (Yes)	0.14	0.00
Sport bike use last week (Yes)	0.14	0.00
Experience_commuting (Yes)	0.24	0.00
Experience_non-commuting (Yes)	0.30	0.00
Experience_sport (Yes)	0.01	0.85
Use of calmed roads (Yes)	0.03	0.63
Use of cycleways (Yes)	0.19	0.00
Mostly using calmedroads (Yes)	0.14	0.13
Mostly using cycleways (Yes)	0.01	0.83
401a_Quick		
401b_Time reliable	0.79	0.00
401c_Relaxing	1.35	0.00
401d_Independent	0.87	0.00
401e_Flexible	0.63	0.00

200d_LV:External facilities	0.41	0.00
300b_Sigma external facilities		
Gender (Male)	0.65	0.00
Age $< 30 / > 49$	0.09	0.03
Age 30-49 / > 49	0.09	0.00
Professional situation (Worker)	0.17	0.00
Family status (Father/Mother)	-0.10	0.00
Income < 2000	-0.07	0.00
Know how to ride a bike (Yes)	0.27	0.00
Bicycle availability (Yes)	0.35	0.00
Commuting bike use last week (Yes)	0.17	0.00
Non-commuting bike use last week (Yes)	0.18	0.00
Sport bike use last week (Yes)	0.08	0.01
Experience_commuting (Yes)	0.10	0.00
Experience_non-commuting (Yes)	0.17	0.00
Experience_sport (Yes)	0.12	0.02
Use of calmed roads (Yes)	0.13	0.08
Use of cycleways (Yes)	0.23	0.00
Mostly using calmedroads (Yes)	0.04	0.71
Mostly using cycleways (Yes)	-0.09	0.20
401a_Cycleways		
401b_Short distance	1.05	0.00
401c_Safe parking	0.90	0.00
401d_Ride separate from the traffic	0.97	0.00
401e_Shower at destination	0.92	0.00

200e_LV:Individual capacities	0.54	0.00
300b_Sigma individual capacities		
Gender (Male)	0.91	0.00
Age $< 30 / > 49$	0.33	0.00
Age 30-49 / > 49	0.33	0.00
Professional situation (Worker)	-0.03	0.56
Family status (Father/Mother)	-0.16	0.00
Income < 2000	-0.19	0.00
Know how to ride a bike (Yes)	0.35	0.00
Bicycle availability (Yes)	0.73	0.00
Commuting bike use last week (Yes)	0.11	0.02
Non-commuting bike use last week (Yes)	0.23	0.00
Sport bike use last week (Yes)	0.12	0.00
Experience_commuting (Yes)	0.28	0.00
Experience_non-commuting (Yes)	0.27	0.00
Experience_sport (Yes)	0.24	0.00
Use of calmed roads (Yes)	0.15	0.08
Use of cycleways (Yes)	0.28	0.00
Mostly using calmedroads (Yes)	0.05	0.69
Mostly using cycleways (Yes)	-0.07	0.39
401a_Hilliness		
401b_Manoeuvring	0.79	0.00
401c_Physical condition	1.35	0.00
401d_Fixing a puncture	0.87	0.00

200e_LV:Individual capacities	0.43	0.00
300b_Sigma individual capacities		
Gender (Male)	0.91	0.00
Age $< 30 / > 49$	0.33	0.00
Age 30-49 / > 49	0.33	0.00
Professional situation (Worker)	-0.03	0.56
Family status (Father/Mother)	-0.16	0.00
Income < 2000	-0.19	0.00
Know how to ride a bike (Yes)	0.35	0.00
Bicycle availability (Yes)	0.73	0.00
Commuting bike use last week (Yes)	0.11	0.02
Non-commuting bike use last week (Yes)	0.23	0.00
Sport bike use last week (Yes)	0.12	0.00
Experience_commuting (Yes)	0.28	0.00
Experience_non-commuting (Yes)	0.27	0.00
Experience_sport (Yes)	0.24	0.00
Use of calmed roads (Yes)	0.15	0.08
Use of cycleways (Yes)	0.28	0.00
Mostly using calmedroads (Yes)	0.05	0.69
Mostly using cycleways (Yes)	-0.07	0.39
401a_Hilliness		
401b_Manoeuvring	0.79	0.00
401c_Physical condition	1.35	0.00
401d_Fixing a puncture	0.87	0.00

Final log-likelihood:	-9,723
Rho bar for the init. model:	0.34
Sample size:	14,406
Number of estimated parameters:	18
CAIC:	19,637

Final log-likelihood:	-9,864
Rho bar for the init. model:	0.33
Sample size:	14,406
Number of estimated parameters:	18
CAIC:	19,919

Appendix G – Aggregate direct and cross elasticities

Elasticities show the percentage change in one variable (e.g. the probability of the bicycle) that is associated with a one-per cent change in another variable (e.g. associated with the bicycle –direct elasticity– or with the car –cross elasticity–). They were calculated for the ICLV-1 model, according to the following equations [see Train (2009)]:

$$\text{Direct elasticities: } E_{i,z_i} = \beta_z * z_i * (1 - P_i)$$

$$\text{Cross elasticities: } E_{i,z_j} = -\beta_z * z_j * P_j$$

Aggregate direct elasticities (E_{i,z_i})			Aggregate cross elasticities (E_{i,z_j})		
Variable (z_i)		Cycling	Variable (z_j)		Using the car
Bicycle-time	25 th percentile	0.00	Bicycle-time	25 th percentile	-0.12
	Mean	0.71		Mean	0.00
	75 th percentile	1.16		75 th percentile	-0.20
Variable (z_i)		Using the car	Variable (z_j)		Cycling
Car-cost	25 th percentile	0.02	Car-cost	25 th percentile	-0.06
	Mean	0.07		Mean	-0.27
	75 th percentile	0.09		75 th percentile	-0.34
Motorised-time	25 th percentile	0.02	Motorised-time	25 th percentile	-0.09
	Mean	0.05		Mean	-0.18
	75 th percentile	0.07		75 th percentile	-0.27

Scientific activities and contributions during the PhD

This doctoral thesis is part of a PhD process, which has consisted of the following research activities:

Projects

- TRANSBICI: Travel behaviour analysis for modelling the potential use of bicycle: transition towards a cycling city
Funding: Ministry of Science and Innovation, Spanish Government
- Demand, social impact and urban mobility analysis of the cycling network of Madrid
Funding: Council of Madrid (Spain)

Publications

- Muñoz, B., Daziano, R.A., and Monzon, A. Modelling the effect of policy measures for improving cycling for urban transport. Submitted to Transportation Research Part A: Policy and Practice. Track number TRA-2016-298.
- Muñoz, B., Monzon, A., and Daziano, R.A. The Increasing Role of Latent Variables in Modelling Bicycle Mode Choice. Published online in *Transport Reviews. A Transnational Transdisciplinary Journal*. DOI: 10.1080/01441647.2016.1162874.
- Muñoz, B., Monzon, A., and Lopez, E. (2016) Transition to a cyclable city: latent variables affecting bicycle commuting. *Transportation Research Part A: Policy and Practice*, 84, 4-17, DOI: 10.1016/j.tra.2015.10.006.
- Muñoz, B., Monzon, A., and Lois, D. (2013) Cycling Habits and Other Psychological Variables Affecting Commuting by Bicycle in Madrid, Spain. *Transportation Research Record: Journal of the Transportation Research Board*, 2382, 1-9, DOI: 10.3141/2382-01.

Papers at congresses

- Muñoz, B., Lopez, E., and Monzon, A. (June, 2014) Transition to a cyclable city: Policies and variables affecting cycling commuting. *Paper presented at the "XVIII Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística, PANAM2014"*. Santander (Spain). pp. 1-16. ISBN 978-84-617-0085-1.
- Muñoz, B., Monzon, A., and Lois, D. (January, 2013) Cycling Habits and Other Psychological Variables Affecting Commuting by Bicycle in City of Madrid. *Poster presented at the "Transportation Research Board 92th Annual Meeting"*. Washington D.C. (USA)

- Muñoz, B., Rondinella, G., and Monzon, A. (June, 2012) Analysis of the key factors for bicycle demand in the city centre of Madrid (Análisis de los factores clave para la demanda ciclista en el centro de Madrid). *Paper Presented at the “X Congreso de Ingeniería del Transporte CIT2012: Transporte innovador y sostenible de cara al siglo XXI”*. Granada (Spain). Page: 259. ISBN: 978-84-338-5402-5.

Papers at conferences and courses

- Muñoz, B. (May, 2015) Who and why do we use the bicycle in Vitoria-Gasteiz? Results from the Household Travel Survey of Vitoria-Gasteiz 2014 (¿Quiénes y para qué nos movemos en bicicleta en Vitoria-Gasteiz? Resultados de la Encuesta Domiciliaria de Movilidad de Vitoria-Gasteiz 2014). *Paper presented at the meeting of “XIV Semana De La Bicicleta, Vitoria-Gasteiz”*. Vitoria-Gasteiz (Spain).
- Muñoz, B. (September, 2014) Changes in mobility habits and attitudes towards the bicycle of the inhabitants of Vitoria-Gasteiz: third wave of the panel survey (Cambios en los hábitos de movilidad y en las actitudes hacia la bicicleta de los vitorianos: tercera ola de la encuesta panel). *Paper presented at the meeting of “Evolución de la percepción de la movilidad ciclista en Vitoria-Gasteiz 2013-2014” inside the European Mobility Week 2014*. Vitoria-Gasteiz (Spain).
- Muñoz, B. (September, 2013) Changes in mobility habits of the inhabitants of Vitoria-Gasteiz and their relationship with the bicycle (Cambios en los hábitos de movilidad de los vitorianos y en su relación con la bicicleta). *Paper presented at the meeting of “Evolución de la movilidad de ciclista en Vitoria-Gasteiz 2012-2013” inside the European Mobility Week 2013*. Vitoria-Gasteiz (Spain).
- Muñoz, B. (July, 2013) Habit and other psychological variables in bicycle mobility (El hábito y otras variables psicológicas en la movilidad ciclista). *Paper presented at the meeting of “Curso de Verano de la Universidad Politécnica de Madrid: Nuevas técnicas de planificación del transporte”*. La Granja-Segovia (Spain).
- Rondinella, G. and Muñoz, B. (September, 2012) The mobility of the inhabitants of Vitoria-Gasteiz and their relationship with the bicycle (La movilidad de los vitorianos y su relación con la bicicleta). *Paper presented at the meeting of “¿Por qué elegir la bici para movernos?” inside the European Mobility Week 2012*. Vitoria-Gasteiz (Spain).

Attended courses

- Introduction to computer science and programming using python. Edx-MITx. 2015
- Microeconometrics of discrete choice. Cornell University (USA). 2013

Research stays

- Host and supervisor: Transportation Systems Engineering group at Civil and Environmental Department, at Cornell University (USA) - Ricardo A. Daziano
Period: 1st of June – 31st of August 2013.
Funding: Ministry of Science and Innovation of Spain

- Host and supervisor: IFFSTAR-INRETS (France) - Francis Papon
Period: 1st-15th December 2011.
Funding: COST Action TU0804 Survey Harmonisation with New Technologies Improvements –SHANTI.

Teaching

- Course 2013-2014: Teaching practical classes in transport subjects of the degree of Civil Engineering, at the Polytechnic University of Madrid (UPM). 55 hours
- Course 2012-2013: Teaching practical classes in transport subjects of the degree of Civil Engineering, at the Polytechnic University of Madrid (UPM). 46 hours
- Course 2011-2012: Teaching practical classes in transport subjects of the degree of Civil Engineering, at the Polytechnic University of Madrid (UPM). 40 hours

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