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

**DETERMINING EXPLANATORY
FACTORS FOR ROAD DEMAND IN
INTERURBAN TOLL ROADS:
AN ASSERTED APPROACH**

DOCTORAL THESIS

JUAN GÓMEZ SÁNCHEZ

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

Madrid, 2016

**DEPARTAMENTO DE INGENIERÍA CIVIL:
TRANSPORTE Y TERRITORIO**
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EL PRESIENTE

LOS VOCALES

EL SECRETARIO

*A mi familia, mis padres y mi
hermano, y a María,
por su apoyo incondicional.*

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SUMMARY

Improving the knowledge of road demand behaviour and estimating more accurate traffic forecasts constitute critical aspects for the evaluation of transport policies and for the assessment of future investment needs. For this reason, stakeholders involved in road infrastructure management (governments, private operators, etc.) find it essential to identify the key parameters influencing road demand, as well as to quantify the relationships between traffic and certain explanatory variables. This is especially critical in the case of toll concession roads, since road infrastructure is directly financed through users' contributions. At this point, since tolls have become a mechanism increasingly adopted to fund road projects worldwide, exploring users' perceptions and willingness-to-pay towards toll facilities is playing a growing role in transport policy initiatives and road infrastructure viability.

The literature in the field of toll road infrastructure is scarce, particularly in the interurban context. Previous research have mainly focused on urban areas, while limited contributions have been made up to date to better understand mobility and users' behaviour in interurban roads, especially tolled ones. Moreover, the existing literature on interurban toll roads has left some issues to be investigated, mainly the identification of the socioeconomic variables better explaining the evolution of road demand over time. In this respect, GDP has usually been the only macroeconomic variable considered to analyse and forecast light and heavy vehicle demand, but this choice has been generally based on no further reason than the usual practice.

Based on the above considerations, the objective of this thesis is about providing knowledge for explaining road traffic demand over time as well as users' perceptions and willingness-to-pay in interurban roads, taking Spain as case study. The research involves analysis at both the macro and the micro level to provide insight regarding road use behavior in interurban roads, particularly tolled ones.

Particularly, a macro analysis is developed aimed at identifying those variables explaining road demand evolution over time in interurban toll roads. Based on a panel data methodology, this analysis is applied at the national level, for both light and heavy vehicle demand. Likewise, a micro analysis is conducted aimed at identifying the explanatory variables determining users' perceptions and willingness-to-pay in interurban toll roads, as well as exploring the relationship observed between these two concepts. The thesis yielded some interesting conclusions for both policymakers and practitioners in the area of road demand management.

RESUMEN

Un mejor conocimiento de la demanda de transporte por carretera y la realización de estimaciones de tráfico más precisas constituyen sin duda cuestiones esenciales en la evaluación de las políticas de transporte y en la planificación de las inversiones futuras. Por todo ello, para los diversos actores involucrados en la gestión de las infraestructuras viarias (administraciones públicas, operadores privados, etc.) resulta esencial poder identificar cuáles son los parámetros clave que influyen en la movilidad por carretera, así como cuantificar dichas relaciones. Esta cuestión es especialmente relevante en el caso de las infraestructuras de peaje, ya que éstas son financiadas directamente a través de los pagos efectuados por los usuarios. Asimismo, debido a la creciente adopción de mecanismos de tarificación en la financiación de infraestructuras a nivel internacional, el estudio de diferentes aspectos como las percepciones de los usuarios a los peajes o su disponibilidad a pagar está cobrando cada vez mayor relevancia a nivel de política de transporte.

La literatura académica en el ámbito de las infraestructuras de peaje es por el momento escasa, especialmente en lo que se refiere al contexto puramente interurbano. Las investigaciones previas se han centrado principalmente en analizar la tarificación en ámbitos urbanos, mientras que las contribuciones que analizan la movilidad y el comportamiento de los usuarios en contextos interurbanos son por el momento más limitadas, particularmente en lo que se refiere a vías de peaje. Asimismo, pueden identificarse distintos aspectos que precisan de un mayor desarrollo, principalmente la identificación de las variables macroeconómicas que mejor pueden explicar la evolución de la demanda de transporte a lo largo del tiempo. En este sentido, la pauta fundamental hasta el momento ha sido el empleo del PIB como variable predictora del tráfico, tanto para la demanda de vehículos ligeros y pesados, sin que dicha elección haya estado fundamentada más que en la práctica habitual.

Teniendo en consideración todo lo anterior, el objetivo de esta tesis es mejorar el conocimiento actual en la explicación de la evolución de la demanda de transporte por carretera a lo largo del tiempo, así como en la determinación de las percepciones de los usuarios y su disponibilidad a pagar en carreteras interurbanas, tomando España como caso de estudio. La investigación comprende dos análisis paralelos, tanto a nivel macro como micro, con el objetivo de realizar aportaciones al estado actual de la materia en relación al comportamiento de la demanda en carreteras interurbanas, principalmente aquéllas que se encuentran tarifadas.

En concreto, se realiza un análisis a nivel macro con el objetivo de identificar aquellas variables que permiten explicar la evolución de la demanda de transporte a lo largo del tiempo en carreteras de peaje interurbanas. Basado en una metodología econométrica de datos de panel, este estudio se ha circunscrito al ámbito nacional, tanto para la demanda de vehículos ligeros como para pesados. De manera paralela, se ha efectuado un análisis micro para determinar las variables explicativas que influyen en las percepciones y la disponibilidad a pagar de los usuarios de las vías de peaje en ámbito interurbano, así como para cuantificar dichas relaciones. La tesis obtiene conclusiones relevantes en el ámbito de la gestión de la demanda de tráfico, de utilidad tanto para planificadores del transporte como para profesionales del sector.

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1. INTRODUCTION

*"Economics is the science of explaining tomorrow why the predictions
you made yesterday did not come true today"*

(Laurence J. Peter)

Improving the knowledge of road demand behaviour and estimating more accurate traffic forecasts constitute critical aspects for the evaluation of transport policies and for the assessment of future investment needs. For this reason, stakeholders involved in road infrastructure management (governments, private operators, etc.) find it essential to identify the key parameters influencing road demand, as well as to quantify the relationships between traffic and certain explanatory variables. This is especially critical in the case of toll concession roads, since road infrastructure is directly financed through users' contributions. At this point, since tolls have become a mechanism increasingly adopted to fund road projects worldwide, exploring users' perceptions and willingness-to-pay towards toll facilities is playing a growing role in transport policy initiatives and road infrastructure viability.

The literature in the field of toll road infrastructure is scarce, particularly in the interurban context. Previous research have mainly focused on urban areas, mainly aimed at analysing the impact of congestion pricing policies on daily mobility, as well on travellers' choices between private car and public transport services. However, up to date limited contributions have been made to better understand mobility and users' behaviour in interurban roads, especially tolled ones. This Introduction chapter summarizes the current state of the art regarding road demand analysis in interurban toll roads, both through a macro approach and at the individual level. The ultimate goal of this introduction is to explore where the current thesis will contribute to fill the research gaps identified, and consequently propose a research approach to solve them.

The document is structured as follows. Section 1.1 briefly presents a theoretical approach to road mobility in interurban corridors, as well as the main

drivers influencing road traffic volume in this situation. Section 1.2 summarizes the state of the art regarding aggregate demand analysis over time in interurban roads, for both light and heavy vehicles. Although the focus is established on toll roads, current evidences for free interurban roads are also reviewed. Next, Section 1.3 presents the socioeconomic explanatory variables used up to date in the literature to determine road demand evolution in interurban roads. Section 1.4 summarizes the current literature regarding users' perceptions and willingness to pay in interurban toll roads, while Section 1.5 makes a special focus on regional analysis conducted up to date in the transport sector, particularly toll roads. Finally, Section 1.6 reviews the methodologies commonly applied in this field of research, while Sections 1.7 to 1.10 identify the research objectives and cites the paper included in the thesis.

1.1 Explaining road mobility in interurban corridors: a theoretical approach

In a theoretical way, an inter-city corridor between points A and B can be considered (see Figure 1.1). Mobility within this corridor may suppose to be determined mainly by two factors. First, we can mention the capacity of attraction and generation of trips for each origin-destination pair, which is strongly related to the socioeconomic environment, that is, the level of economic activity in the area. Secondly, mobility between these two points can be also influenced by the degree of impedance encountered when making a trip within this particular corridor. In this respect, not only physical factors such as distances can play a role, but also e.g. the quantity and quality of available modes of transport connecting the two cities.

Figure 1.1 includes a theoretical case, considering two cities A and B, each one with a certain potential of attraction and generation of trips. These cities are connected by different transport modes: air transport, rail services and road transport, in which different alternatives in terms of quality (high capacity/conventional) or payment required (free/tolled) could be considered. Figure 1.1 shows the most representative case, at least in Spain, in which an interurban toll road is competing with a free parallel road of lower quality within the same corridor.

Figure 1.1. Mobility within an interurban corridor: general case

Source: Author's elaboration

Likewise, the variable of final interest in our case –traffic volume in a particular road– is obtained after the interaction of four principal issues (see Tables 1.1 and 1.2):

- The global mobility within the corridor, which is strongly related to the capacity of generation and attraction of trips for the A-B pair and, consequently, to its socioeconomic conditions.
- The modal share, influenced by the services supplied through those alternative transport modes competing in the corridor. In this respect, different parameters such as travel time, generalized cost, comfort, reliability, etc. offered by each mode, play a major role in users' choices and, consequently, in demand split.
- Traffic diversion between the several roads available in the corridor, determined by differences in generalized costs for each alternative, road infrastructure attributes, users' characteristics (e.g. level of income), etc.
- Vehicle occupancy or vehicle use, mainly influenced by vehicle characteristics and mobility habits. For instance, practices like carpooling can reduce road traffic (veh-km), whereas they keep unchanged global mobility (travellers-km) within the corridor.

To sum up, vehicle traffic in a particular interurban road for a certain period t can be considered as a result of the classic four-stage model, described in detail in Ortúzar et al. (2011) and illustrated in Figure 1.2. This stepwise process is influenced by a series of explanatory variables X_i , as shown below. Therefore, it becomes necessary to develop a suitable identification of those key explanatory variables X_i in order to make more accurate traffic forecasts afterwards.

Table 1.1. Main parameters determining passenger mobility within a given corridor

PASSENGERS MOBILITY			Global mobility in the corridor	Modal share	Traffic diversion (road)	Vehicle occupancy
Socioeconomic variables	Macro parameters	GDP	X			
		Population	X			
		GDP per capita	X	*	X	*
		Employment	X	*	X	*
		Motorization	X	X		
Transport supply	Transport supply of alternative modes	Generalized cost	X	X		
		Travel time	X	X		
		Service quality	*	X		
	Road sector supply	Infrastructure quality	X	X	X	
		Generalized cost	*	X	X	*
		Toll	X	X	X	
		Fuel		X	X	
		Distance-speed		X	X	
Vehicle characteristics and mobility habits	Vehicle characteristics	Reliability		X	X	
		Services supplied		X	X	
	Mobility habits	Type of passenger vehicle	*		X	X
		Car sharing/Car pooling	*	X	X	X
		Teleworking	X		*	
		Legislation	*	*		

X: strong influence; *: weak influence. Source: Author's elaboration

Table 1.2. Main parameters determining freight mobility within a given corridor

FREIGHT MOBILITY			Global mobility in the corridor	Modal share	Traffic diversion (road)	Vehicle occupancy
Socioeconomic variables	Macro parameters	GDP	X			
		Population	X			
		GDP specific sectors	X	*		*
		Motorization	X	X		
		Foreign trade	X			
Transport supply	Transport supply of alternative modes	Generalized cost	X	X		
		Travel time	X	X		
		Service quality	*	X		
	Road sector supply	Infrastructure quality	X	X	X	
		Generalized cost	*	X	X	*
		Toll	X	X	X	
		Fuel		*	*	
		Distance-speed		X	X	
Vehicle characteristics and mobility habits	Vehicle characteristics	Reliability		X	X	
		Services supplied		X	X	
	Mobility habits	Type of freight vehicle	*	X	*	X
		Logistic organization	X	X		X
		Location of production & consumption centres	X			
		Legislation		*		

X: strong influence; *: weak influence. Source: Author's elaboration

$$\begin{aligned}
 \text{Road mobility}_{AB}(t) = & \\
 = & \text{Trips}_{\text{Corridor}}(X_i, t) * \text{Modal share}_{AB}(X_i, t) * \\
 & * \text{Traffic diversion}(X_i, t) * \text{Vehicle occupancy}(X_i, t)
 \end{aligned}
 \tag{1}$$

Tables 1.1 and 1.2 include a preliminary classification of explanatory parameters for estimating road mobility, distinguishing both passengers and freight demand. Likewise, they indicate the influence we may expect from each parameter in relation to different aspects dealing with transport demand in the corridor: global mobility, modal shift to alternative modes, traffic diversion between roads, etc. In this respect, a detailed example of modelling inter-city travel demand can be found in Kato et al. (2011) for the case of Japan, in which three sub-models are subsequently developed: trip generation/attraction, trip distribution and trip modal choice sub-model

Figure 1.2. The classic four-stage transport model

Source: Ortúzar and Willumsen (2011)

1.2 Traffic demand analysis over time in interurban roads

The evolution of road demand over time has generally been a matter of interest in transport economics, and numerous studies have been conducted in the last decades to estimate the influence of certain explanatory variables in travel demand

patterns. The general approach adopted by researchers is the use of statistical techniques, particularly econometric specifications, to model and analyse traffic evolution over time. These studies are aimed at quantifying the responsiveness of road traffic with respect to different explanatory factors, which can be measured through the concept of elasticity. By definition, the elasticity with regard to a certain explanatory variable X_k is calculated as the relative change in travel demand (D) induced by a relative change in X_k :

$$\varepsilon_k = \frac{\Delta D / D}{\Delta X_k / X_k} = \frac{X_k}{D} \frac{\Delta D}{\Delta X_k} \quad (2)$$

In line with the economic theory, the scientific literature in this field distinguishes between short-run and long-run elasticities. Then, the analyses aim to distinguish between traffic reactions right after a certain incidence/change in travel conditions (e.g. a sharp increase in fuel prices) and demand behaviour observed a considerable period of time after the change, that is, once greater flexibility in trip planning is possible for users.

Literature analyzing traffic evolution for light vehicle demand is quite extensive, particularly with regard to free roads. By contrast, research on toll roads contexts –especially, interurban roads– is still limited, and it has not been addressed in a somewhat deeper way until the last decade. Current evidence for light vehicle demand analysis is presented in Section 1.2.1. By contrast, literature on heavy vehicle demand has especially focused on modelling commodity or delivery movements, with a minor interest purely on traffic evolution. Current research for heavy vehicle demand analysis is summarized in Section 1.2.2.

1.2.1 Current evidence for light vehicle demand

The literature analyzing travel patterns for light vehicle demand is extensive, specifically those studies estimating the influence of fuel prices on road mobility. In the 1970s, due to the consecutive increases experienced in gasoline prices worldwide, the first research works were conducted in order to measure the impact of gas prices on fuel consumption and road demand (Matas and Raymond, 2003). During the 1990s, the increasing concerns on transport externalities (air

pollution, climate change, accidents, etc.), particularly road transport ones, encouraged the development of different researches to estimate to what extent higher taxes on fuel products could help to reduce road demand and, consequently, the negative effects of road transport.

This type of studies represented the first step to estimate and quantify the influence of different explanatory variables on road traffic volume. More recent research contributions such as Goodwin et al. (2004), Graham and Glaister (2004) or De Jong and Gunn (2001) focused on the impact of gas prices on the evolution of aggregate traffic volume, but also started to analyse additional explanatory variables. These authors found that short-run elasticities with respect to fuel prices commonly ranged between -0.10 and -0.40, and typically averaged about -0.30. Nevertheless, they observed that fuel demand elasticity can vary depending on different factors, such as the magnitude of price changes, individuals' car availability, perceived stability of price changes, or quality of the alternatives available, among others (Litman, 2013). The percentage that fuel represents on the total cost of driving is also an aspect to be taken into account when analyzing the influence of fuel costs on travel behavior.

Other studies (Su, 2011; Hymel et al., 2010) also addressed the magnitude of the *rebound effect*, that is, the additional mileage driven that results from increased fuel efficiency. Among other variables analysed to explain road demand, mainly for urban and metropolitan areas, the level of income is worth mentioning. Different authors (Boilard, 2010; Goodwin et al., 2004; Hanly et al., 2002) concluded that a 10% increase in personal income may rise road demand by 2% in the short-run, and by 5% in the long-run.

For the case of Spain, the most significant research analysing aggregate traffic demand in interurban roads was conducted by González and Marrero (2011). They developed a dynamic panel data approach to quantify the induced road traffic in Spanish regions for the 1998-2006 period. The research obtained a short-run fuel price elasticity of -0.28, and also a significant effect coming from the evolution of the national vehicle fleet (+0.39) and the expansion of the Spanish high capacity network (+0.12) over time. By contrast, these authors did not find

any significant result attributable to variations in macroeconomic variables such as GDP.

After this brief introduction on road demand analysis for free roads, previous research on traffic evolution in toll roads is summarized below.

Previous research for toll roads

As mentioned above, the literature regarding demand evolution for interurban toll roads is still limited, since previous research has mainly focused on exploring tolling effects on urban areas or particular tolled sections, such as bridges or tunnels. Therefore, this type of tolled infrastructure needs to be considered to properly position the current state of knowledge in this field.

In theory, the implementation of tolls on roads can affect different aspects of travel patterns, as the user may reduce the mileage driven, change the origin/destination of the trip, shift to alternative modes, etc. (Litman, 2013). In the long-term, it could even affect the location of residential housing, as well as manufacturing and distribution activities. Nevertheless, toll elasticities can show a wide range of values depending on different factors such as trip purpose, income levels and overall trip costs, as well as the attractiveness of alternative routes (Lake and Ferreira, 2002). Therefore, the level of toll elasticity has evidenced to significantly vary depending on the context. Table 1.3 includes the most important previous studies analyzing light vehicle demand in toll roads, both in the urban and interurban context, and summarizes their main characteristics and results.

Regarding **urban areas**, a great attention has been directed to the implementation of congestion charging schemes in city centres, such as Singapore (1975), London (2003), Stockholm (2006) or Milan (2012), among others. For instance, Olszewski and Xie (2005) measured the impact of the implementation of the Singapore Electronic Road Pricing (ERP) system by using traffic volume data collected before and after its introduction. They identified some peak spreading effect due to variable road pricing, concerning re-scheduling and re-routing trips.

Table 1.3. Main research studies analyzing light vehicle demand in toll roads, both in the urban and interurban context

Context	Author (year)	Country	Type of road	Years covered	Elasticity results (short-run)			
					Fuel	Toll	GDP	Household income
Urban	Jones et al. (1992)	Norway	Urban toll rings	1989		-0.22 to -0.45		
	Harvey (1994)	United States	Urban bridges and roads	1991		-0.05 to -0.15		
	Hirschman et al. (1995)	United States	Urban bridges and tunnels	1989		-0.25		
	Gifford et al. (1996)	United states	Urban bridge	1979-1984		-0.09 to -0.18		
	Cain et al. (2001)	United States	Urban bridges	1993-1995		-0.03 to -0.36		
	Loo (2003)	Hong Kong	Urban tunnels	1979-2000		-0.10 to -0.29		
	Odeck et al. (2008)	Norway	Urban motorways	2005		-0.45		
	De León et al. (2009)	US-Mexico	Urban bridges	1991-2004		-0.00 to -0.28		
	Cervero (2013)	United States	Urban bridge	2009-2011	-0.07	-0.23		
	Matas et al. (2003)	Spain	National tolled network	1979-1997	-0.31	-0.31	0.89	
Interurban	Álvarez et al. (2007)	Spain	Tolled motorway	1989-2000	-0.06	-0.54	0.83	
	Odeck et al. (2008)	Norway	Rural roads	2005		-0.74		0.39
	Burris et al. (2011)	United States	Interurban and metropolitan roads	2000-2010		-0.30		1.31
	Matas et al. (2012)	Spain	National tolled network	1980-2008		-0.15 to -0.49	0.75	
	Cantos et al. (2010)	Spain	Metropolitan motorway	2006		-0.92		

From a different perspective, Borjesson et al. (2012) analyzed the impact of the implementation of a congestion charging policy in Stockholm, addressing different topics beyond purely traffic reduction, such as environmental issues or public support. In the same line, Borjesson et al. (2015) studied the effects of the time-of-day cordon pricing scheme adopted in Gothenburg in 2013, observing a significant percentage of commuting trips switching to public transport to enter the city centre. In urban areas, authors generally agree that a higher toll elasticity indicates that the user has the possibility of easily changing her/his travel schedule, changing the route or even deciding not to make the trip.

Also in urban or metropolitan areas, numerous studies have analysed the evolution of traffic demand in **particular tolled sections**, such as bridges and tunnels. For instance, Hirschman et al. (1995) estimated the elasticity of road traffic with regard to the toll price in six bridges and two tunnels within the metropolitan area of New York. The authors concluded that the demand is more elastic in those tolled facilities that have a good free alternative. Likewise, different studies in the United States (Gifford et al., 1996 for the Golden Gate bridge in California; Swenson et al., 2001 and Cain et al., 2001 for two toll bridges in Florida) identified significant intraday differences in toll elasticities when applying a time-varying toll scheme. More recent contributions (Cervero, 2013; De León et al., 2009) have obtained low values for toll elasticities in those bridges with a great level of congestion but a lack of free alternatives or poor quality ones.

After excluding studies in urban areas and special tolled sections (bridges and tunnels), only a handful of papers can be found regarding **interurban toll roads**. Additionally, they have been conducted on just a few nations, mainly Spain, Norway, Portugal and the United States. Nevertheless, the research by Dwijono (1997) for the Jakarta-Cikampek toll road can be considered probably the first study deeply analysing road demand in interurban contexts. Focusing on the estimation of toll elasticities, he found that elasticities were fairly inelastic to price changes (-0.35), although they could vary according to a wide variety of factors such as trip distance or the period of time considered. Regarding subsequent research conducted in this field, it is surprising the lack or scarcity of contributions

up to date from countries such as France or Italy, given their extended interurban toll road network.

Interurban roads generally show higher toll elasticities when compared to road traffic in urban contexts, as can be observed in Table 1.3. These differences may be caused by the higher cost associated and the greater percentage of long-distance trips in road demand for interurban contexts. According to the literature, long-distance trips have empirically shown higher travel demand elasticities than short-distance movements, typically within urban areas. In this respect, despite not being conducted particularly for toll roads, Mattson (2008) concluded that vehicles operating for longer distances are more sensitive to changes in gas prices than those travelling shorter ones. Regarding transit ridership, a study conducted in Australia by Currie and Phung (2008) found that short-run fuel elasticities for journeys over 25 km were four times higher than those routes below 7 km. More specifically focused on tolled facilities, Odeck and Brathen (2008) calculated toll elasticities for different Norwegian roads, with higher values for rural roads compared to urban motorways. Therefore, long-distance trips seem to be more sensitive to changes in generalized transport costs. This varying responsiveness of long and short-distance trips have been linked (Mattson, 2008) to the higher amount of costs—fuel, tolls, etc.—associated with the former, since long-distance trips provide the user greater motivation for changing the route, shifting to alternative modes of transport, or cancelling the trip altogether.

Of special interest is the theoretical approach conducted by Burris (2003) on how variable tolls can affect road traffic. After analysing demand behaviour in different road facilities, he concluded that elasticities tend to be higher in this type of pricing schemes when compared to fixed tolls. For instance, the A1 expressway in France (Lille - Paris), offering discounts in the toll price in certain schedules, showed toll elasticities ranging between -0.16 and -0.28, somewhat higher than other toll facilities in that country. The author observed that some users were ready to modify their habits and were willing to realize the trip out of the rush hours. By contrast, higher values were obtained in metropolitan highways such as Hardy Toll Road in Houston (between -0.40 and -0.80), with a greater number of available alternatives to avoid tolls. These results have been confirmed by

subsequent research studies mentioned below, such as Saens and Lobos (2013) in Chile or Santos et al. (2012) in Portugal.

Next, we summarize the main results of interurban toll roads found in the literature, sorted by country. In the case of the United States, the most consistent and deep research was developed by Burris and Huang (2011), who analyzed a sample of 12 interurban and metropolitan toll roads throughout the nation during an eleven-year period (2000–2010). They conducted an approach based on time series ADL models, including population, unemployment rate, gas prices and toll rates as explanatory variables for light vehicle demand evolution. The authors obtained statistically significant results for light vehicle traffic elasticities with respect to gas prices (with a mean of -0.06) and toll rates (averaging -0.30). As for the socioeconomic variables in the model, short-run elasticities with respect to population averaged 1.31, while results for unemployment rate were surprisingly small (+0.0) on average.

Figure 1.3. Preliminary analysis of population and traffic volume evolution over time

Source: Burris and Huang (2011)

For the case of the Oklahoma interurban toll network, Zhang et al. (2012) modelled car travel demand by adopting non-agricultural employment as the socioeconomic parameter, with an estimated elasticity of 0.25. Demand responsiveness evidenced to be highly inelastic, with low elasticities for both fuel (-0.05) and toll rates (between -0.04 and -0.17). For the first time, this research pointed out the

importance of including the penetration of Electronic Toll Collection (ETC) systems as an explanatory variable for road demand evolution. From a different perspective, the study by Wilbur Smith (2008) for the North Texas Tollway Authority focused on the potential impacts that gas prices can have on toll revenues rather than purely on travel demand, with no deep analysis conducted on traffic data.

In Portugal, the implementation of an explicit toll scheme in a road network initially operated as a shadow toll one, has attracted the attention of researchers in the last years. Santos et al. (2012) analysed variation in traffic demand in Portugal after the first year of introduction of real tolls in former SCUT roads. They concluded that traffic demand in Portugal was elastic to the introduction of tolls, with an average toll elasticity of -0.88. This high result is explained given that the network analysed is mainly located in the surroundings of metropolitan areas, provided with many alternatives to those drivers that want to avoid the tolled roads. A general picture of toll elasticities in Portugal can be also found in Barata (2012), exploring toll road demand evolution in different Portuguese NUTS. Again, an individual model was calibrated for each toll section, considering different socioeconomic explanatory variables such as employment per capita, GDP per capita or bank loan interest rates. A more particular view was provided by Bandeira et al. (2012), who analysed the impact that the implementation of tolls had on route choice for the A29 motorway near Oporto, and evaluated its consequences in terms of emissions and energy use. Also near Oporto, Ferreira et al. (2015) explored the toll implementation in the A28 motorway, also with a toll elasticity (-0.57) in the upper range of values found in the literature. The authors pointed out that among the most relevant factors explaining the decrease in the A28 traffic are the collection of electronic tolls and the slowdown of economic activity in the country.

Regarding Norway, Odeck and Brathen (2008) calculated the demand elasticities in 19 Norwegian toll road projects, including cordon toll rings, tolled trunk roads between cities, and tolled roads in peripheral regions. Explanatory variables in the analysis comprised generalized transport costs, household income and toll rates. Detailed results were only provided for the last variable, with short-

run toll elasticities of motorways moving from -0.40 to -0.48. Later, Odeck and Kjekreit (2010) provided further insight into users' attitudes towards charges for road user by examining 6 different Norwegian toll schemes, with results for toll elasticities approximately equal to those ones derived in previous research.

For the case of Spain, the research on the interurban toll motorway network by Matas and Raymond (2003) can be considered as the most significant. For the 1979–1997 period, they developed a panel data approach, showing an average demand elasticity of around -0.30 with respect to both gasoline prices and toll rates. National GDP was the socioeconomic variable chosen in the analysis, with a demand elasticity of 0.89. More recently, results for Spain have been updated by Matas et al. (2012). In their new research paper, that included the 1980–2008 period, they obtained toll elasticities between -0.15 and -0.49, while short-run elasticities with respect to gasoline prices and GDP were, respectively, -0.39 and 0.75. The authors pointed out that it is often unrealistic to assume a constant elasticity, as it can vary depending on such factors as road capacity constraints. Furthermore, Cantos and Álvarez (2009) analyzed demand behavior in the radial toll roads in Madrid, with a special focus on the influence of congestion experienced in the high quality free alternative available. Ursúa (2012) studied empirically the lack of accuracy on traffic forecast conducted for the tolled highways Radial 3 and 5 in Madrid. Finally, Álvarez et al. (2007) calculated the value of time and travel elasticities for both a Spanish toll motorway and its free parallel road in the Mediterranean coast. In this case, the authors concluded a substantial influence of toll prices (-0.54) and GDP (0.83) on road demand, with a lower value for fuel prices (-0.06).

Finally, some apart studies on interurban toll roads can be found in the literature for specific nations. Nicolini (2001) conducted an OLS approach to model road traffic for the 1991-2000 period in different Argentinian toll sections, although the toll network as a whole was not analysed. By adopting either GDP or GDP per capita as explanatory variables, he obtained significant demand elasticities for both toll (-0.44) and fuel prices (-0.54). More recently, several contributions have appeared in a wider variety of countries. Also in America, Saens and Lobos (2013) obtained a lower demand elasticity with regard to toll rates (-

0.17) when compared to fuel prices (-0.35). The authors pointed out that these low toll elasticities may be caused by the lack of alternative free roads in the Chilean interurban toll network, so road charging does not seem to be a suitable policy to manage road demand in these situations. Regarding Europe, Musso et al. (2013) analysed the impact experienced in Greek toll roads due to a dramatic increase in fuel taxes as a result of a harsh program to restore governmental budget surplus. Finally, Tsukada and Fukuda (2013) focused on quantifying the impact on toll elasticities in Japanese expressways, due to changes in certain explanatory parameters such as trip distance, peak-hours or Electronic Toll Collection (ETC) systems diffusion.

1.2.2 Current evidence for heavy vehicle demand

The existing literature concerning road freight demand has mainly focused on modelling commodity or vehicle movements, both at the macro and micro levels, in terms of certain explanatory variables. These demand modeling analyses have been used for different purposes, such as testing transport policy measures, forecasting freight transport demand, or predicting the impacts of the provision of new infrastructure (Ben-Akiva and de Jong, 2008). According to Nuzzolo et al. (2013), two main technical approaches have been adopted to that end: behavioural models and macro-economic models (both joint and partial share specifications). An overview of their basic characteristics as well as some examples found in the literature are included in Table 1.4. Furthermore, a detailed review in this field, which is out of scope of this introductory section, can be found in De Jong et al. (2013) and Chow et al. (2010).

Behavioral models simulate mode and route choice, and generally employ disaggregate information, so more detailed policy-relevant variables can be covered (Nuzzolo et al., 2013). By contrast, macro-economic models, which use aggregate information, are aimed at estimating the level and spatial distribution of goods or traffic flows. Within macro-economic models, partial share specifications progressively calculate consecutive steps of transport modelling (generation, distribution, etc.), while direct models simultaneously consider the whole process when estimating road freight demand.

Table 1.4. Overview of the main approaches to model road freight transport

Type of model	Subtype	Level of detail of the data	Aims of the analysis	Examples	Methods employed
Disaggregate models		Individual shipments	Estimate route and/or mode choice	Abdelwahab (1998)	Mixed discrete/continuous choice
				Beuthe et al. (2001)	Travel costs minimization
		Individual cargo companies		Rich et al. (2011)	Weighted nested logit
				Yang et al. (2011)	Intermodal network optimization
Aggregate models	Partial share models	Macro national/regional parameters	Estimate the traffic volume	Nuzzolo et al. (2009)	Category regression, multinomial logit, etc.
				Bröcker et al. (2011)	Gravity modeling
				Kveiborg et al. (2007)	Decomposition analysis
	Joint/direct models	Production of economic sectors	Estimate the amount and spatial distribution of goods	Agnolucci et al. (2009)	ARDL, ECM
				Li et al. (2009)	ARIMA, VAR, BVAR, etc.
				Matos et al. (2011)	OLS

Source: Author's elaboration

Some interesting findings have been concluded from **disaggregate** and **partial share models**. According to Abdelwahab (1998) and Oum et al. (1990), truck price elasticities significantly vary across commodity groups, so elasticities for lower-value commodities tend to be greater when compared to higher-value goods. In the same line, for the case of Italy Nuzzolo et al. (2009) found that explanatory variables for freight demand do also vary for each commodity group. From a wider perspective, Rich et al. (2011) assessed the extent to which mode substitution in freight transport was affected by lack of alternative freight networks from origin to destination. In this respect, they observed some “structural inelasticity” of modal substitution due to a sparser layout of rail and ship-based freight networks compared to road. Additionally, Bröcker et al. (2011) and Meersmann et al. (2013) approached the importance of globalization on road freight flows, and identified three driving forces of the current transport flows dynamics: economic growth, globalization (reduction of trade barriers) and changes in the commodity composition of trade.

Furthermore, other previous contributions conducted aggregate analyses through **direct macro models**. With a similar approach as the forementioned research on light vehicle traffic, these studies were aimed at calculating the relationship between heavy goods vehicle demand and certain macro explanatory

variables. Among the first research studies in this field, Gately (1990) employed an econometric analysis of US data to explain the evolution of road freight traffic. He found statistically significant elasticities for both fuel prices (-0.37) and GDP (1.23). More recently, Li and Hensher (2009) identified the key drivers associated with the growth of heavy goods vehicle traffic in Australia, and established several time series models to forecast future demand. Matos and Silva (2011) investigated energy efficiency in the road freight transportation sector in Portugal. They adopted an Ordinary Least Square (OLS) estimator and calculated a statistically significant elasticity (0.96) of heavy vehicle demand with respect to national GDP.

For the case of Spain, Baños et al. (2007) studied interregional road freight demand by modelling both number of transport operations and flow of goods. Through a gravitational model, they obtained significant elasticities for the explanatory variables included in the analysis: GDP of the region originating the trip (+1.00), GDP of the region of destination (+1.02), transport prices (-0.98) and travel distance (-1.18). They also concluded a significant influence for the stock of high capacity roads (+0.44). In the same line, Arbués et al. (2004) adopted a dynamic panel data gravity specification to model road freight flows for the 1990-2010 period. The elasticities obtained were lower for GDP of origin (+0.33), GDP of destination (+0.34) and trip distance (-0.71) when compared to the previous research.

Despite the above contributions, both the explanatory variables chosen and the results derived from them should be approached with caution since many countries –particularly, European ones– have in recent years experienced a decoupling of the growth in road freight traffic from economic growth (Kveiborg and Fosgerau, 2007). Such recent experiences as that in the UK (Agnolucci and Bonilla, 2009; Mc Kinnon, 2007) thus suggest that the relationship between GDP and heavy goods vehicle demand may not be as enduring as often supposed.

Finally, other studies not particularly focused on demand modelling have analyzed additional aspects of road freight transport. Allen et al. (2012) investigated the relationship between truck demand, facility location, logistics management and urban form, by exploiting the British Survey of Road Goods Transport. Forkenbrock (1999) estimated external costs for intercity freight

trucking in the US and proposed increasing road user charges as a way to internalize external costs. Furthermore, Winebrake et al. (2012) explored the *rebound effect*, that is, the additional mileage driven as a result of increased fuel efficiency, specifically for heavy vehicle demand, and identified that freight elasticity estimates are influenced by a number of factors of variability depending on the shipping activity, etc.

Previous research for toll roads

Literature regarding road freight demand for toll roads is still limited and mainly concentrates on aggregate models to estimate the level of traffic. The focus on direct macro-economic models for analyzing this type of roads may be due to two main aspects. First, toll roads are still relatively scarce at the international level, what reduces the opportunity of collecting detailed trip information. Second, traffic volume is the variable of special interest for the operator of the toll road since it is the main determinant to anticipate future financial requirements, equipment acquisition, etc., as pointed out by Nuzzolo et al. (2013).

Different research studies can be identified for **urban and metropolitan areas**. Hirschman et al. (1995) estimated toll elasticities for several tolled bridges and tunnels in New York City, obtaining considerable higher values when compared with results for light vehicles. Holguín-Veras et al. (2006) assessed the impact of the Port Authority of New York and New Jersey's time-of-day pricing initiative on the behavior of commercial carriers. Moreover, Arentze et al. (2012) examined how sensitive were truck drivers for possible pricing policies by focusing on short-distance road freight transport, and identified the weight of the vehicle as a key variable determining truck drivers' choice. Liang et al. (2009) explored the effects of a toll-by-load policy on the vehicle type constitution pattern by analysing truck demand in the Chinese Jin-Ji expressway.

By contrast, only a very few papers can be found regarding heavy vehicle demand in **interurban toll roads** and experiences mainly comprise direct modelling approaches on just a few nations. In the case of the United States, the forementioned research by Burris and Huang (2013) for 12 interurban and

metropolitan toll roads is again the most consistent analysis. By adopting a careful segmentation of heavy vehicle demand depending on the number of axles, they found statistically significant results for toll elasticities, averaging -0.35. Concerning fuel prices, demand elasticities (from -0.22 to +0.14, with a mean of -0.03) showed a scarce impact on truck demand, or even positive in some cases. Anyway, truck drivers' responsiveness towards fuel cost evidenced to have increased (-0.23) during the economic crisis. As for the socioeconomic variables in the model, unemployment rate was found to negatively affect road freight traffic (elasticities with a mean of -0.03), likely as a result of the economic slowdown.

Additionally, for the Ohio turnpike Taft (2004) obtained a toll elasticity of -0.59 for heavy vehicle volume, while Swan and Belzer (2010) estimated truck traffic diversion caused by changes in the toll rates applied. Based on an OLS technique, they also forecasted the impact of toll rates on heavy vehicle revenue. From the same perspective, Reebie Associates (2004) quantified the potential truck diversion of tolling on the I-81 expressway in Virginia, finding no significant differences between commodity groups. Finally, Holguín-Veras et al. (2003) analyzed toll lanes for exclusive use by heavy trucks in Southern California.

Figure 1.4. Percentage of vehicle miles diverted by commodity group due to the implementation of a tolling system in the I-81 expressway in Virginia

Source: Reebie Associates (2004)

Next, results conducted for modelling truck demand in other nations are summarized. Among the first studies in this field, Dwijono (1997) obtained average toll elasticities of -0.26 for truck demand in Indonesia. Regarding Norway,

the research by Odeck and Brathen (2008) analyzing travel demand in 19 Norwegian toll road projects provided an average toll elasticity of -0.51 for heavy goods vehicles. As for Australia, Hensher et al. (2013) investigated the response of road freight operators to price signals under different access charging schemes, defined by combinations of distance, mass and location. In the case of Argentinian toll roads, demand elasticities for heavy vehicle traffic with regard to toll rates (-0.59) and fuel costs (-0.13) happened to be, respectively, higher and lower when compared to light vehicle traffic. More recently, Musso et al. (2013) obtained fuel elasticities of around -0.30 in the Greek Elefsina-Patra toll road. Saens and Lobos (2013) modelled truck demand in the Chilean interurban toll network, with lower demand elasticities with regard to tolls (-0.05), fuel (-0.11) and GDP (+1.37) compared to light vehicles. Finally, for the case of Spain, Álvarez et al. (2007) estimated the value of time and travel elasticities for both a Spanish toll motorway and its free parallel road, finding statistically significant results for tolls (-0.39) but no for fuel prices (-0.09). GDP was the socioeconomic variable chosen to model truck demand, obtaining an elasticity of 1.32.

1.3 Key socioeconomic variables explaining road demand evolution

Identifying the most suitable socioeconomic variables explaining road demand evolution over time is an issue not solved up to date in the literature. Although different research studies have previously developed some explanatory analysis for road demand, they did not explicitly justified their choices for a specific variable. The socioeconomic parameters most commonly referred in this field are:

- **GDP** constitutes the socioeconomic variable mostly used to make traffic forecasts and explanatory analyses in the literature, not only for road transport but also for other alternative modes. With regard to interurban road demand, the use of GDP as the socioeconomic explanatory variable presents two main advantages: abundant information in statistical data basis; as well as numerous predictions conducted by international organizations for future years, which can facilitate the accomplishment of traffic forecasts.

Previous research in interurban roads, both tolled and free ones, have obtained GDP elasticities around 1.0 when analysing light vehicle traffic. Values calculated in the literature range from 0.75 in Spain (Matas et al., 2012) to 2.04 in Argentina (Nicolini, 2001). As for road freight demand, some previous research have estimated higher values for GDP elasticities, with values ranging from 1.32 in Spain (Álvarez et al., 2007) to 2.5 in Argentina (Nicolini, 2001).

Despite its wide use to explain both light and heavy vehicle demand, it is not generally taken into account that GDP consists of the aggregation of different sectors of the economy, some of them with scarce or no relation with the transport sector. Thus, those territories with a higher percentage of their economy focused in activities such as services (health care, financial services, education, etc.) may experience a process of decoupling, in the sense that the link between economic growth and transport activity becomes weaker (Alises et al., 2014). During the last decade, this process has started to be observed in nations such as Denmark (Kveiborg et al., 2007) or the UK (McKinnon, 2007). In this case, it can be expected that the relation between GDP and road mobility, particularly road freight one, may not keep stable along time.

- **Population** constitutes an appropriate variable to measure the effect that demographic growth can cause on road mobility. This explanatory parameter presents the advantage of showing a relatively stable behavior throughout the time, in comparison with other socioeconomic indicators such as GDP. Nevertheless, the stability of this variable also represents its main limitation. The size of the population has a great influence as a structural long-term element, but its effect on road mobility is not transmitted immediately. Unlike GDP, population accounts for the number of inhabitants within a territory but does not reflect the changes in the economic cycle, so it cannot approach users' level of income, an issue greatly determining personal demand of mobility.

Therefore population seems to constitute only a proxy of the potential mobility within a territory, but the real demand of mobility needs to be taken into account by including a socioeconomic variable better following the economic cycle. The only academic research up to date including population as the

socioeconomic variable to explain road traffic evolution were conducted by Burris et al. (2011) in the US, Ruiz et al. (2009) for Spain and Ferreira et al. (2015) for Portugal, finding elasticities of around 0.9-1.3 for light vehicle demand, and no significant results for heavy vehicle volume.

- **GDP per capita** considers the evolution of the economic activity in relation to the population of a certain territory. Since it indicates the average value of the wealth produced by inhabitant, this variable can constitute a good proxy of the individual level of income. Nevertheless, up to date it is a parameter scarcely used to analyse road demand over time.

The only previous studies using GDP per capita as an explanatory variable for road demand were Ruiz et al. (2009) in Spain and Barata (2012) in Portugal. They obtained elasticities ranging from 0.6 and 1.0. Nevertheless, again we find the limitation that no GDP per capita forecast are available in order to make traffic forecasts so predictions need to be derived from those ones conducted by governments and international organizations for GDP and population.

- With some similarities with GDP per capita, **Employment** takes into account the part of the whole population which is employed, therefore with higher income and greater mobility demand. Unlike GDP per capita, it does not reflect the evolution of the average income per inhabitant within a certain territory, but only approaches the amount of those individuals potentially having a higher income. The only reference of Employment as an explanatory variable for road traffic is found in Zhang (2012) for the case of the Oklahoma toll network. This author considered employment of non-agricultural sectors, obtaining an elasticity of 0.25.
- **Vehicle fleet** is a socioeconomic variable scarcely used to explain the evolution of road mobility. The only reference found in the literature is González et al. (2012), who estimated an elasticity of 0.5 in the Spanish road network. Additionally, some studies from consultancy groups have indicated that motorization can constitute a good explanatory variable for road mobility, though there must be taken into account the maturity of the economy in each

case. In this respect, emergent economies experiment higher vehicle fleet growths than most developed countries.

Nevertheless, motorization presents some limitations as an explanatory variable. First, it actually measures the potential mobility of the population but not the real vehicle use, what really causes traffic volume and is strongly connected to the economic activity. Secondly, forecasts for vehicle fleet are not available, what makes traffic forecasts more uncertain.

As can be seen, different types of socioeconomic variables have been considered up to date in the literature to explain interurban road demand at the macro level. At this point, it seems clear that some of these variables are highly correlated each other, particularly those ones reflecting or influenced by the evolution of the economic cycle, such as GDP, Employment or vehicle fleet. Nevertheless, their relationship with road transport evolution should not necessarily be the same in each case, given their mentioned particularities.

This fact seems to have been disregarded by previous research since the choice of the socioeconomic variable(s) to model road traffic evolution is not generally a justified step. Rather, it seems that this decision has just been based on traditional practices, such as the use of GDP as the explanatory parameter to take into account the evolution of the economy when modelling road traffic. Then, the use of alternative socioeconomic variables is not considered despite also having data available. More importantly, the explanatory performance of each socioeconomic parameter available is not compared before defining the final variables to be included in the model. Furthermore, potential differences in this respect may become more evident in times of great changes in the economic environment, as it is the case of the current period. Then, the following research question is established, with a special focus on socioeconomic variables:

Which are the explanatory variables that better determine road demand evolution over time for light and heavy vehicle demand in interurban toll roads?

1.4 Users' perceptions and willingness to pay in interurban toll roads

Together with the study of road traffic evolution at a macro level, the scientific literature has also addressed further explanatory factors at the individual level as a way to complement the analysis of road demand. Particularly in the latest years, different research projects have been conducted in order to explain road users' perceptions and willingness to pay (WTP), especially for those roads subject to tolls or any other type of user charge. At this point, it seems evident that certain individual factors, such as the level of income or the value of travel time savings considered by the driver, can play a major role in the choice of toll/untolled routes and, consequently, in the traffic volume of toll roads.

As commented above, road charging mechanisms have been increasingly adopted by governments and road operators in the last decade, as a tool to fund road infrastructure in times of budgetary constraints. Although road charging has been demonstrated to be a powerful tool to collect funds, it has been generally associated to some controversy in those territories where its implementation has been approved or proposed. In this respect, the subject of users' WTP and perceptions towards road pricing strategies represents a key factor affecting road charging viability, and particularly toll road demand, for two main reasons. Firstly, WTP of real and potential users should be deeply investigated in order to optimize the ratio between users captured and charging revenues raised in each toll road, in the direction towards the most efficient use of the toll facility. And second, users' acceptability has traditionally been identified as one of the key drivers to achieve a successful implementation of different policy initiatives (Marciano et al., 2014; Aitken et al., 2014), with special relevance in the case of road charging strategies (Zheng et al., 2014; Kockelman et al., 2009). In this respect, users' perceptions and WTP have a significant role on toll roads viability, since road infrastructure is directly financed through users' contributions in this case. Therefore, according to Dill et al. (2007), policy makers must seek to recommend measures that not only have strong public support, but are also desirable in terms of equity, ability to generate stable revenues, capacity to encourage environmentally responsible choices, etc.

In line with the literature on traffic demand evolution, previous studies on WTP and attitudes towards tolls have mainly focused on urban and metropolitan contexts, with special attention to the implementation of congestion charging systems in city centres. For instance, Gaunt et al. (2007) and Kottenhoff et al. (2009) evaluated public acceptability of urban pricing in the cases of Stockholm and Edinburgh, respectively. After a referendum process to vote for the implementation of the measure, results and public acceptability were radically different in each case. Further evidence in this field can be found for the implementation of charging strategies in cities such as Milan (Percoco, 2014), London (Buckingham et al., 2010) or Singapore (Phang, 2004).

Additionally, other research studies have been conducted to explore perceptions towards the hypothetical introduction of charging schemes in different cities. For the case of Copenhagen, Gehlert et al. (2011) used a segmentation approach to identify groups of car users with a similar socioeconomic background and compared their responses towards urban pricing. Pronello et al. (2014) looked at citizens' reactions in Lyon and concluded that charging acceptability increased when information and explanations were provided with regard to its role, as well as its importance to tackle traffic congestion and environmental problems. For Vienna, Furst et al. (2014) found that public acceptability was higher when road pricing led to perceived personal benefits.

1.4.1 Users' perceptions in interurban toll roads: previous research

Unlike the urban contexts, the scientific literature exploring attitudes in interurban roads, particularly tolled ones, is still limited and primarily concerns residents' perceptions rather than purely users' (Kockelman et al., 2009; Dill et al., 2007). In this respect, an overview of the scarce background in this field, as well as the main characteristics of the previous studies, are summarized in Table 1.5. As can be seen, although acceptability towards toll road pricing constitutes a complex matter, previous research studies in interurban contexts have traditionally analysed the influence of socioeconomic factors (age, income, education, etc.) on users' perceptions towards tolls. The results of these studies are useful to target

specific user market segments as well as to predict future behaviour of individuals. Nevertheless, they have not generally led to conclusive and coincident results about the influence of these variables on users' attitudes (Gehlert et al., 2011).

For instance, while the level of income significantly influenced users' perceptions towards tolls in Norway according to Odeck et al. (2010), it did not resulted to be a significant explanatory variable to determine residents' perceptions in California, as denoted by Dill et al. (2007). These inconclusive effects have been also observed with other socioeconomic variables such as age (see Podgorski et al., 2006 and Odeck et al., 2008) or gender (see again Dill et al., 2007 and Odeck et al., 2010), among others.

Table 1.5. Overview of the influence of different socioeconomic parameters on attitudes towards tolls

Author (year)	Podgorski et al. (2006)	Dill et al. (2007)	Odeck et al. (2008)	Odeck et al. (2010)	Chen et al. (2014)
<i>Context</i>	Texas residents	California residents	Road users in Norway	Road users in Norway	Road users in Taiwan
<i>Explanatory variables included</i>					
Trip length	n.s.s.	n.s.s.	--	n.s.s.	--
Travel frequency	--	--	--	--	--
Age	n.s.s.	++	n.s.s.	++	
Gender	s.s.	s.s.		n.s.s.	
Education	++	++			
Employment	s.s.				
Income		n.s.s.	n.s.s.	++	
Political leaning		s.s.			
Level of information			++	++	
Type of vehicle			s.s.		
Travel purpose			n.s.s.		s.s.
Who pays the toll			n.s.s.		

Note: ++: statistical positive influence; --: statistical negative influence;
s.s.: statistically significant differences; n.s.s.: non statistically significant differences

Source: Author's elaboration

Because of this lack of evidence, some authors (Schade et al., 2000; Rienstra et al., 1999) have pointed out that socioeconomic factors might have a somewhat lesser impact on acceptability compared to other drivers such as attitudinal factors. The latter may be determined by variables of a different nature, mainly psychological drivers: existing community values (Yusuf et al., 2014), political bias (Hårsmann et al., 2010), the perceived fairness of charges (Bonsall et al., 2007; Schade et al., 2007), etc. At this point, the use of toll revenues raised from the

charging scheme turns especially relevant to determine acceptability, as found by Schuitema et al. (2008) and Jaensiriak et al. (2005). Likewise, the level of information supplied to users (objective, earmarking of revenues, etc.) prior to the implementation of road charging has been also identified as an important factor influencing public attitudes.

Despite these contributions on acceptability towards tolls and road user charges at the interurban context appearing in the last decade, the previous studies have been limited to a particular region or area, as it is the case of Texas in Podgorski et al. (2006), the state of California in Dill et al. (2007) or the island of Taiwan in Chen et al. (2014). Then, the research on users' acceptability in the Norwegian toll network by Odeck et al. (2008; 2010) can be considered the most relevant study, since it is the only contribution up to date addressing attitudes towards tolls nationwide. By contrast, no similar research projects have been developed at the national level in other European countries with an extensive toll road network, such as France, Italy or Spain.

Curiously, the scarcity of the current background on perceptions towards road charges has left a noteworthy body research for truck demand. Among the first studies in this area, Gupta et al. (2008) pointed out the influence that an existing tolling culture can have on the responsiveness of road freight with respect to tolls. For the case of Austin (Texas), Zhou et al. (2009) conducted a survey to quantify the impact of incentives on toll road use by truck drivers. They found that owner-operators were less supportive of using toll roads because of the difficulty in passing the associated cost to the customer, when compared to company-employed drivers. In the same line, a research developed in Tennessee by Cherry et al. (2012) examined drivers' preferences on future truck lane management strategies for those road corridors crossing through urban areas. Finally, Arentze et al. (2012) conducted a survey to explore how sensitive were truck drivers for possible pricing policies in the Netherlands. The results showed a relatively strong base preference for highways and wish to avoid local roads and traffic congestion.

1.4.2 Willingness to pay in interurban toll roads: previous research

In contrast with perceptions and acceptability towards tolls, the literature regarding road charging and willingness-to-pay (WTP) is relatively extensive at the interurban context. Research studies have been generally based on surveys conducted to road users in order to measure their behaviour and perceptions towards toll roads. Specifically, the majority of contributions at the interurban level up to date have focused on analysing the managed lanes in the United States.

The first studies in the field of road pricing and users' willingness-to-pay were conducted in the urban context, such as Small (1992) and Calfee et al. (1998), the latter one concluding a low value for WTP even for wealthy individuals. The importance of users' WTP in the transportation research literature lies in its major role for project evaluation, as pointed out in a study by Mackie et al. (2001) discussing whether and how users' travel time valuation should be used in the assessment processes. This research also set further milestones of great interest, such as mentioning the six major influences on an individual's value of travel time savings (VTTS), as well as questioning the strong link traditionally supposed in the literature between users' WTP and their valuation of travel time savings (VTTS) or Value of Time (VOT).

Among the first contributions deeply investigating users' WTP in interurban contexts, it is remarkable the research by Lam et al. (2001) regarding the actual behaviour of commuters in the SR91 in California, in which the influence of different parameters such as car occupancy are explored. In subsequent years, a wide literature has been developed with regard to users' WTP and users' VOT savings in the interurban context. These variables have evidenced to vary according to a wide range of explanatory factors, particularly transport-related attributes such as trip length (Jou et al., 2014; Shires et al., 2009), day of the week (Jou et al., 2012), time of day (Tseng et al., 2008), the information provided to the user (Rong-Chang et al., 2013) or trip direction (Devarasetty et al., 2012). It is also worth mentioning the result concluded by Azari et al. (2013), according to whom workers have a greater willingness-to-pay regarding road user fees and charging options, compared to non-workers.

Figure 1.5. Factors influencing the distribution of travel time

Source: Li, Hensher and Rose (2010)

Probably the explanatory parameter most greatly influencing users' WTP is the travel time reliability provided by the charged road. As pointed out by Brownstone et al. (2005), this variable accounts for to what extent individuals are willing to pay for reductions in the day-to-day variability of travel time facing a particular type of trip. A wide literature has been deployed regarding reliability for personal travel and its influence in users' WTP, therefore with important implications to ensure a more efficient use of toll roads (Small et al., 2005). Two main frameworks have been adopted when estimating users' valuation of travel time reliability: *centrality dispersion*, analyzing day-to-day travel time distributions and assuming symmetric penalties for travel time variability; and *scheduling models*, linked to the departure time choice, so this approach rests on the time constraints (e.g. work starting time) a traveller may face and thus associates costs due to early or late arrivals. Among the first research studies in this topic, Bates et al. (2001) provided an overview of the general theory underlying individual's valuation of travel time reliability, and identified some interesting findings such as the importance that travellers place on punctuality. On the other hand, for the SR91 facility in California, Brownstone et al. (2005) empirically identified the substantial heterogeneity in the individual's VOT across the population. More recently, Li et al. (2010) reviewed the modelling frameworks and empirical measurement paradigms to obtain WTP for improved

travel time reliability. Finally, Carrion et al. (2012) performed a meta-analysis of existing research on the value of travel time reliability.

Next, some of the most recent contributions in the field of WTP in interurban contexts are reviewed, sorted by country. For the case of the US, research up to date has focused on behavioural and travel-related characteristics influencing users' choices in High-Occupancy Toll (HOT) lanes already in operation. Among the most practice-oriented studies, Burris et al. (2012) examined travellers' WTP for travel time savings for two express lanes in the I-394 MnPass in Minnesota and the I-15 in San Diego. The authors observed that drivers were willing to pay for even a relatively small amount of travel time savings, so they concluded that it is likely that users were paying for more than saving time, probably travel time reliability. In the same line, the research by Sheikh et al. (2014) found that VOT estimated in the I-85 Express Lanes in Atlanta exceeded the average wage in the region, what revealed that HOT lane users had a higher purchasing power compared to non-users. Also in the United States, Wood et al. (2014) analysed the conversion of a high-occupancy vehicle (HOV) lane to a HOT lane, finding no statistical differences between frequent and occasional users of the toll facility. For the case of the Katy Freeway in Houston (Texas), Patil et al. (2013) investigated how users' WTP did over time in the aftermath of opening and operating a managed lane, finding that users' VTTS in urgent situations were almost doubled after the opening date. Also in Texas, Devarasetty et al. (2012) developed a SP survey to examine the value placed on travel time savings and travel time reliability by users, making a great stress on the relevance of this variable when modelling drivers' behaviour.

Figure 1.6. Cost of travel time savings for all trips and AM trips in the I-85 Express Lanes in Atlanta (Georgia)

Source: Wood, Burris and Danda (2013)

Apart from the United States, the literature exploring users' WTP in interurban toll contexts is still scarce. Spain is one of the countries with some interesting contributions in this field. Álvarez et al. (2007) conducted a SP survey to calculate the VOT in a road corridor made up of a toll motorway and a free parallel road in the Mediterranean corridor. In line with the previous literature, the authors identified that VOT for work reasons generally doubled that of travel time for leisure reasons. Furthermore, for a toll road competing with a free parallel road in the Barcelona metropolitan area, Asensio et al. (2008) explored the influence of travel time variability on commuters' WTP. This parameter evidenced to depend on time restrictions faced by the individuals, such as entry flexibility and maximum delays allowed at work. With regard to third countries, Kato et al. (2011) focused on Japan to estimate the valuation of travel time savings in the context of an expressway versus non-expressway route choice, by exploiting a nationwide RP interregional survey. From a methodological point of view, they obtained the interesting finding that VOT calculated through mixed logit models was lower than those determined by standard logit models. Finally, Li et al. (2010) explored the value of reliability and scheduling costs in the context of Australian toll roads.

Despite the relatively wideness of the existing literature, different authors such as Hensher (2010) have argued about the scarcity of research regarding choice activity in a natural environment, where the individuals do not know they are in an experiment. In this respect, the vast majority of the research already developed is based on users' information collected through surveys, either stated or revealed preference ones. In this respect, differences can be found between VOT estimates conducted through SP or RP experiments (Small, 1992; Lam, 2001; Brownstone et al., 2001) but these divergences are inherent in the methodologies. More importantly, Hensher (2010) underlined that supporting research only on surveys, either SP or RP ones, may produce a certain bias when estimating users' VOT and WTP. Likewise, the contributions on the hypothetical implementation of managed lanes present a lower interest when accurately determining real users' WTP. This is the case of Cirillo et al. (2014) for Capital Beltway (United States) and Azari et al. (2013) for Mashhad (Iran). However, they remain interesting to approach, in each particular case, users' behaviour under different hypothetical

scenarios when a certain policy is being considered for implementation. Finally, from a methodological and practice-oriented perspective, the research by Fosgerau (2006) is worth mentioning due to its analysis of the distribution of the VTTS. This author pointed out that in some empirical research the right tail of the mean distribution of VTTS cannot be observed in most of cases, what is also the reason behind the wide variability of values provided in the literature.

In contrast with the abundant research for car passenger users, very few contributions have been made regarding road freight demand. Among the first studies, Kawamura (2000) estimated VOT for truck users from a SP survey in California, in which respondents were asked about a choice between an existing free road versus a toll facility for different combinations of travel time and cost. He found that for-hire truck drivers tended to have higher VOT than private ones; likewise, the companies that pay drivers hourly wages had higher VOT than those who pay commissions or fixed salary. More recently, Cherry et al. (2012) investigated perceptions of truck drivers towards managed truck lanes and tolling aimed at alleviating congestion, finding no statistically significant differences among respondents. Furthermore, Mesa-Arango et al. (2014) explored the selection of trucking services and the quantification of the shipper's WTP through a SP choice experiment.

Figure 1.7. Preliminary results concerning willingness-to-pay for truck drivers in the Knoxville metropolitan area (Tennessee)

Source: Cherry and Adalakun (2012)

As can be seen, a wide body research has been provided up to date in the field of users' perceptions and willingness-to-pay towards road charging facilities. Particularly for the latter one, a considerable amount of contributions have been made to explore individuals' value of time as well as their willingness-to pay in different tolling scenarios. Nevertheless, some research gaps can be identified.

Firstly, scarce contributions have been made to analyse users' perceptions and willingness-to-pay in interurban contexts, apart from the abundant research background on managed lanes in the United States. In this respect, further efforts are needed to explore users' behaviour in pure interurban toll roads, given that these facilities present mobility characteristics far different from either urban pricing systems or high-occupancy toll (HOT) lanes. Additionally, it is necessary to continue investigating the explanatory factors determining perceptions and WTP towards tolling, given the inconclusive results obtained in some previous studies. Particularly for interurban roads, further analysing the role of context-specific variables may shed light on their real influence on users' choices, a critical issue to evaluate the future viability of toll facilities.

Secondly, the review of the current literature on users' attitudes and WTP towards tolling has evidenced the lack of an integrated approach comprising both issues, while the previous research has analyzed perceptions and willingness-to-pay by separate, a direct comparison between them has not been established up to date. At this point, it seems necessary to take some preliminary steps to simultaneously analyze the results obtained for both concepts, and evaluate to what extent they are related. This approach would be of great interest to determine e.g. whether a positive/negative attitude towards toll roads would lead the user to a higher/lower willingness-to-pay for using a certain toll facility. Then, in the light of the previous considerations, the following research questions are established:

What are the main individual characteristics and road-related attributes determining users' perceptions and willingness-to-pay in interurban toll roads? Is there any strong relationship between users' perceptions and their willingness-to-pay?

1.5 Road charging asymmetry and the regional perspective in users' perceptions and willingness to pay

The previous subchapter has summarized the current state of the art regarding users' perceptions and willingness to pay in interurban toll roads. According to this review, the variability observed in users' behaviour can be explained by a significant number of variables:

- Socioeconomic factors: age, gender, individual/household income, etc.
- Trip-related attributes: trip frequency, trip length, type of vehicle, trip purpose, etc.
- Other explanatory factors: road infrastructure attributes, attitudinal variables.

As noted above, previous literature has mainly focused on analyzing the influence of different socioeconomic and trip-related explanatory characteristics on users' attitudes and WTP, often with no clear results for some of them. Nevertheless, other drivers potentially useful to explain users' perceptions have been barely explored. Particularly, Smirti et al. (2007) acknowledged that the level of users' acceptability may sometimes be highly context-specific, so attitudes may change across roads or, at an upper level, even across territories with different characteristics of the transport system. This issue can be especially critical at the interurban level, since users may be involved in a different environment each other depending on e.g. the region of residence. Although the importance of context-specific variables is an issue already identified in the literature, as of today, little effort has been made to incorporate the regional perspective in the analysis of acceptability, or to measure regional differences in users' perceptions towards road charging.

Up to date, only few research studies have incorporated the regional perspective in the field of transport:

- Regarding the air transport, Alberts et al. (2009) analysed the position of the Berlin airport in relation to the German airport system, by studying the influence of larger economic and political forces.

- As for the maritime sector, Oosterhaven et al. (2001) analyzed intraregional clusters of economic activity, linkages and interregional spillovers for the two Dutch mainports. By using a bi-regional input-output methodology, their conclusions did not substantiate the assumed importance of the transport sector in those regions. More recently, Castillo-Manzano et al. (2014) identified the determinants of governmental investments in port infrastructure for the Spanish regions. Explanatory variables such as specialization and efficiency were found as significant to explain regional allocation of investments.
- With regard to road transport, the analysis of regional differences have been limited to specific areas, particularly road safety and spillover indicators. Regarding the former ones, Lassarre et al. (2005) addressed the regional patterns of road mortality in Western Europe and proposed a new road mortality ratio. By adopting a wider perspective, Eksler et al. (2008) explored variations in road mortality within 24 European countries and sought for structural factors through a Bayesian spatial multi-level model. Focused in Spain, Tolon-Becerra et al. (2013) established a regional analysis of road accidents for the 1998-2009 period. The research was aimed at explaining the progress observed in road mortality ratios in this country, as well as proposing a set of measures and new safety policies to continue improving the positive trend.

Nevertheless, only two of the papers identified have explicitly incorporated the geographic perspective in the analysis of travellers' behaviour. Sandow (2008) explored the impact of the local labour market's geographical structure on users' willingness to commute longer distances. For that purpose, they used a set of geo-referenced data to model individuals' commuting propensities in a peripheral and sparsely populated area in northern Sweden. By contrast, Condeço-Melhorado et al. (2011) assessed the accessibility impacts of a road pricing policy in the Spanish regions. Based on the use of Geographical Information Systems (GIS) techniques and accessibility indicators, they measured the accessibility changes occurring in a certain region produced by charges implemented in other different territories.

Regarding acceptability towards road charging, some papers made a preliminary approach to regional differences. Nevertheless, up to date only divergences between residents in urban and rural areas have been addressed:

- Podgorski et al. (2006) conducted different statewide surveys followed by a series of focus groups in order to analyze public support for toll roads in Texas. They found that those regions with small urban areas were more receptive to road charging. According to the authors, this result may be influenced by the fact that residents could be thinking of tolls not applied to roads in their areas.
- As a continuation of the previous study, Kockelman et al. (2009) examined the influence of demographic, location and transport-related attributes on respondents' opinions towards road pricing. The authors modeled residents' support for different proposed congestion pricing policies and identified a higher acceptability in those regions having past positive experiences with toll roads.
- In the same line, the research by Dill et al. (2007) conducted a survey of public preferences on different taxes and fee options to fund transportation in California. They pointed out that regional experience with toll facilities appeared to increase positive perceptions towards charging, and also found higher support for tolling in rural or smaller urban areas. In addition, more positive reactions towards road charging were observed when linking road user fees with environmental objectives.

As can be noticed, the previous literature approaching the regional perspective on tolling attitudes did not specifically focus on users' attitudes but on public perceptions in general. Therefore, there is a need of particularly addressing perceptions from road users and not only on residents' attitudes, since they have a more direct experience and knowledge about tolling mechanisms and their implications. Additionally, again the role of context-specific factors, such as infrastructure-related attributes or regional parameters, needs to be further explored when explaining users' perceptions in interurban toll roads. This fact could be critical in cases where a tolling asymmetry is observed throughout regions, with toll roads concentrated in few territories while other ones present

scarce or no tolled sections. At this point, considering that e.g. users from the same region may show a similar perception, in turn different to what is perceived in other different regions, seems a reasonable idea. Then, the following research question is established:

Do users' perceptions towards tolls significantly vary within the same interurban corridor, either across toll roads or regions? If so, what are the reasons explaining such differences?

In order to deeply explore regional differences in users' perceptions towards toll roads, it should be useful to analyse an extreme case. In this respect, Spain represents a very interesting case in the international context, given the marked asymmetry of the toll network across regions. Then, the main characteristics of the Spanish toll road network are briefly summarized below.

1.5.1 The Spanish toll road network and regional issues

With a total of 16,582 km, Spain has currently one of the longest high capacity road networks within Europe. Given the scarcity of quality roads in the nation until the mid-1960s, a great effort was made over the last decades to build an extensive road network aimed at promoting economic growth and territorial cohesion among regions. As of 2014 toll road concessions were 18.1% of the high capacity network currently in operation (Ministerio de Fomento, 2015), what also makes Spain one of the longest national tolled networks in the world.

Since the early 1970s, more than 3,000 km of toll highway concessions have been put in operation (Matas et al., 2012) in Spain. The current national toll network comprises two different types of toll roads. Firstly, few of the toll sections are tunnels, where a fixed toll is charged for crossing them. In terms of unitary values, toll rates for light vehicles in this type of infrastructure are quite expensive, ranging from 0.143 Euro/km (Eje Aeropuerto tunnel) to 0.49 Euro/km (Artxanda tunnels). However, the vast majority of the toll network is made up of interurban road sections (99.6% of tolled km), where users are charged per km driven. Toll rates within this group are lower –they range between 0.07 and 0.10 Euro/km for

light vehicles–, and fairly homogeneous over the territory. Furthermore, tolls in Spain vary across vehicle types, with toll rates applied to heavy vehicles being around 50% higher than those to light vehicles.

Spanish toll roads are far from constituting a homogeneous network throughout the country. They were built in different periods, and are asymmetrically distributed over the territory. According to Vassallo et al. (2012), three different periods can be identified in the development of the interurban road network in Spain:

- First period (1962-1975): Despite the aim of the government to provide the nation with a modern high capacity network, the budgetary resources were not enough to finance the program through public funds. In order to develop these high investment road projects, several toll highways were granted by the government to private concessionaires.

The toll highways built during this period were mainly located in the most industrialized regions such as Catalonia, the Basque Country, Valencia, etc. Different toll roads were built to conduct road traffic along the Mediterranean coast (Valencia–Alicante, Tarragona–Valencia), to improve transnational road connections with France (Montmeló–La Jonquera, Bilbao–Behobia) or to strengthen one of the main freight corridors in the country, located between Catalonia and the Basque Country (Bilbao–Zaragoza, Zaragoza–Mediterráneo).

- Second period (1975-1995): The petroleum crisis in the 1970s destabilized the Spanish economy and postponed further extensions of the high capacity network. Later, the socialist government elected in 1982 aimed to promote new road projects in the country, but was politically opposed to those funding mechanisms directly charging the driver for the use of roads. The option adopted was a fully public-financed program, through both national and European regional development funds, to modernize the interurban road network. It consisted on widening and upgrading existing corridors up to high capacity roads, but lacking most of the quality standards of the tolled network.

The program mainly focused on providing Madrid –geographically located in the centre of the peninsula– with radial high quality connections up to the

most important Spanish cities. It also aimed at alleviating the deficit of road infrastructure in less developed regions, not attended to in the previous period.

- Third period (1996-2008): The liberal position of the elected Popular Party and the need to contain the public deficit as a prerequisite for joining the Eurozone, moved the central government towards using again the toll concession approach to build new high capacity roads. Concessions awarded in this period followed different approaches, not always based on road user charging, such as shadow tolls, availability payment mechanisms, etc. Nevertheless, toll highways comprised a significant number of the new road projects promoted.

Despite some sections built in the Mediterranean coast (Alicante–Cartagena, Cartagena–Vera, Estepona–Guadiaro, Circunvalación de Alicante), toll highways granted in this period especially focused on the Madrid region. In order to tackle with the increasing road congestion in the area, the central government decided to promote 5 toll roads (with a total of 240 km) parallel to the existing free radial highways entering the city of Madrid. Furthermore, regional and even local governments became actively involved in road infrastructure and promoted numerous highway projects within their competency. Due to the greater electoral profitability of free roads, they generally avoided those approaches requiring payments from the user, so shadow tolls and availability payment schemes became the most common funding mechanisms at those governmental levels.

Consequently, the current situation in Spain is an interurban toll network asymmetrically located throughout the country. As can be seen in Table 1.6 and Figure 1.2, great contrasts can be found in the Spanish high capacity network. While regions such as Catalonia, Valencia or Galicia have an extensive tolled network (above 300 km), other territories such as Extremadura, Cantabria or Asturias have few, or even no, tolled kilometers. As mentioned above, this is a result of the historical evolution of road policy in the country (see Figure 1.8). At the beginning of the 1980s, high capacity roads in Spain were scarce and mainly

comprised tolled sections concentrated in few regions. It was not until the 1990s and early 2000s that the high capacity network significantly increased and spread over most of the territory, generally financed through the public budget.

Figure 1.8. Evolution of the interurban high capacity network in Spain (1990-2010)

Source: Author's elaboration from Ministerio de Fomento (2011)

Every toll highway in Spain have a free parallel road competing with it. The quality of the alternative route can significantly vary depending on the case, since it can be either a conventional (two-lane) road, generally with poor quality, or a high capacity road (highway). In parallel to the asymmetrical density of toll roads throughout the territory, great heterogeneity can be also observed regarding the quality of the alternative route. Tolled sections competing with free highways are numerous in regions such as Madrid, while in the Basque Country or Catalonia the alternative route is generally formed by a conventional road. As a consequence, since a higher quality in the free parallel road available increases the ability to avoid tolls, this asymmetrical distribution forces drivers –in a certain way– more strongly to use toll roads in some specific regions to save travel time.

The regional asymmetry of the tolled network has been one of the reasons why people in certain Spanish regions have a sentiment of unfairness for especially enduring the burden of tolls. While drivers in Catalonia or Valencia have been paying tolls for decades, regions such as Castilla y León, Castilla-La Mancha or Andalusia have been provided with many free high capacity kilometers in the last 20 years (see Table 1.6). Territorial inequity in this respect is an issue repeatedly claimed and proposed in the political agenda by nationalist parties in regions such

as Catalonia. Furthermore, social movements and associations have recently appeared at the regional level to coordinate protests and actions towards tolls, claiming for undergoing charging unfairness compared to the rest of Spaniards. This is the case of the so-called *No vull pagar* (in Catalan, “not wanting to pay”) movement, present in the region of Catalonia and, to a lesser extent, in Valencia. Since 2012, this movement has occasionally organized protests in existing toll roads, encouraging drivers to cross tollgates without paying the toll and collapsing toll plazas for hours. At this point, it might happen that users’ perceptions towards toll roads in some of these regions may be a result of their political ideology, what is strongly related to sociological aspects and the feeling to be part of a particular social group.

Table 1.6. Evolution of the interurban high capacity and toll road network in Spanish regions (1990-2010)

Region	Surface (10 ³ km ²)	1990			2010		
		High capacity network (km)	% tolled	Tolled network (km)	High capacity network (km)	% tolled	Tolled network (km)
Andalusia	87.6	726	24.2	176	2,642	9.1	241
Aragon	47.7	330	58.2	192	781	20.1	157
Asturias	10.6	80	76.3	61	408	5.4	22
Balearic Islands	4.9	42	0.0	0	183	0.0	0
Basque Country	7.2	359	62.1	223	598	41.5	248
Canary Islands	7.4	198	0.0	0	308	0.0	0
Cantabria	5.3	42	57.1	24	220	0.0	0
Castilla-La Mancha	79.4	435	0.0	0	1,809	13.2	239
Castilla y León	94.2	501	41.3	207	2,303	11.9	275
Catalonia	32.1	838	68.4	573	1,336	47.2	631
Extremadura	41.6	17	0.0	0	744	0.0	0
Galicia	29.6	141	83.7	118	1,055	31.1	328
Madrid	8.0	472	20.1	95	973	14.9	145
Murcia	11.3	82	14.6	12	630	18.3	115
Navarra	10.4	172	88.4	152	380	36.6	139
La Rioja	5.0	129	91.5	118	165	72.1	119
Valencia	23.2	561	68.6	385	1,427	25.7	367

Source: Author's elaboration from Ministerio de Fomento (2011)

1.6 Methodological approaches adopted

This chapter briefly summarizes the methodological approaches most commonly adopted up to date in the literature when analyzing road demand behavior either at the macro or micro level.

Macro approach: evolution of aggregate traffic: panel data methodology

With a similar approach as other research studies in the field of Economics, some previous contributions have analysed the evolution of road traffic demand through a macro approach. In essence, this framework consist on explaining the evolution of traffic demand (Y) by determining its short and long-run relationships with different explanatory factors (X_k).

$$Y = f(X_k) \quad (3)$$

To that end, different econometric and regression techniques can be adopted, depending on the hypothesis assumed in the analysis and the data available. Among the most used approaches, we can find *time series* analysis, in which the same individual (e.g. a certain dependent variable) is observed over time; or *cross-section* analysis, in which observations of different individuals are collected for a specified period. As an extension of the common specifications, the so-called panel data techniques allow the researcher to combine both strategies, since observations from different individuals over time can be analysed. The panel approach represents a great contribution to explain road traffic through a macro approach: while the incorporation of the time variable enables evaluating the sensibility of road demand towards changes in the evolution of the explanatory parameters, the cross-section component adds variability to the sample.

In its general form, the panel specification can be considered as:

$$y_{it} = f(x_{it}) = \alpha y_{i,t-1} + \beta_1 x_{1it} + \beta_2 x_{2it} + \dots + \varepsilon_{it}, \quad i = 1, 2, \dots, n; \quad t = 1, 2, \dots, T \quad (4)$$

where: y_{it} : dependent variable, referred to individual i for time t.
 x_{kit} : explanatory variable referred to individual i for time t.
 ε_{it} : idyosincratic error (random), referring to individual i for time t.

Panel data specifications can be divided into static and dynamic ones, the latter including a lag of the dependent variable in the model expression. As pointed out by Garín-Muñoz (2004) or King et al. (2011) among others, not including the lag of the dependent variable can produce an overestimation for the rest of explanatory variables in the results.

Likewise, structures adopted in panel data techniques have varied over time in order to overcome the weaknesses and limitations subsequently encountered. Then, panel data structures have evolved from *Ordinary Least Squares* (OLS), to *Within Groups* (WG) estimators and finally *Generalized Method of Moments* (GMM). This technique, proposed by Arellano and Bond (2001), is the most widely used in the literature when analyzing panel trends over time.

Micro approach: analysing users' choices at the individual level

In contrast with the previous macro approach, the majority of the existing research has focused on analyzing road demand behavior from a micro approach. Basically, this perspective is aimed at determining the explanatory parameters determining or influencing drivers' choices, so a more detailed level of information is required. To that end, two main methodologies have been adopted to collect data at the individual level:

- Conducting surveys to road users, either stated preference (SP) or revealed preference (RP) surveys, so respondents report their perceptions and choices in hypothetical or real scenarios. This is the methodological framework mainly adopted to analyse users' willingness-to-pay and valuation of travel time reliability.
- Collecting data from loop detectors or automatic license plate recognition (ALPR) systems installed in the road network, so the choice made by every single vehicle within a certain number of road sections can be known by the researcher.

Both approaches are developed as empirical data collectors to subsequently feed discrete choice models, generally developed through logit specifications. With regard to the first methodological framework, **stated preference (SP) surveys** are characterized by a variety of presentations for questionnaires. As pointed out

by Hensher (1994) time ago, they have been widely used in travel behavior research and practice to identify behavioral responses to choice situations which are not revealed in the market. Nevertheless, some limitations and problems can be encountered with this technique, since the attribute levels offered by survey choices are often modified to a great extent compared to real conditions. According to Odeck et al. (2010), SP surveys may show a limited usefulness since potential users are asked about choices they may have not experienced or are not easy for them to imagine. For these reasons, economists have generally regarded SP methods with some scepticism, preferring choices observed in the market place (Wardman, 1998). Nevertheless, SP techniques allow conducting a first approach to evaluate demand responsiveness under conditions which do not yet exist (Kroes et al., 1988). Among other advantages, they are easier to control, since the researcher defines the conditions that are being evaluated by respondents; show greater flexibility, because a wider variety of variables can be explored; and are cheaper to apply, given that multiples observations are provided for variations in the explanatory variables of interest for the researcher.

Figure 1.9. Data sources for value of travel time reliability studies

Source: Carrion et al. (2012)

By contrast, **revealed preference (RP) techniques** consider observations on actual choices made by individuals when modelling travel behavior preferences. As mentioned by Hicks (2002), their main advantage is that this methodology avoids the potential problems associated with hypothetical responses such as the so-

called strategic responses, or failures to properly consider behavioral constraints, e.g. scarce variability, in real choices. Nevertheless, the strength of this technique is also its primary weakness. Since RP specifications only rely on observable trips, the analyses are limited to a limited number of case studies or roads already in operation, so the effect of the potential implementation of policy measures cannot be approached through this framework. Therefore, RP surveys may not be a suitable tool for quantifying preferences in those situations with a lack of variation or not observable attributes (Hicks, 2002).

Finally, traffic data at the individual level can be collected through technological developments. The solutions most commonly used are **loop detectors and automatic license plate recognition (ALPR) systems** installed in the road network. The main advantage of this approach is the collection, with no intrusive methods, of a great amounts of data regarding not only traffic variables, but also some characteristics associated to each particular vehicle (e.g. type of model as a proxy of users' income) or traffic conditions (average speed, congestion, etc.). In this framework, the information is collected every 30-60 seconds, so average travel times in the road network can be estimated every 5-15 min intervals. The data collected is subsequently treated in order to analyze the distribution and variability of travel time by its median, and travel time reliability by the difference between a certain percentile (typically the 90th) and the median, as in Lam et al. (2001).

The data collected through any of the methods commented above is generally used to feed a discrete choice model to measure users' perceptions or willingness-to-pay. Choice models fall into the category of utility maximization models and incorporate the micro-economic theories of consumer behavior and psychological choice behavior. Rational choice models assume that a person chooses the alternative with the higher utility (Ben-Akiva et al. 1985; Train, 2003) among all the options available. The utility of each choice can be determined by a number of parameters related to both personal attributes of the individual (X) and characteristics of the alternative itself (S), which are described below. Then the utility in the model is approached as follows:

$$U_{ik} = f(X_{ik}, S_{ik}) \quad (5)$$

where U_{ik} is the utility gained by individual k for choosing alternative i . U_{ik} is considered a random variable and therefore consists of a sum of observed V_{ik} – systematic or representative component of the utility– and random components ε_{ik} :

$$U_{ik} = V_{ik} + \varepsilon_{ik} = \beta_k X_{ik} + \varepsilon_{ik} \quad (6)$$

where is X_{ik} a vector of measurable characteristics that defines utility, such as age, income, trip frequency, etc.; and β_k is a vector of parameters to be estimated in the model (Louviere et al., 2006). Economic theory assumes that the individual k will choose the option with the highest utility ($U_{ik} > U_{jk}$). Among the discrete choice or probability models, logit specifications are clearly the most used ones, due to some of their advantages such as the lack of linear relationship between probabilities modelled and explanatory variables. In the general form of a logit model, the probability that respondent k will choose alternative i is expressed as (Ben-Akiva et al., 1985):

$$P_i = \frac{e^{V_{ik}}}{\sum_j e^{V_{ij}}} \quad (7)$$

Then, the logistic regression predicts the logit of the odds ratio, L_i , given multiple explanatory variables X_i (Peng et al., 2002):

$$L_i = \ln \frac{P_i}{1 - P_i} = \alpha + \beta_1 X_1 + \beta_2 X_2 \dots + \beta_k X_k \quad (8)$$

As a result of this linearization process, the interpretation of the β_i coefficients is different compared to those from lineal regression models. Furthermore, the model resort to nonlinear estimating procedures using the method of maximum likelihood (Gujarati et al., 2004), so a quite large sample size is required.

1.7 Objective and research questions

Based on the above considerations, the objective of this thesis is about providing knowledge for explaining road traffic demand over time as well as users' perceptions and willingness-to-pay in interurban roads, taking Spain as case study.

The research involves analysis at both the macro and the micro level to provide insight regarding road use behavior in interurban roads, particularly tolled ones. The research framework comprises two main areas (see Figure 1.10):

- A Macro analysis aimed at identifying those variables explaining road demand evolution over time in interurban toll roads. This analysis is conducted at the national level, for both light and heavy vehicle demand.
- A Micro analysis aimed at identifying the explanatory variables determining users' perceptions and willingness-to-pay in interurban toll roads, as well as exploring the relationship observed between these two concepts.

Figure 1.10. Overall picture of the research framework

To achieve these objectives, several questions stated above need to be answered and these are developed in different academic papers, namely:

I & II. Which are the explanatory variables that better determine road demand evolution over time for light and heavy vehicle demand in interurban toll roads? Can the significant road demand decrease observed since the beginning of the economic crisis be considered an anomaly from a statistical point of view?

The reason for this research question is that the existing literature on interurban toll roads has left some issues to be investigated, mainly the identification of the socioeconomic variables better explaining the evolution of road demand over time. In this respect, GDP has usually been the only socioeconomic variable considered to analyse and forecast light and heavy vehicle demand, but this choice is based on no further reason than the usual practice. To solve this problem, the thesis will develop a dynamic panel data methodology to assess to what extent GDP constitutes a suitable explanatory variable for toll road demand, and to explore the explanatory power of other variables.

Additionally, few researches have analyzed the impact of an economic crisis on toll road demand. Therefore there is a need to explore to what extent sharp reductions observed in road demand during economic crises can be explained through the current methodologies applied. In addition, it is necessary to identify those variables valid to simultaneously explain road traffic evolution both in times of economic growth and slowdown. To that end, the research will analyze road demand comprising different time periods in terms of economic growth, applied to an interesting case as it is the Spanish interurban toll network. The sharp traffic reductions experienced in the toll network in this country since 2007, for both light (-28%) and heavy vehicles (-39%), makes it an ideal case to be studied.

To sum up, this question wonders about suitable explanatory variables for road demand, in order to provide policymakers and stakeholders involved in road management, a useful path to estimate more accurate traffic forecasts. This can be considered crucial for the evaluation of transport policies and the assessment of future investment needs.

III. What are the main individual characteristics and road-related attributes determining users' perceptions and willingness-to-pay in interurban toll roads? Is there any strong relationship between users' perceptions and their willingness-to-pay?

Up to date, users' perceptions and willingness-to-pay have been widely studied in the literature, mainly for urban and metropolitan roads. Nevertheless, there is scarce literature regarding interurban roads, where mobility characteristics are far different from these ones previously mentioned. At this point, it is necessary to check to what extent travel patterns and explanatory factors can vary when considering interurban roads. The analysis is particularly relevant for context-specific variables, as they evidenced to be more determinant on users' perceptions than purely individual socioeconomic characteristics such as age, income, etc.

Additionally, the majority of papers found in the literature do analyze perceptions and willingness-to-pay separately, so a direct comparison between them has not been established and commented up to date. In this respect, it is needed to simultaneously analyze the results obtained for users' perceptions and willingness-to-pay, and evaluate the relationship between them. It will be essential to determine to what extent a positive/negative attitude towards toll roads will lead the user to a higher/lower willingness-to-pay for using a certain toll facility. The trends concluded from this relationship will be relevant to approach the influence of public acceptability on users' choices and, subsequently, on road infrastructure viability.

IV. Do users' perceptions towards tolls significantly vary within the same interurban corridor, either across toll roads or regions? If so, what are the reasons explaining such differences?

The existing literature has evidenced that individual socioeconomic variables are not generally conclusive to explain users' perceptions towards toll roads, while context-specific variables (comprising road-related attributes, social atmosphere, etc.) may play a major role in certain situations. This seems to be the case of interurban roads –characterized by long-distance trips– where users from different toll roads and even regions are usually involved in a different

environment each other. At this point, considering that e.g. users from the same region may show a similar perception, in turn different to what is perceived in other different regions, seems a reasonable idea.

To that end, a special focus on users' perceptions will develop a regional analysis to explore whether significant differences can be concluded across different regions. It will be tested for the Spanish toll network, an interesting case study in the international context given the marked asymmetry of its interurban high capacity network, with toll roads concentrated in few regions while other ones present scarce or no tolled sections. Then, the thesis will explore potential differences in users' perceptions across regions by adopting an econometric technique specifically suited for this purpose. As far as the author is concerned, this type of analysis has not been implemented in the transport sector.

1.8 Research methodology

The process to achieve the above objectives and to answer the research questions has been structured into the following stages in Figure 1.11:

- Review of econometric methodologies previously applied to explain road demand evolution, and data availability to develop the new analysis at both the macro and the micro level.
- Regarding the macro approach to road demand evolution: development of an original approach, through an econometric specification, to identify the most suitable variables explaining road traffic volume over time, for both light and heavy vehicle demand. Additionally, the econometric approach will analyze the impact of the economic crisis on toll road demand, as well as on the consistency of the results obtained.
- Regarding the micro approach to road demand evolution: firstly, the thesis will model users' perceptions and willingness to pay in interurban toll roads by exploiting data from a nationwide survey. After analyzing each concept through the proper econometric technique, we will explore the potential relationship between perceptions and WTP reported in the sample. Secondly, a special focus will be made to measure potential differences in users'

perceptions due to the asymmetrical distribution of toll roads across regions. To that end, an econometric technique especially suited for this type of analysis will be adopted.

- Finally, draw conclusions on practice-oriented and policy recommendations and identify areas for further research.

Figure 1.11. Research steps

1.9 Thesis structure

The research questions previously identified were synthesized in academic papers that have been published or submitted to international journals included in the Journal Citation Report (JCR) index. Consequently, the thesis is structured into 5 chapters that contain the research papers. These papers develop an analysis of road demand in interurban toll roads, both at the macro –aggregate traffic evolution over time– and the micro –perceptions and willingness-to-pay for individual users– approach. The application to the Spanish case represents an interesting example in the international context, given the sharp traffic reduction experienced since the beginning of the economic crisis; as well as the marked heterogeneity of the toll network across regions. The results of the research have important implications for policymakers and stakeholders involved in the management of interurban toll roads.

The papers are referred to in the text by Roman numerals I to IV (see Section 1.10):

- **Chapter 1** is the present introduction. It summarizes the literature review in the field of interurban toll roads and includes a description of the research gaps identified and the main objective of the research.
- **Chapter 2** develops the macro approach towards traffic analysis in interurban toll roads. It addresses road demand evolution over time for light and heavy vehicle demand, identifies some key explanatory variables, and studies the potential impact of the economic crisis on the results. (papers I and II).
- **Chapter 3** develops the micro approach towards road demand analysis in interurban toll roads. It explores users' perceptions and willingness-to-pay by exploiting a nationwide survey conducted to road users in the Spanish toll road network (paper III). Additionally, it establishes a special focus on users' perceptions towards toll roads by analyzing regional differences observed in a toll network asymmetrically distributed throughout the territory (paper IV).
- Based on the results of the previous chapters and papers, **Chapter 4** is a summary of the main conclusions and contributions of the thesis. It also includes some future research lines.
- **Chapter 5** includes a compilation of all references used in the research.

1.10 List of original publications

This thesis is based on the following papers that have been published, are forthcoming or have been submitted to a scientific peer-reviewed journal. As a result there is some overlap in the content between the chapters (papers), which address those research questions previously identified.

The papers are referred in the text by Roman numerals I-IV:

- I. Gomez, J., Vassallo, J.M., Herraiz, I. (2015). Explaining light vehicle demand evolution in interurban toll roads: a dynamic panel data analysis in Spain. Published online in *Transportation*, doi: 10.1007/s11116-015-9612-3.
- II. Gomez, J., Vassallo, J.M. (2015). Evolution over time of heavy vehicle demand in toll roads: a dynamic panel data to identify key explanatory variables in Spain. *Transportation Research Part A: Policy and Practice*, v.74, pp. 282-297. ISSN 0965-8564, doi: 10.1016/j.tra.2015.02.017.
- III. Gomez, J., Papanikolaou, A., Vassallo, J.M. (2015). Users' perceptions and willingness to pay in interurban toll roads: identifying differences across regions from a nationwide survey in Spain. Published online in *Transportation*, doi: 10.1007/s11116-015-9662-6.
- IV. Gomez, J., Papanikolaou, A., Vassallo, J.M. (2016). Measuring regional differences in users' perceptions towards interurban toll roads. *Journal of Transport Geography*, v. 54, pp. 22-33. ISSN 0966-6923, doi: 10.1016/j.jtrangeo.2016.05.001

2. ROAD DEMAND EVOLUTION OVER TIME: A MACRO APPROACH TO IDENTIFY KEY EXPLANATORY VARIABLES IN INTERURBAN ROADS

This chapter develops a macro approach on toll roads demand to identify the key variables explaining its evolution over time. Although the previous research studies and traffic forecasts have used GDP as the socioeconomic variable to explain both light (article I) and heavy vehicle (article II) demand, the current analysis explores its suitability as an explanatory variable. Alternatively, different variables are tested to explain road demand at a macro level: Employment and GDP per capita for light vehicles, and GDP of transport-intensive sectors for heavy vehicles. Furthermore, the influence of toll road location (interior/coast) on demand behaviour is explored. Finally, the research discusses the impact of the economic crisis on road demand evolution.

Figure 2.1. Chapter 2 scheme

To that end, these papers develop a dynamic panel data methodology to measure variability on demand elasticities over time. This approach is applied to the

Spanish toll roads for the 1990-2011 period, which constitutes a very interesting case given the sharp traffic decrease experienced since the beginning of the economic crisis.

This chapter includes two papers that have been published as:

- I. Gomez, J., Vassallo, J.M., Herraiz, I. (2015). Explaining light vehicle demand evolution in interurban toll roads: a dynamic panel data analysis in Spain. Published online in *Transportation*, doi: 10.1007/s11116-015-9612-3.
- II. Gomez, J., Vassallo, J.M. (2015). Evolution over time of heavy vehicle demand in toll roads: a dynamic panel data to identify key explanatory variables in Spain. *Transportation Research Part A: Policy and Practice*, v.74, pp. 282-297. ISSN 0965-8564, doi: 10.1016/j.tra.2015.02.017.

Explaining light vehicle demand evolution in interurban toll roads: a dynamic panel data analysis in Spain

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Abstract Tolls have increasingly become a common mechanism to fund road projects in recent decades. Therefore, improving knowledge of demand behavior constitutes a key aspect for stakeholders dealing with the management of toll roads. However, the literature concerning demand elasticity estimates for interurban toll roads is still limited due to their relatively scarce number in the international context. Furthermore, existing research has left some aspects to be investigated, among others, the choice of GDP as the most common socioeconomic variable to explain traffic growth over time. This paper intends to determine the variables that better explain the evolution of light vehicle demand in toll roads throughout the years. To that end, we establish a dynamic panel data methodology aimed at identifying the key socioeconomic variables explaining changes in light vehicle demand over time. The results show that, despite some usefulness, GDP does not constitute the most appropriate explanatory variable, while other parameters such as employment or GDP per capita lead to more stable and consistent results. The methodology is applied to Spanish toll roads for the 1990–2011 period, which constitutes a very interesting case on variations in toll road use, as road demand has experienced a significant decrease since the beginning of the economic crisis in 2008.

Keywords Light vehicle demand · Toll road · Demand elasticities · Dynamic panel data · Spain

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Introduction

Tolls have increasingly become a common mechanism to fund road projects (Matas and Raymond 2003). Improving knowledge of road demand behavior and estimating more accurately traffic forecasts constitute critical aspects for the evaluation of transport policies and for the assessment of future investment needs. Therefore, stakeholders involved in toll road management (governments, private operators, etc.) find it essential to identify the key parameters influencing road demand, as well as to quantify the strength of the relationships between traffic and certain socioeconomic variables. However, the state of knowledge concerning demand behavior for toll roads is still limited, partly because of its scarce number in the international context (Odeck and Brathen 2008; Matas and Raymond 2003).

Most of the previous research studies have been focused on urban areas (Borjesson et al. 2012; Olszewski and Xie 2005) or on particular tolled sections, such as bridges or tunnels (Holguín-Veras et al. 2011; Hirschman et al. 1995). However, research on interurban toll roads is scarcer and leaves some aspects insufficiently studied. Among other issues, GDP is generally the only socioeconomic explanatory variable included in the analysis. Furthermore, the econometric models applied often do not disaggregate toll road traffic into light and heavy vehicle demand, despite it being clear that the use of the two kinds of vehicles differs, based on different behavioral patterns. Finally, the impact of an economic crisis on road demand has hardly been analyzed in the literature.

The aim of this paper is to contribute to a better knowledge of the evolution of light vehicle demand on interurban toll roads by identifying some of the key socioeconomic variables influencing traffic behavior. Through an original methodology, we discuss the suitability and limitations of GDP as a socioeconomic explanatory variable of light vehicle demand on toll roads, and present alternative variables. The main objective is thus to fill the research gap found in the literature regarding the socioeconomic variables that better explain the evolution of light traffic demand over time. Additionally, this paper analyzes the effects of the economic crisis on light traffic for toll roads, and tests the suitability of the explanatory variables chosen.

The paper focuses on the Spanish toll road network, which constitutes an interesting case in the international context. The deterioration of the economic situation in Spain since 2008 has had a great impact on the level of traffic in the toll road network. According to data from the Spanish Ministry of Transportation (Ministerio de Fomento 2013), traffic has undergone a reduction of 28 % as compared with the peak reached in 2007. As a consequence, demand on toll roads has returned to levels of 1998, when the toll road network was 46 % shorter. Revenues of private concessionaires have decreased by 10 % in 2012 as compared with levels in the previous year, which led the government to take critical measures to relieve their financial situation. This research discusses whether the significant reductions in recent years can be considered an anomalous fact when compared to previous trends.

This paper is organized as follows. After the introduction in “[Introduction](#)” section, “[State of knowledge](#)” section summarizes the state of knowledge regarding road traffic analysis, mainly focusing on interurban toll roads. In the “[Methodology](#)” section establishes the methodology of this research, by describing both data series and the panel data specification used to estimate demand elasticities. In the “[Modeling Results and Discussion](#)” section presents and discusses the results. Finally, “[Conclusions and further research](#)” section sets out the main conclusions and further research.

State of knowledge

Evolution of road demand over time has generally been a matter of interest in transport economics, and numerous studies have been conducted in the last decades to identify the key parameters influencing travel patterns. The responsiveness of road traffic with respect to different factors is measured through the concept of elasticity, by definition the relative change in travel demand induced by a relative change in a certain explanatory variable. Research studies aimed at calculating the demand elasticity on free and tolled roads are briefly summarized in the following subsection.

Previous research for free roads

The literature analyzing travel patterns on free roads is extensive, specifically those studies measuring the influence of fuel prices on road demand. In the 190s, the first research works appeared which measured the impact of substantial gasoline price rises on fuel consumption and travel demand (Matas and Raymond 2003). More recent studies (Goodwin et al. 2004; Graham and Glaister 2004; De Jong and Gunn 2001) found that short-run elasticities with respect to fuel prices commonly range between -0.10 and -0.40 , and typically average about -0.30 . Nevertheless, demand elasticity can vary depending on different factors, such as magnitude of price changes, level of users income, perceived stability of price changes, or quality of alternatives, among others (Litman 2013). The percentage that fuel represents on the total cost of driving is also an aspect to be taken into account when analyzing the influence of fuel costs on travel behavior.

Other studies (Su 2011; Hymel et al. 2010) also mention the significance of the *rebound effect*, that is, the additional mileage driven that results from increased fuel efficiency. The elasticity of road demand with respect to income is also analyzed (Boilard 2010; Goodwin et al. 2004; Hanly et al. 2002) in urban and metropolitan areas. For Spain, González and Marrero (2011) have quantified the induced road traffic in Spanish regions, with a short-run fuel price elasticity of -0.28 , but they did not find significant results attributable either to variations in GDP or in GDP per capita.

Previous research for toll roads

As mentioned above, the literature regarding demand evolution for toll roads is still limited. After excluding studies in urban areas and special tolled sections (bridges and tunnels), only a handful of papers can be found, and they are focused on just a very few nations, including Spain, Norway, and the United States.

The implementation of tolls on roads can affect different aspects of travel patterns, as the user may reduce the mileage driven, change the origin/destination of the trip, shift to alternative modes, etc. (Litman 2013). In the long-term, it could even affect the location of residential housing, as well as manufacturing and distribution activities. Nevertheless, toll elasticities can show a wide range of values depending on the different purposes of a trip, income levels, and overall trip costs, as well as the attractiveness of alternative routes (Lake and Ferreira 2002). Therefore, the level of toll elasticity can significantly vary depending on the context, mainly in urban and metropolitan areas. Table 1 includes the most important previous studies analyzing light vehicle demand in toll roads, both in the urban and interurban context, and summarizes their main characteristics and results.

Table 1 Main research studies analyzing light vehicle demand in toll roads, both in the urban and interurban context

Context	Author (year)	Country	Type of road	Years covered	Elasticity results (short-run)				
					Fuel	Toll	GDP	Household income	Population
Urban	Jones and Hervik (1992)	Norway	Urban toll rings	1989		−0.22 to −0.45			
	Harvey (1994)	United States	Urban bridges and roads	1991		−0.05 to −0.15			
	Hirschman et al. (1995)	United States	Urban bridges and tunnels	1989		−0.25			
	Gifford and Talkington (1996)	United States	Urban bridge	1979–1984		−0.09 to −0.18			
	Cain et al. (2001)	United States	Urban bridges	1993–1995		−0.03 to −0.36			
	Loo (2003)	Hong Kong	Urban tunnels	1979–2000		−0.10 to −0.29			
	Odeck and Brathen (2008)	Norway	Urban motorways	2005		−0.45			
	De León et al. (2009)	US-Mexico	Urban bridges	1991–2004		−0.00 to −0.28			
	Cervero (2012)	United States	Urban bridge	2009–2011	−0.07	−0.23			
	Matas and Raymond (2003)	Spain	National tolled network	1979–1997	−0.31	−0.31	0.89		
Interurban	Álvarez et al. (2007)	Spain	Tolled motorway	1989–2000	−0.06	−0.54	0.83		
	Odeck and Brathen (2008)	Norway	Rural roads	2005		−0.74		0.39	
	Burris and Huang (2011)	United States	Interurban and metropolitan roads	2000–2010	−0.06	−0.30			1.31
	Matas et al. (2012)	Spain	National tolled network	1980–2008	−0.39	−0.15 to −0.49	0.75		
	Cantos and Álvarez (2009)	Spain	Metropolitan motorway	2006		−0.92			

This paper focuses on interurban roads, generally with higher toll elasticities as compared to road traffic in urban contexts, as can be observed in Table 1. These differences may be caused by the higher cost and the greater percentage of long-distance trips in interurban road demand. According to the literature, long-distance trips have empirically shown higher travel demand elasticities than short-distance movements, typically within urban areas. Mattson (2008) concluded that vehicles operating for longer distances are more sensitive to changes in gas prices than those travelling shorter ones. Regarding transit ridership, a study conducted in Australia by Currie and Phung (2008) found that short-run fuel elasticities for journeys over 25 km were four times higher than those routes below 7 km. Furthermore, Odeck and Brathen (2008) calculated toll elasticities for different Norwegian roads, with higher values for rural roads than for urban motorways. Therefore, long-distance trips seem to be more sensitive to changes in generalized transport costs. This varying responsiveness of long and short-distance trips have been linked (Mattson 2008) to the higher amount of costs—fuel, tolls, etc.—associated with the former, with long-distance trips providing greater motivation for changing the route, shifting to alternative modes of transport, or cancelling the trip altogether.

Next, we summarize the main results of interurban toll roads from the literature, sorted by country. In the case of the United States, the most consistent research was developed by Burris and Huang (2011), who analyzed a sample of 12 interurban and metropolitan toll roads throughout the nation during an 11 year period (2000–2010). They establish an approach based on time series ADL models, including population, unemployment rate, gas prices and toll rates as explanatory variables. They found statistically significant results for light vehicle demand elasticities with respect to gas prices (with a mean of -0.06) and toll rates (averaging -0.30). As for the socioeconomic variables in the model, short-run elasticities with respect to population averaged 1.31, while results for unemployment rate were not completely consistent. On the other hand, the study by Wilbur Smith (2008) for the North Texas Tollway Authority focused on the potential impacts that gas prices can have on toll revenues rather than solely on travel demand.

Regarding Norway, Odeck and Brathen (2008) calculated the elasticity of travel demand in 19 Norwegian toll road projects, including cordon toll rings, tolled trunk roads between cities and tolled roads in peripheral regions. Explanatory variables considered in the analysis were generalized transport costs, household income and toll rates. Detailed results were only provided for the last variable, with short-run toll elasticities of motorways around -0.40 and -0.48 . Furthermore, Odeck and Kjekreit (2010) provided further insight into users' attitudes towards charges for road user by examining 6 different Norwegian toll schemes.

For the case of Spain, the study on the tolled motorway network by Matas and Raymond (2003) can be considered as the most significant. For the 1979–1997 period, they develop a panel data approach, showing an average demand elasticity of around -0.30 with respect to both gasoline prices and to toll rates. National GDP is the socioeconomic variable chosen in the analysis, with a demand elasticity of 0.89. More recently, results for Spain have been updated by Matas et al. (2012). In their new research paper, that included the 1980–2008 period, they obtained toll elasticities—between -0.15 and -0.49 —, while short-run elasticities with respect to gasoline prices and GDP were, respectively, -0.39 and 0.75. The authors pointed out that it is often unrealistic to assume a constant elasticity, as it can vary depending on such factors as road capacity constraints. Furthermore, Cantos and Álvarez (2009) analyzed demand behavior in the radial toll roads in Madrid, while Álvarez et al. (2007) calculated the value of time and travel elasticities for both a Spanish toll motorway and its free parallel road. In this case, short-run elasticities concluded a

substantial influence of toll prices (-0.54) and GDP (0.83) on road demand, with a lower value for fuel prices (-0.06).

As can be seen, the existing literature on interurban toll roads leaves some aspects to be investigated. First, GDP is generally the only socioeconomic variable included in the analysis for light vehicle demand. In this respect, it is necessary to assess to what extent GDP constitutes a suitable explanatory variable for toll road demand, and to explore other possible alternatives. Furthermore, few researchers (Burris and Huang 2011) have analyzed the impact of an economic crisis on toll road demand. For the case of Spain, no previous studies have addressed this particular question.

Methodology

This section presents the data collected for the analysis of light vehicle demand on Spanish toll roads, as well as the methodology we followed to develop the dynamic panel data approach.

Previous data analysis

In order to estimate the demand equation for light vehicle traffic, we establish a dynamic panel data corresponding to 14 Spanish toll roads observed between 1990 and 2011. The sample includes those toll highways whose traffic data series are sufficiently long for the statistical approach adopted in this paper, which analyzes—as shown later—the evolution of demand elasticity values as the time period becomes longer. Other existing tolled sections in Spain—those toll highways resulting from the second phase of tender offers in the Spanish toll network, whose operation started after 1998—provide traffic data series too short to be usefully considered in the analysis. All the toll highways in the sample have a free parallel conventional road that competes with it. The analysis then focuses on toll roads for which a free alternative of lower quality exists, characteristics of which have kept constant during the period analyzed. Additionally, competing alternative modes have remained almost unchanged for the sample selected. Use of only two toll highways may be influenced by the new high-speed rail services operating between Madrid–Valladolid and Madrid–Barcelona since 2007 and 2008, respectively. The toll roads included in the study, and new high speed services implemented in Spain, do not generally belong to the same travel demand corridor. For the only two cases where toll road demand may have been affected by new rail services, the effect can be considered limited as the implementation of high speed rail may only affect 4–6 observations in a sample with a total of 294 observations. Then, it can be assumed that they do not provide a lot of insight, and their effect on the results is expected to be very limited. Additionally, passenger transport in Spain mainly corresponds to road transport (91.5 % of total passenger-km in 2012), whose percentage is even greater when considering only land transport (94.3 % of total passenger-km in 2012). Therefore we have not taken into account competing modes in the model, given the size of the sample and the length of the period covered (1990–2011) in the analysis.

The dependent variable of the demand equation is the annual average daily traffic volume (AADT) for light vehicles in each toll road. These data have been collected from the statistics of the Spanish Ministry of Transportation (Ministerio de Fomento 2012). Although traffic data from shorter tolled sections were available—approximately, every 20 km—, only the data for the entire length of a toll road has been considered in order to

avoid spatial correlation problems in the models, since data from short sections of the same highway are highly dependent on each other. That is, traffic volumes from consecutive road sections are very similar and clearly related to each other.

Three kinds of explanatory variables have been included in the demand equation (see Table 2): demand variables of previous years, socioeconomic variables and generalized cost ones. The demand variable ($AADT_{(-1)}$) consists of a lag of the traffic volume, a term needed due to the dynamic nature of the panel. For socioeconomic variables, three alternatives have been considered: GDP, employment, and GDP per capita. These data have been collected from the Spanish National Statistics Institute (INE). Other socioeconomic variables, such as population and size of vehicle fleet, have been discarded for two main reasons. Firstly, they are highly correlated with other socioeconomic variables included in the model. And secondly, weaker relations with traffic evolution were observed when compared to other explanatory variables considered, especially after the beginning of the crisis.

As mentioned before, three kinds of explanatory variables are included in the demand equation: previous demand, socioeconomic variables, and generalized cost variables. Specifically, it incorporates a lag of the traffic volume ($AADT_{(-1)}$), a Socioeconomic variable and two Generalized cost parameters (Toll and Fuel), which results in a total of four categories of independent variables:

$$AADT = f(AADT_{(-1)}, Socioeconomic., Toll, Fuel) \quad (1)$$

According to Table 2, the analysis often considers alternatives within these four categories, mainly in the socioeconomic one. This methodology allows us to calibrate several versions of the model just by taking one variable in each category presented for the demand equation. Therefore, by running all the available combinations of variables, we can establish up to 12 different versions of the model specification we propose. This variability improves the analytical capability of the methodology applied. Further details about both the demand equation and the methodology specification are provided in “[Dynamic panel data methodology specification](#)” section. Additionally, a precise definition of each variable included in Table 2 is presented in the [Appendix](#).

Concerning socioeconomic variables, two levels of data have been considered in the analysis: the provincial level and the national level. With the aim of better understanding

Table 2 Explanatory variables included in the analysis

Dependent variable	Explanatory variables				
	Previous demand	Socioeconomic	Generalized cost		Location in the country
			Toll	Fuel	
AADT (light vehicles)	AADT (-1)	GDP (provincial)	Toll rates (light vehicles)	Fuel Price: Gasoline and diesel prices (€/l)	Coast
		GDP (national)			
		Employment (prov.)			
		Employment (national)		Fuel cost: Fuel prices & Efficiency (€/km)	Interior
		GDP per capita (prov.)			
		GDP per capita (national)			

the influence of local socioeconomic characteristics on light vehicle demand, data have been collected at the provincial level. In Spain, a province is a geographical and political subdivision of a region. Each toll road is assigned the socioeconomic data from the various provinces it crosses, as detailed in the Appendix. Furthermore, data at the national level has also been tested, since the panel analysis comprises different toll roads spread throughout the country. National parameters are expected to constitute a good proxy for socioeconomic data, not for any particular road, but for the panel as a whole. Likewise, national data may be a satisfactory explanatory variable, as a significant part of light vehicle traffic in Spanish toll roads makes long trips, generally less related to local activities. Monetary socioeconomic variables (GDP and GDP per capita) have been deflated by the consumer price index (CPI) to reflect their real value over time.

With regard to economic variables, historical toll rates—expressed in euro/km—were collected from the statistics by the Spanish Ministry of Transportation (Ministerio de Fomento 2012). As for fuel cost, two simplifications have been effected when including this variable in the analysis. First, gasoline and diesel prices—expressed in euro/liter—have been taken together to create a *Fuel price* variable. To that end, both values are weighted by the proportion of gasoline and diesel light vehicle fleet for each year in the 1990–2011 period in Spain. And second, in order to include the *rebound effect* and reflect real fuel costs when driving (euro/km), an alternative variable called *Fuel cost* incorporates values of fuel consumption (liter/km) for light vehicles. For calculating fuel consumption over the 1990–2011 period, we introduce linear improvements in fuel efficiency, from average 1990 values provided by the Ministry of Transportation (MOPU 1990), to current levels, as supplied by the Ministry of Industry (Idae 2011). This way, we include the progression in fuel efficiency experienced during the 1990–2011 period in Spain. Both toll rates and fuel prices/costs have been adjusted for inflation by using the CPI.

As shown in Table 2, the model includes an explanatory variable to indicate the location of the toll road within the country. Although we usually work with the whole sample, separate analyses have been conducted for coastal and interior roads in Spain. Our analysis is intended to identify potential differences in traffic trends depending on the location of the toll road. Traditionally, the economy in coastal regions (Catalonia, Valencia, Andalusia, etc.) has been highly dependent on local activities such as tourism. Road traffic in these regions experiences significant peaks during the summer time and at Easter, and is expected to be greatly influenced by tourist demand. By contrast, toll roads in the inner part of the peninsula generally pass through less developed areas, with low population density, so their traffic is expected to be influenced more by the general status of the economy in the country. Then, it may happen that light traffic along coastal roads is better explained by provincial socioeconomic variables, whereas traffic along interior roads is better explained by national data. This distinction tries to evaluate what explains differences in toll road demand in coastal and interior areas, particularly with respect to both national and provincial socioeconomic data.

At this point, we want to emphasize the analytical capability of our methodology. Given the explanatory variables considered according to Table 2, the panel data allows us to calibrate up to 36 different versions of the model, if we take into account the 3 possibilities regarding the size of the sample. Numerous and quick cross-comparisons of elasticity estimates can be made in order to identify the most suitable explanatory variables of light vehicle demand.

Table 3 provides an overview of the evolution of some of the provincial socioeconomic variables for the toll roads selected before and after the economic recession. It shows the information for three significant years in the sample: the starting point (1990), the peak reached just before the economic crisis (2007), and the ending point (2010) because

information for 2011 at this level was not available at the time of the writing of this paper. Figures show the long and strong economic growth experienced in Spain during the 1990–2007 cycle, when national GDP increased by 78.0 %. For the provinces crossed by the toll roads selected, information presents average growth rates of 76.4 % for GDP, 50.2 % for employment and 55.4 % for GDP per capita. This period of prosperity has been followed by a slowdown that entailed a deterioration of the overall economic performance since 2008. National GDP fell by 7.4 % between 2007 and 2011. Provincial socioeconomic data also experienced significant average reductions from 2007 to 2010 for GDP (−5.2 %) as well as for employment (−8.9 %) and GDP per capita (−8.5 %).

Light vehicle demand has experienced trends similar to those of socioeconomic variables. For the selected toll roads, demand rose on average by 146.8 % over the period 1990–2007, which was in line with the economic growth in the country. Since the crisis began, the trend has changed, and traffic levels in 2010 were 9.9 % lower than the peak reached in 2007. These sharp variations observed in the toll road network during the last 20 years make Spain an interesting case to be analyzed, as well as a way to test the robustness of the models.

Dynamic panel data methodology specification

In this section we present a dynamic panel data methodology for studying the behavior of light vehicle demand in toll roads. It allows us to estimate short-term demand elasticities with respect to explanatory variables included in Table 2. All variables are expressed in logarithms. The form proposed for the estimation models is:

$$AADT_{it} = \eta_i + \lambda AADT_{i,t-1} + \beta_1 Fuel_t + \beta_2 Toll_{it} + \beta_3 Socioec_{it} + \varepsilon_{it} \quad (2)$$

With provincial socioeconomic data: $t = 1990, \dots, 2010$; $i = 1, \dots, 14$

With national socioeconomic data: $t = 1990, \dots, 2011$; $i = 1, \dots, 14$

Given the dynamic nature of the analysis, the equation includes a lag of the demand variable ($AADT_{t-1}$). *Fuel* denotes fuel costs assumed by users, expressed either in euro/liter or euro/km. *Toll_{it}* denotes the toll rate (euro/km) applied in road *i* for year *t*. Finally, *Socioec_{it}* denotes different socioeconomic data (GDP, Employment and GDP per capita) assigned to road *i*, either at the provincial or national level. Regarding the rest of the parameters, β_k is the short-run elasticity of road demand with respect to explanatory variable *k*; λ measures possible autocorrelation in traffic data series; η_i denotes unobserved individual effects, that is, constant and specific factors for each tolled road, not accounted for by in the rest of the variables in the model; finally, ε_{it} is the residual or idiosyncratic error.

Regarding initial conditions, we assume (Blundell and Bond 1998) that η_i and ε_{it} are independently distributed across *i* and have the familiar error components in which:

$$E(\eta_i) = 0, E(\varepsilon_{it}) = 0, E(\eta_i \varepsilon_{it}) = 0 \quad \text{for } i = 1, \dots, N \text{ and } t = 2, \dots, T \quad (3)$$

$$E(\varepsilon_{it} \varepsilon_{is}) = 0 \quad \text{for } i = 1, \dots, N \text{ and } \forall t \neq s$$

In addition, there is the standard assumption concerning the initial conditions of the demand variable, included in (4). According to Blundell and Bond (1998), these conditions imply moment restrictions that are sufficient to identify and estimate η_i in a dynamic panel data for $T \geq 3$, as it is in our case.

Table 3 Evolution of average light vehicle demand for Spanish tolled motorways considered and provincial socioeconomic data (1990–2010)

Tolled roads	AADT			GDP			Employment			GDP per capita		
	1990	2007	2010	1990	2007	2010	1990	2007	2010	1990	2007	2010
Montmeló–La Jonquera	22,069	38,526	35,315	49.7	89.9	84.7	2,046	3,241	2,935	9.6	14.9	13.5
Barcelona–Tarragona	33,519	53,092	45,646	50.3	90.5	85.4	2,041	3,222	2,923	9.7	14.9	13.5
Zaragoza–Mediteráneo	9,827	13,254	11,076	16.8	30.3	28.9	733	1,107	1,023	9.8	14.4	13.0
Villalba–Adanero	11,844	29,628	27,075	54.8	105.2	101.5	2,148	3,622	3,388	10.5	16.4	14.9
Sevilla–Cádiz	6,364	23,122	21,156	17.5	30.6	28.6	822	1,241	1,117	6.6	10.0	9.1
Tarragona–Valencia	10,310	19,656	15,066	27.1	47.5	44.1	1,253	1,846	1,604	8.7	12.4	11.0
Valencia–Alicante	11,045	26,978	19,915	26.5	48.2	44.2	1,277	1,967	1,692	7.8	11.2	9.8
Bilbao–Zaragoza	5,868	12,822	12,413	23.4	40.9	39.3	989	1,403	1,298	9.2	15.2	14.2
Burgos–Armiñón	6,955	18,290	17,429	6.3	10.9	10.2	252	358	334	10.1	16.2	14.7
León–Campomanes	3,117	8,633	8,126	11.5	18.1	17.2	589	660	609	7.1	11.5	10.9
Montgat–Mataró	30,158	84,246	77,903	44.4	79.5	74.9	1,816	2,847	2,581	9.6	14.9	13.6
Bilbao–Behobia	14,151	28,186	27,456	17.5	29.8	28.9	681	971	906	9.3	16.2	15.5
Tudela–Iruzun	4,343	15,370	15,900	5.5	9.6	9.6	218	354	329	10.5	15.9	15.0
San Cugat–Manresa	6,364	22,179	19,514	44.4	79.5	74.9	1,816	2,847	2,581	9.6	14.9	13.6
Units	Light vehicles/day			10 ³ M€ (constant)			Thousand people			Thousand €/person (constant)		

$$E(AADT_{it} \varepsilon_{it}) = 0 \quad \text{for } i = 1, \dots, N \text{ and } t = 2, \dots, T \quad (4)$$

As pointed out by Graham et al. (2009), the main issue to be addressed in the context of dynamic panel estimation is correlation between the lagged dependent term ($AADT_{i,t-1}$) and the unobserved cross-section individual effects (η_i). This fact greatly limits the use of the estimators to be applied. The ordinary least squares (OLS) estimator for λ is then inconsistent (Hsiao 1986; Bond 2002) and biased upwards, at least in large samples (Nickell 1981; Blundell et al. 2000). The Within Groups (WG) estimator eliminates this source of inconsistency by transforming the equation to eliminate η_i , but gives an estimate of λ that is biased downwards, especially in short panels (Blundell and Bond 1998; Bond 2002). Therefore, a consistent estimate of λ can be expected to lie between the OLS and WG estimates (Arellano and Bond 1991; Bond et al. 2001).

Better estimates can be calculated with a generalized method of moments (GMM) approach, proposed by Arellano and Bond (1991). Within this technique, Eq. (2) is differenced to eliminate the individual effects:

$$\Delta(AADT_{it}) = \lambda \Delta(AADT_{i,t-1}) + \beta_1 \Delta(Fuel_t) + \beta_2 \Delta(Toll_{it}) + \beta_3 \Delta(Socioec_{it}) + \Delta\varepsilon_{it} \quad (5)$$

In this expression, we find that $\Delta(AADT_{i,t-1})$ is correlated with $\Delta\varepsilon_{it}$, since $AADT_{i,t-1}$ and ε_{it-1} are clearly correlated. Therefore, the condition of moment restrictions expressed in (4) cannot be fulfilled. To solve this problem, Arellano and Bond (1991) adopted the so-called difference GMM estimator (GMM-DIFF), which includes an instrumental variables (IV) approach. The GMM-DIFF estimator assumes that values of the dependent variable lagged two periods or more ($AADT_{i,t-s}$, for $s \geq 2$) are valid instruments for the lagged dependent variable in the differenced equation, $\Delta(AADT_{i,t})$. That is, assuming a set of instrumental variables which are correlated with $\Delta(AADT_{i,t-1})$ but orthogonal to the differenced residuals $\Delta\varepsilon_{it}$, we can establish a set of *moment conditions* that would be satisfied by the true values of the parameters to be calculated (Graham et al. 2009). Then, the moment conditions are defined as:

$$E(AADT_{i,t-s} \Delta\varepsilon_{it}) = 0 \quad \text{for } t = 3, \dots, T \text{ and } s \geq 2 \quad (6)$$

In this respect, if we assume an absence of serial correlation, in the differenced Eq. (5) we find that, for $t = 3$, $AADT_{i,1}$ will be correlated with $\Delta(AADT_{i,2})$ but orthogonal to $\Delta\varepsilon_{i,3}$, so that it can be used as an instrumental variable. Equally, for $t = 4$ $\Delta(AADT_{i,3})$ can be instrumented by $AADT_{i,1}$ and $AADT_{i,2}$, and so on. Then, it can be easily noted that an extra valid instrument is available with each additional time period. Nevertheless, due to some problems that can arise when too many instruments are considered (Roodman 2009), we have opted for using only the first lag available in each time period. Furthermore, according to Judson and Owen (1999), limiting the number of instruments does not materially reduce the performance of this technique.

The GMM-DIFF approach generates consistent and efficient estimates of the parameters (Rey et al. 2011), among other attractive properties noted in the literature (Graham et al. 2009). However, it suffers from very low precision in particular situations with finite samples (Kiviet 1995), mainly for highly autoregressive panel series. As pointed out by Blundell and Bond (1998), the instrumental variables estimator performs poorly as the value of λ increases towards unity, particularly at values around and above 0.8. In these cases, lagged levels $AADT_{i,t-s}$ become weak instruments in the differenced Eq. (5), which can result in serious problems of bias.

To overcome the *weak instrument* problem for persistent series, Arellano and Bover (1995) and Blundell and Bond (1998) suggested a system GMM estimator (GMM-SYS). This approach establishes a system of equations in both first differences and levels, where the instruments used in the levels equations are lagged first differences of the series. It allows yielding $(T-2)$ additional moments:

$$E[\varepsilon_{it} \Delta(AADT_{i,t-1})] = 0 \quad \text{for } t = 3, \dots, T \quad (7)$$

Exploiting these additional moment conditions can produce some advantages in cases where the autoregressive parameter is only weakly instrumented. Among other issues, the GMM-SYS approach can reduce the finite sample bias of results, improves the precision and constitutes a more efficient estimator (Arellano and Bover 1995). However, despite being smaller, the finite sample bias of the GMM-SYS estimator is generally upwards, in the direction of OLS levels (Blundell and Bond 1998). Finally, it must be noted that the most suitable technique in each case can change depending on the size of the panel (Judson and Owen 1999).

The most widely used tests to check the validity of hypotheses assumed in GMM estimators are the m1 and m2 tests, as well as the Sargan test (González and Marrero 2011). The m1 and m2 tests, proposed by Arellano and Bond (1991), detect first and second-order serial correlation problems in $\Delta\varepsilon_{it}$, respectively. Both tests are generally used to check that no serial correlation is observed in the estimated residuals ε_{it} , by meeting certain requirements (see “[Robustness of results](#)” section). Basically, there should be evidence of negative first-order correlation and no evidence of second-order correlation in $\Delta\varepsilon_{it}$ (González and Marrero 2011). Not fulfilling the needed requirements in m1 and m2 tests can reveal inconsistency of estimates (Garín-Muñoz 2006) or the possibility of improving the instruments chosen (Rey et al. 2011).

Additionally, the Sargan test checks the validity of the instruments used in the model. It is asymptotically distributed as a Chi square under the null of instrument validity, and detects possible correlation between the instruments and differenced residuals $\Delta\varepsilon_{it}$. It is a test of over-identifying restrictions, so that not rejecting the null is consistent with valid instruments. However, as noted by Böckerman et al. (2009), the Sargan test can have extremely low power when using too many instruments in the GMM model, so that results from the test should be interpreted with care (Graham et al. 2009). In order to limit this problem, we have adopted the alternative procedure proposed by Roodman (2009) consisting of using only the first lag instead of all available lags for instruments in the demand equation.

Further details about validity tests used in this paper are displayed in “[Robustness of results](#)” section analyzing robustness of results.

Modeling results and discussion

This section summarizes the main findings from the analysis of light vehicle demand evolution over time applied to Spanish toll roads. First, general aspects of the panel data approach adopted in this paper are shown in “[General aspects](#)” subsection. Next, “[Analysis of explanatory variables influencing light vehicle demand](#)” section presents the main results of travel demand elasticities and discusses the suitability of explanatory variables considered in the specification model. “[Summary of results](#)” section displays a summary

of the results previously estimated. Finally, the robustness of results is discussed in “[Robustness of results](#)” section.

General aspects

This paper develops an original approach in order to analyze travel demand evolution over time and identify the key explanatory variables influencing road traffic. This research is based on estimating short-run demand elasticities with a panel data specification. Nevertheless, we include some new aspects in the analysis:

- Stability of results is checked by gradually calibrating new runnings of the model with a longer time period considered in the analysis. Thus, the traditional static approach that presents elasticity results for a specific period is replaced by a dynamic approach, including the evolution of demand elasticities over time, when the time period is gradually extended. In this respect, those variables with poor stability and significant variations in their demand elasticities over time can be considered as unsuitable to explain the evolution of travel demand in the long term.
- As mentioned in “[Methodology](#)” section, the methodology includes a great variety of explanatory variables with regard to socioeconomic data, hypotheses about fuel costs, location of the toll road, etc. This variation enables us to run many different versions of the model and hence to make a direct and deeper comparison of available alternatives within the panel data specification. This analysis facilitates the identification of the variables that explain road demand evolution in a better way.
- Very few studies (Burris and Huang 2011) have included the period of economic crisis in the analysis of toll road demand. Studying such an interesting case as the Spanish tolled network allows testing the robustness of the results when the economic outlook changes dramatically.

The great diversity of versions within the model presented in the methodology makes it impractical to show the results for each and every one of the calibrations available. Instead, our research focuses on the behavior of some variables, especially the socioeconomic ones, due to their great explanatory potential for road demand. Furthermore, different figures below summarize the evolution of short-run demand elasticities as described above, in order to make the presentation of the analysis both more appealing and more easily grasped. The following subsection presents and discusses the most interesting results from all the runnings of the model considered in the analysis.

Analysis of explanatory variables influencing light vehicle demand

This subsection summarizes the estimates of elasticities of light vehicle demand by using the panel data methods described before (OLS, WG and GMM), when taking into account all the variables considered according to Table 2. Results are sorted by socioeconomic variable (GDP, Employment and GDP per capita) as they may constitute the key explanatory variable of demand behavior.

Table 4 includes detailed results for the most common estimates of toll road demand in the literature, considering applicable local (i.e., according to province) GDP, toll rates, and fuel prices (€/l) as explanatory variables for the 1990–2010 period. According to Arellano and Bond (1991) and Bond et al. (2001), the λ estimates for OLS-pool (0.975) and WG (0.311) are biased upwards and downwards, respectively. Regarding the GMM-DIFF estimator, the elasticity result (0.436) comfortably falls between that of OLS and WG, and is

Table 4 Estimation of short-run travel demand elasticities for the 1990–2010 period, through different panel data estimators

	OLS-pool		WG fixed effects		GMM-DIFF		GMM-SYS	
	Estimate	p value	Estimate	p value	Estimate	p value	Estimate	p value
AADT (−1)	0.975	0.0000	0.311	0.0000	0.436	0.0000	0.917	0.0000
GDP (prov.)	0.004	0.4175	0.941	0.0000	0.596	0.0000	0.028	0.2162
Fuel prices	−0.206	0.1716	−0.145	0.0098	−0.129	0.0090	−0.101	0.2128
Toll	−0.037	0.0000	−0.214	0.0000	−0.400	0.0000	−0.103	0.0134
R ²	0.9946	–	0.4289	–	–	–	–	–
m1-test	–	–	–	–	−1.821	0.0342	−1.895	0.0290
m2-test	–	–	–	–	0.554	0.2896	−0.546	0.2926
Sargan test	–	–	–	–	14.0	0.7290	14.0	1.0000

significantly different from zero. However, the λ estimate for the GMM-SYS estimator (0.917) is very close to that from the OLS-pool, which suggests some kind of bias in the results. It has been a circumstance frequently met along the analysis, so in the end we have chosen the GMM-DIFF approach for the analysis. Some reasons support this choice. In this particular case, problems regarding persistence of series are not found with GMM-DIFF estimators, as λ estimates for all the runnings of the model developed below range from 0.310 to 0.596, clearly lower than 0.8. Furthermore, our case constitutes a long panel, with at least $T = 21$. Finally, choosing a GMM-DIFF approach rather than a GMM-SYS method limits some problems arising when robustness tests are applied (see “[Robustness of results](#)” section).

For the particular case shown in Table 4, as well as for the results presented below, detailed comments addressing the robustness of the estimates are displayed in “[Robustness of results](#)” section.

Previous studies often conclude their research at this point. We now introduce some variability in the analysis by calibrating new runnings of the model specification with time periods progressively extended over time. An illustrative example of how the results are displayed can be seen in Fig. 1. It shows elasticity results from models including GDP by province, toll rates and either fuel prices (Fig. 1a) or fuel costs (Fig. 1b) as explanatory variables. Furthermore, each subfigure reveals how short-run demand elasticities vary when the time period being considered changes over time. The y-axis measures demand elasticities. The x-axis indicates the last year considered in the time period, taking 1990 as the starting point, so it allows for analysis of the evolution of travel elasticities when an additional year is included in the model. Therefore, subfigures show how elasticity results change when the time period gradually varies from 1990–2000 to 1990–2010. It can be easily seen that results shown in Table 4 are displayed in Fig. 1a (fuel prices) in the right-hand side, specifically for $x = 2010$. As can be noted, all the elasticities have the expected sign: positive for GDP, and negative for both Toll and Fuel prices.

We want to draw attention to the great analytical capability of Fig. 1. As can be seen, it enables a quick and simultaneous comparison of the results for 22 different runnings of the model (11 runnings per subfigure). This approach is useful to analyse elasticity *evolutions* over time, observe trends and identify key explanatory variables.

In analyzing the results from Fig. 1, some questions arise. As for the influence of fuel—both prices and costs—on light vehicle demand, it can be noted that traffic elasticities

Fig. 1 Demand elasticities (short-run) when considering fuel prices (*left*) and fuel costs (*right*) in the model

experience limited variation when including improvements in fuel efficiency. Demand elasticities with respect to fuel prices (see Fig. 1a) and fuel costs (Fig. 1b) present values of the same order of magnitude in most of cases. Particularly before including year 2005 in the analysis, fuel elasticities in Fig. 1a lie between -0.10 and -0.20 , while values in Fig. 1b are often near zero and not statistically significant. These findings are in line with the results concluded by Burris and Huang (2011) and Álvarez et al. (2007). It is also important to note that the other explanatory variables in the model (GDP, toll) present only comparatively small changes and clearly exhibit the same trend in both subfigures. Since fuel costs (€/km) provide a more realistic approach of fuel influence on travel demand than simply considering fuel prices (€/l), and given the limited influence in the rest of the estimation results, this is the option adopted from this point onwards.

Figure 2 includes results for short-run demand elasticities when considering GDP as the socioeconomic variable in the model, either at the provincial or national level. It therefore enables quick and visual comparison of model estimations when taking provincial or national socioeconomic data. Both cases show very similar results. Regarding demand elasticities with respect to GDP, three distinct periods emerge. Until 2004, demand elasticity moves around 0.8 – 1.0 , which is in line with previous studies for toll roads in Spain

Fig. 2 Demand elasticities (short-run) when considering provincial GDP (*left*) and national GDP (*right*) as the socioeconomic variable in the model

(Matas et al. 2012; Matas and Raymond 2003). These results corresponded to the peak in the economic growth experienced by Spain during the 1990s and early 2000s. Next, a decline in GDP estimates is observed when gradually including the 2004–2009 period. Elasticities tend to decrease, from almost 1.0 in 2004 to values near 0.4 after incorporating 2009. These years corresponded to a slowdown in the long and deep period of economic growth in Spain. That decrease makes clear that, once a certain level of economic development is reached, further increments in growth consecutively cause smaller increases in road traffic. Finally, GDP elasticities rise again after the beginning of the economic crisis, with values around 0.6.

Figure 2 evidences that demand elasticity with respect to GDP experiences great variability over time. The results support that, as pointed out by Matas et al. (2012), it is often unrealistic to assume a constant elasticity over time for certain explanatory variables. GDP elasticities move from 0.45 to 0.96 when considering provincial data, and range from 0.40 to 0.98 when choosing GDP data at the national level. This significant variability in demand elasticities lessens its usefulness in explaining traffic behavior in the long term and to make traffic forecasts, since the relationship between both variables shows little stability over time. This makes evident that GDP does not represent the most suitable explanatory socioeconomic variable to be considered for light vehicle demand on toll roads.

Figure 2 also demonstrates that light vehicle behavior during the crisis on Spanish toll roads cannot be considered an anomaly, despite sharp reductions suffered since 2007. GDP elasticities in recent years move within the usual range of values of previous years and, therefore, nothing can be concluded in this respect. Furthermore, we want to point out that Fig. 2a and b present quite similar results. We could initially expect better results for data displayed according to province, as there is a stronger relationship with local specific factors for each road. Nevertheless, GDP data at the national level have also been shown to be a good proxy for the whole tolled network. Furthermore, this good performance of national GDP as explanatory variable can be attributed to the high share of long-distance trips in the tolled high capacity network, less influenced by local effects.

Now we are going to focus on demand elasticities with respect to toll rates and fuel costs. Toll elasticities show a quite stable trend, with values moving from -0.20 to -0.41 , which is consistent with previous research (Matas et al. 2012; Burris and Huang 2011; Odeck and Brathen 2008). This behavior is likely caused by the fact that real toll rates in the sample remain constant, as toll rates in Spain are usually adjusted through inflation. It is also noted that toll elasticities tend to increase over time, especially when the most recent years (2008–2011) are added and, consequently, the price-sensitivity of users seems to have considerably risen since the beginning of the economic crisis. Nevertheless, this result needs to be reinforced through a model specification explicitly taking account of temporal variation of elasticities, as shown below. Regarding fuel elasticities, greater variations are observed. Estimates move from 0.0 to -0.31 , not being far from zero in most of the versions of the model, as in Burris and Huang (2011). Thus, toll elasticities are generally above fuel ones. This result suggests that users' perception of the burden of tolls seems to be higher than that for fuel costs.

In this respect, a comprehensive analysis of potential differences in users' attitudes towards tolls and fuel costs has scarcely been addressed in the literature. Only some remarks from previous studies have been found. Matas and Raymond (2003) wondered about reasons why users may react differently to changes in a discrete and fixed cost, such as tolls, and changes in per-km costs, such as fuel prices. They gave as estimates similar values of demand elasticities for both components of generalized transport cost, but noted that toll elasticities can vary greatly depending on the quality of the free alternative road.

Burris and Huang (2011), however, found that the magnitude of the elasticity estimates with respect to toll rate was generally larger than that for gas price. They explained that “this makes sense as increases in the toll price can only be avoided by no longer taking the toll route, while increases in the price of fuel may be mitigated by driving more fuel efficient vehicles or by switching routes”. Similarly, toll elasticities (-0.54) calculated by Álvarez et al. (2007) regarding light vehicle demand were significantly higher than that for fuel costs (-0.06). Despite being far from conclusive, our results seem to be in line with previous studies concerning demand responsiveness to tolls and fuel costs.

Figure 3 includes elasticity estimates when considering Employment as the key socioeconomic variable in the model, either at the provincial (Fig. 3a) or the national level (Fig. 3b). Unlike GDP, results for Employment show great stability when gradually varying the time period. Demand elasticities move from 0.54 to 0.72 with provincial data, and from 0.49 to 0.78 when taking national data. Again, demand elasticities when including the crisis are of the same order of magnitude as that of previous years, so traffic reductions in Spanish toll roads cannot be considered anomalous.

Stability of elasticity results, even when incorporating the crisis, demonstrates that Employment constitutes a suitable explanatory variable for light vehicle demand. This contrasts with results shown for GDP elasticities, where there is greater variability over time. There seems to be some reasons behind that. While GDP is made up of the aggregation of different and heterogeneous sectors of the economy, Employment could be a better proxy for income and mobility. This variable does not refer to all the potential users of a toll road—that is, the whole population—but only to those who are employed, generally with higher income and greater mobility potential.

Results for toll and fuel elasticities are similar to those concluded for Fig. 2. Toll elasticities present a fairly level trend over time, slightly increasing when we include the period of the economic crisis. Elasticities with respect to fuel costs, moving between -0.17 and -0.38 , show higher values when compared with Fig. 2. Although the relative position of toll and fuel curves can change over time, both elasticities now show similar values.

Figure 4 includes short-run elasticity results when GDP per capita is the socioeconomic variable in the model. It constitutes the most solid alternative, as all demand elasticities—socioeconomic, tolls and fuel costs—present very constant results over time. GDP per capita turns out to be a very stable socioeconomic variable. Elasticities run from 0.77 to

Fig. 3 Demand elasticities (short-run) when considering provincial employment (*left*) and national employment (*right*) as the socioeconomic variable in the model

Fig. 4 Demand elasticities (short-run) when considering provincial GDP per capita (*left*) and national GDP per capita (*right*) as the socioeconomic variable in the model

0.98 with data displayed according to provinces, and from 0.94 to 1.18 with national data. Despite some extra volatility experienced when including the economic crisis, the relation of GDP per capita to toll road demand can be considered highly satisfactory.

Elasticities with respect to toll rates and fuel costs also show significant stability. Trends of toll elasticities are very constant and values move around -0.20 , while those for fuel elasticities are lower and lie between 0.0 and -0.15 . These results support the notion that the average user's perception of tolls seems to be higher than that for fuel costs.

Analysis of temporal variation in travel demand elasticities

Figures 1, 2, 3 and 4 show the evolution of demand elasticities over time for the toll roads selected. This visual display of information can be complemented with a statistical analysis explicitly considering temporal variation in the results. In order to do this, a dummy variable is included in (8) to test whether, as expected from figures previously shown, statistically significant changes over time can be observed for certain demand elasticities, such as GDP.

$$AADT_{it} = \eta_i + \lambda AADT_{i,t-1} + \beta_1 Fuel_t + \beta_2 (Fuel_t \times \delta_{2005-2011}) + \beta_3 Toll_{it} + \beta_4 (Toll_{it} \times \delta_{2005-2011}) + \beta_5 Socioec_{it} + \beta_6 (Socioec_{it} \times \delta_{2005-2011}) + \varepsilon_{it} \quad (8)$$

$$\begin{aligned} \delta_{2005-2011} &= 0 \text{ for: } t = 1990, \dots, 2004; i = 1, \dots, 14 \\ &= 1 \text{ for: } t = 2005, \dots, 2011; i = 1, \dots, 14 \end{aligned}$$

Through the $\delta_{2005-2011}$ dummy variable, the model measures potential structural changes in demand elasticities for 2005–2011 when compared to the previous period (1990–2004). It allows us to test whether demand elasticities in Spain were significantly different between periods of prosperity (1990–2004), and economic slowdown and recession (2005–2011). Although a separate analysis for the period of economic crisis (2008 forward) would be desirable, it has not been possible due to the paucity of data, as only information up to 2011 is available. Just analysing the 2008–2011 period would result in a panel specification with $T = 4$. According to Bond et al. (2001), the GMM estimator has been found to have poor

finite sample properties in terms of bias and imprecision, so its use is not sufficiently reliable when T gets smaller. In these cases, the scarcity of instruments may lead the GMM estimator to be subject to a large downward bias (Blundell and Bond 1998), which suggests the need for caution concerning the time length in the panel.

The dummy variable $\delta_{2005-2011}$ is applied to both socioeconomic and generalized cost variables (fuel, toll), with the aim of measuring potential changes in users' responsiveness to costs when changes in the economic environment occur. Results are summarized in Table 5, sorted by the socioeconomic variable chosen (GDP, Employment, GDP per capita) included in the model.

From the results above, some interesting conclusions can be obtained, in line with Figs. 2, 3 and 4. Despite being limited, a structural change is observed for GDP elasticities from 2005 onwards. After the long period of prosperity in the Spanish economy, the GDP elasticity has experienced a statistically significant decrease of 8.0 %. By contrast, elasticities with regard to other socioeconomic variables (Employment, GDP per capita) cannot be concluded to have structurally changed in the last years, since the parameter ($\text{Socioec.} \times \delta_{2005-2011}$) is not statistically significant for them. This fact supports the notion noted below that GDP does not represent the most suitable explanatory socioeconomic variable to explain light traffic evolution due to its variability. Other explanatory variables have displayed a better performance in the sense of showing a stable relationship with light vehicle demand evolution over time.

Regarding generalized costs of transport, toll elasticities present similar results in all cases, around -0.25 , which is in line with previous studies of interurban toll roads. Despite noticeable increases observed in the most recent years (see Figs. 1, 3) for which data is available, toll elasticities have not statistically changed during the economic slowdown and recession, as the ($\text{Toll} \times \delta_{2005-2011}$) parameter shows. Results for fuel costs are less conclusive. In this case, elasticities present greater variability and are often not statistically different from zero. Neither is the analysis of potential structural changes over time conclusive, likely due to the volatility of fuel elasticities. As a result of this analysis, we cannot firmly conclude that, for the case of Spanish toll roads, users' responsiveness in the

Table 5 Estimation of short-run demand elasticities for the 1990–2011 period, enabling temporal variation for demand elasticities

	Socioec. = GDP		Socioec. = Employment		Socioec. = GDP per capita	
	Estimate	p value	Estimate	p value	Estimate	p value
AADT (-1)	0.444	0.0000	0.466	0.0000	0.429	0.0000
Socioec.	0.813	0.0003	0.714	0.0000	1.004	0.0000
Socioec. $\times \delta_{2005-2011}$	-0.065	0.0393	0.068	0.1533	0.111	0.2316
Toll	-0.276	0.0000	-0.336	0.0000	-0.239	0.0000
Toll $\times \delta_{2005-2011}$	0.087	0.1459	0.024	0.7568	-0.019	0.7359
Fuel cost	-0.103	0.1768	-0.268	0.0001	-0.007	0.9057
Fuel cost $\times \delta_{2005-2011}$	-0.324	0.0005	0.195	0.0083	0.063	0.1500
m1-test	-1.561	0.0493	-2.041	0.0205	-1.763	0.0388
m2-test	0.815	0.2076	-0.381	0.3514	0.232	0.4081
Sargan test	14.0	0.5987	14.0	0.7836	12.0	0.6671

last few years has varied significantly when compared to the earlier period of economic growth.

Analysis of variation in travel demand elasticities depending on the location of the toll road

As previously mentioned, light vehicle demand in coastal and interior toll roads has also been individually analyzed. Results (see Fig. 5) are quite similar to those previously calculated for the whole sample. The most relevant point has to do with different behaviors often observed to be specific to each kind of road. As expected, models for coastal roads better fit with the socioeconomic data for each province, given the greater stability of estimates observed in Fig. 1a when compared to Fig. 1b. By contrast, interior roads (Fig. 2a and b) perform slightly better when considering national data. Figure 5 shows that GDP per capita elasticities in coastal roads lie between 1.21 and 1.52 when considering data at the level of the individual province, but a larger range of values (from 0.36 to 1.05) is observed with national data. As for interior roads, despite showing solid results in both cases, elasticity estimates with national data (0.85–1.14) are more stable than those ones with provincial data (0.57–0.96). These results can be explained by the strong relationship between light demand in coastal roads and such local activities as tourism, as well as the high proportion of long-distance trips—less related to local effects—in interior roads.

Again, this visual display of analysis is complemented with a panel data regression to test whether statistically significant differences on demand elasticities can be identified

Fig. 5 Demand elasticities (short-run) when considering provincial GDP per capita (*left*) and national GDP per capita (*right*) as the socioeconomic variable in the model, for coastal (*above*) and interior roads (*below*)

depending on the location of the toll road. As shown in (9), structural differences between coastal and interior roads are captured through the δ_{COAST} dummy variable (equals 1 if the toll road is located near the coast; 0 otherwise).

$$AADT_{it} = \eta_i + \lambda AADT_{i,t-1} + \beta_1 Fuel_{it} + \beta_2 (Fuel_{it} \times \delta_{COAST}) + \beta_3 Toll_{it} + \beta_4 (Toll_{it} \times \delta_{COAST}) + \beta_5 Socioec_{it} + \beta_6 (Socioec_{it} \times \delta_{COAST}) + \varepsilon_{it} \quad (9)$$

Socioeconomic data at the provincial level: $t = 1990, \dots, 2010$; $i = 1, \dots, 14$

The model is calibrated for the whole time period (1990–2010), considering socioeconomic data at the level of the provinces. Results are included in Table 6.

Figures from Table 6 do not provide conclusive results regarding structural differences between coastal and interior roads. Elasticities with regard to socioeconomic variables seem to be higher for coastal roads in all the cases. Nevertheless, differences among the different kinds of roads ($Socioec. \times \delta_{COAST}$) are noticeable and statistically significant only when considering GDP per capita in the model. This may be caused by the fact that the economy in Spanish regions near the coast is highly dependent on tourism activities, which have an important impact on light vehicle volume. Toll elasticities are generally smaller (less negative) in coastal roads, but statistically significant estimates for $Toll \times \delta_{COAST}$ are only observed when considering GDP per capita in the model. In this respect, traffic volume in coastal roads may be less sensitive to tolls since a high percentage of trips are occasional, generally linked to leisure activities. Again, results for fuel costs present great volatility depending on the model we choose. By contrast, differences between coastal and interior roads are not statistically significant in any of the models presented in Table 6. This analysis clearly shows that estimates can vary considerably depending on the socioeconomic variable considered in the model, so a great deal of attention needs to be paid when selecting the explanatory parameters.

Summary of results

Finally, Table 7 summarizes the main elasticity estimates calculated by means of this panel data approach. As the analysis over time has demonstrated, a range of values seems a more complete and fairer way to present results for demand elasticities, rather than the

Table 6 Estimates of short-run travel demand elasticities for the 1990–2010 period, considering the location (coastal/interior) of the toll road

	Socioec. = GDP		Socioec. = Employment		Socioec. = GDP per capita	
	Estimate	p value	Estimate	p value	Estimate	p value
AADT (−1)	0.376	0.0000	0.411	0.0000	0.410	0.0000
Socioec.	0.639	0.0003	0.745	0.0000	0.902	0.0000
Socioec. $\times \delta_{COAST}$	0.027	0.9206	0.035	0.8626	0.460	0.0432
Toll	−0.571	0.0049	−0.465	0.0084	−0.396	0.0078
Toll $\times \delta_{COAST}$	0.168	0.5646	0.113	0.6451	0.333	0.0267
Fuel cost	−0.032	0.7092	−0.145	0.0771	−0.060	0.4616
Fuel cost $\times \delta_{COAST}$	−0.003	0.9769	−0.060	0.5252	−0.069	0.4834
m1-test	−1.921	0.0273	−1.762	0.0390	−1.832	0.0334
m2-test	−0.035	0.4857	0.425	0.3355	0.214	0.4149
Sargan test	12.0	0.8472	12.0	0.8472	12.0	0.8472

traditional approach of simply showing a single value for each variable. This procedure gives essential information for traffic forecasts, since it can be generally assumed that the shorter the range of elasticities for a certain variable, the greater its ability to explain road traffic evolution.

Regarding socioeconomic variables, we found that GDP does not exhibit a stable behavior over time, as elasticity values generally vary in parallel with the cycles in economic growth. However, such variables as Employment and GDP per capita have a shorter range of values, both at the provincial and national level, so they are more consistent explanatory variables of light vehicle demand. Significant variability in the values for fuel costs and for tolls respond to the numerous runnings and versions of the model calibrated, since these variables generally show a fairly constant trend for each single model.

Robustness of results

With regard to the robustness of the estimates, we have opted for showing one case in detail, displayed in Table 4, and briefly summarize the results for the other versions of the model. Detailed results for the 80 runnings included in Figs. 1, 2, 3 and 4, are very similar to those of the example discussed and all of them fully meet the requirements pointed out in “[Dynamic panel data methodology specification](#)” section.

Next, robustness of results regarding m1 and m2 tests is noted. According to González et al. (2011), two main conditions must be fulfilled in order to test that no serial correlation is observed in the estimated residuals ε_{it} . First, there should be evidence of negative first-order serial correlation of differenced residuals ($\Delta\varepsilon_{it}$), so that the value of the statistic m1 must be negative, with a p value preferably below 0.05. Second, there should not be evidence of second-order correlation of differenced residuals, so that the p value associated to the statistic m2 should be greater than 0.05. Regarding the example detailed in Table 4, results for m1 and m2 tests are consistent with absence of serial correlation in the residuals. As can be noted, the value of the statistic m1 is negative (−1.82) with a p value of 0.034 (<0.05), while the p value for the m2 test is 0.289 (greater than 0.05). Robustness of estimates for the rest of the models presented in Figs. 1, 2, 3 and 4 is very similar to the example from Table 4. The value of statistic m1 moves from −2.258 to −1.152, with an associated p value ranging between 0.011 and 0.043. Furthermore, the p value for the m2

Table 7 Summary of short-run elasticity estimates concluded from the analysis of the different versions of the model

Variables	Range of elasticities
Provincial socioeconomic variables	
GDP	0.45–0.96
Employment	0.54–0.72
GDP per capita	0.77–0.98
National socioeconomic variables	
GDP	0.40–0.98
Employment	0.49–0.78
GDP per capita	0.94–1.18
Toll	−0.4 to −0.19
Fuel costs (€/km)	−0.37 to −0.01

test runs from 0.103 to 0.317. Then, the requirements needed for the Arellano and Bond tests of serial correlation are fully met for all the alternatives shown.

With regard to the Sargan test, the validity of instruments used in the demand equation is checked when the null hypothesis is not rejected. Specifically, González et al. (2011) pointed out the convenience of having an associated p value greater than 0.10. For the case detailed in Table 4, we can observe that the p value in the Sargan test for GMM-DIFF (0.729) is far above the reference value. Although GMM-SYS also presents a p value greater than 0.10, values near 1.0 are clear symptoms of the low power of the test in that case, since the null hypothesis may exhibit almost zero rejection frequency of the validity of instruments null hypothesis (Baum et al. 2007). These results for the Sargan test support the choice of a GMM-DIFF approach for the analysis rather than a GMM-SYS one. Robustness estimates for the rest of the models are very similar to this case, as the associated p value for the Sargan test lies from 0.373 to 0.783, again greater than the reference value (0.10) and also not close to 1.0.

Conclusions and further research

This paper has developed a panel data methodology to analyze light vehicle traffic evolution in toll roads. The analysis has provided some interesting conclusions.

First, this paper establishes a feasible and original alternative, which consists of gradually varying the time period in the model specification, to analyze the stability of short-run elasticities over time. This approach has some advantages not present in the traditional procedure. First, it enables us to identify which parameters have a more constant and solid relationship with the dependent variable and, therefore, which are more suitable to be chosen as explanatory variables for long term estimates. Second, it makes the analysis more complete, objective, and rigorous.

The second conclusion is that, despite being an important element, GDP does not seem to be the most suitable socioeconomic explanatory variable for light vehicle demand. The significant variability of elasticity results, especially when changes in the economic environment occur, weakens its value in explaining traffic behavior and in making traffic forecasts. However, such socioeconomic variables as Employment and GDP per capita provide more consistent estimates, and clearly improve the performance of GDP. Employment as a variable considers only that part of the population who is employed, and better approximates income level and mobility. Moreover, GDP per capita constitutes a better proxy of a person's income.

The third conclusion points out that some differences can be observed in traffic behavior in toll roads depending on where, within the country, they are located (coast, interior). Roads near the coast seem to be more influenced by local activities such as tourism and better correspond to socioeconomic data of provinces, while the traffic in interior roads tends to fit better with global economic variables. Moreover, even though toll roads near the coast seem to be more sensitive to changes in socioeconomic data and less responsive to toll rates than interior roads, the results are not conclusive in this matter.

The last conclusion concerns the traffic decreases experienced on Spanish toll roads since the arrival of the recession. According to the results, it cannot be concluded that the reduction in demand is an anomaly, given the fairly constant trends shown by travel demand elasticities, mainly with regard to socioeconomic data. Furthermore, the paper has shown that users' responsiveness towards generalized costs of transport (toll, fuel) have not

statistically varied in recent years despite the deterioration observed in the Spanish economy.

From the results of this paper, several aspects can be pointed out as subjects for further research. First, the analysis can be extended to heavy vehicle demand on toll roads, as the literature in this area is very scarce, and no specific research for heavy vehicles has been conducted in Spain. Furthermore, it would be interesting to compare these results with estimates from free high capacity motorways in Spain, in order to check whether each type of roads exhibits different behavior. Finally, a trans-national analysis could be developed in order to compare the influence that the key explanatory variables studied for light vehicles—GDP, Employment and GDP per capita—can have on toll road demand in different countries.

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Appendix: description of explanatory variables included in the model

AADT (light veh./day): annual average daily traffic volume for light vehicles in each toll road, as recorded in the statistics of the Spanish Ministry of Transportation.

AADT (−1)(light veh./day): lag of the annual daily traffic volume for light vehicles in each toll road.

GDP, national (M€): Gross domestic product at the national level, as recorded in the Spanish National Statistics Institute (INE) database. In constant euros.

GDP, provincial (M€): sum of the GDPs from the K provinces crossed by each toll road:

$$GDP, provincial = \sum_{i=1}^K GDP_i$$

Employment, national (10^3 people): number of people employed in the country, as recorded in the Spanish National Statistics Institute (INE) database.

Employment, provincial (10^3 people): sum of people employed in the K provinces crossed by each toll road:

$$Employment, provincial = \sum_{i=1}^K Employment_i$$

GDP per capita, national (10^3 euro/person): Gross domestic product per person at the national level, as recorded in the Spanish National Statistics Institute (INE). In constant euros.

GDP per capita, provincial (10^3 euro/person): average GDP per capita from the K provinces crossed by each toll road:

$$GDP\ per\ capita, provincial : \frac{\sum_{i=1}^K GDP_i}{\sum_{i=1}^K population_i}$$

Toll rate (euro/km): toll rate applied in each toll road, as recorded in the statistics of the Spanish Ministry of Transportation. In constant euros.

Fuel price (euro/liter): gasoline and diesel prices in constant euros, weighed by the proportion of gasoline and diesel light vehicle fleet in each year:

$$\text{Fuel price} = \frac{\text{Gasoline price (€/l)} \times \text{Gasoline light vehicle fleet} + \text{Diesel price (€/l)} \times \text{Diesel light vehicle fleet}}{\text{Light vehicle fleet}}$$

Fuel cost (euro/km): product of Fuel price and Fuel consumption:

$$\text{Fuel cost} = \text{Fuel price (euro/liter)} \times \text{Fuel consumption (liter/km)}$$

Fuel consumption is assumed as a linear progression from average 1990 levels according to the Spanish Ministry of Transportation to 2011 values by the Spanish Ministry of Industry.

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Evolution over time of heavy vehicle volume in toll roads: A dynamic panel data to identify key explanatory variables in Spain

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ABSTRACT

Improving the knowledge of demand evolution over time is a key aspect in the evaluation of transport policies and in forecasting future investment needs. It becomes even more critical for the case of toll roads, which in recent decades has become an increasingly common device to fund road projects. However, literature regarding demand elasticity estimates in toll roads is sparse and leaves some important aspects to be analyzed in greater detail. In particular, previous research on traffic analysis does not often disaggregate heavy vehicle demand from the total volume, so that the specific behavioral patterns of this traffic segment are not taken into account. Furthermore, GDP is the main socioeconomic variable most commonly chosen to explain road freight traffic growth over time. This paper seeks to determine the variables that better explain the evolution of heavy vehicle demand in toll roads over time. To that end, we present a dynamic panel data methodology aimed at identifying the key socioeconomic variables that explain the behavior of road freight traffic throughout the years. The results show that, despite the usual practice, GDP may not constitute a suitable explanatory variable for heavy vehicle demand. Rather, considering only the GDP of those sectors with a high impact on transport demand, such as construction or industry, leads to more consistent results. The methodology is applied to Spanish toll roads for the 1990–2011 period. This is an interesting case in the international context, as road freight demand has experienced an even greater reduction in Spain than elsewhere, since the beginning of the economic crisis in 2008.

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1. Introduction

Improving the knowledge of road demand evolution and estimating better traffic forecasts are critical aspects in properly evaluating transport policies and accurately forecasting future investment needs (Matas et al., 2012). Stakeholders involved in roads management (such as governments, and operators) find it indispensable to identify the key parameters influencing road demand, as well as to quantify the strength of the relationships between traffic and certain explanatory variables over time. This issue becomes even more critical in toll roads, as they are financed mainly through user's contributions. However, the state of knowledge concerning demand behavior for toll roads is still limited (Odeck and Brathen, 2008), and leaves some aspects to be investigated in greater detail.

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Previous research studies generally pay little attention to road freight demand evolution over time. Methodological specifications on traffic analysis do not often disaggregate heavy vehicle demand from the total volume, so that the specific behavioral patterns of this segment of the traffic are not taken into account. Furthermore, the literature concerning road freight traffic is mainly focused on urban areas (Cherry and Adalakun, 2012; Holguín-Veras et al., 2006) or on quite specific tolled sections, such as bridges or tunnels (Hirschman et al., 1995; McKnight et al., 1992). By contrast, existing research explaining heavy vehicle demand evolution in interurban toll roads are sparse, and commonly include GDP as the only socio-economic explanatory variable in the analysis. Finally, the impact of the current economic crisis on road freight traffic has barely begun to be analyzed in the literature.

The aim of this paper is to contribute to a better knowledge of the evolution of heavy vehicle demand on interurban toll roads by identifying some of the key socioeconomic variables influencing traffic behavior. Through an original methodology, we discuss the suitability of GDP as a socioeconomic explanatory variable of road freight traffic on toll roads, and propose alternative variables. The main objective is thus to fill the research gap found in the literature regarding the socioeconomic variable that better explains the evolution of road freight demand over time. Additionally, this paper analyzes the effects of the economic crisis on heavy vehicle demand for toll roads, and tests the suitability of the explanatory variables chosen.

The methodology is applied to the Spanish toll road network, which represents a very interesting case in the international context. The deterioration of the economic environment in Spain since 2008 has had a great impact on the level of traffic in the tolled network, particularly as regards heavy vehicle demand. According to data from the Spanish Ministry of Transportation (Ministerio de Fomento, 2013), road traffic has undergone a reduction of 28% compared with the peak attained since 2007. Regarding heavy vehicle demand, traffic in toll roads has fallen, since the beginning of the crisis, after 6 years of consecutive decreases, by a full 40%. As a result, road freight demand has returned to levels of 1994, when the tolled network was 46% smaller. Revenues of private concessionaires have decreased by 10% in 2012 compared with levels in the previous year, which has led the government to take critical measures to relieve their financial situation. Then, we seek to evaluate to what extent significant reductions undergone by road freight traffic in recent years in Spain can be considered an anomalous fact when compared to previous trends.

This paper is organized as follows. After the introduction in Section 1, Section 2 summarizes the state of knowledge regarding heavy vehicle demand, focusing mainly on interurban roads. Section 3 establishes the methodology of this research, by describing both data series and the panel data models used to estimate demand elasticities. Section 4 presents and discusses the results. Finally, Section 5 sets out the main conclusions and suggests avenues of further research.

2. State of knowledge

Road demand evolution over time has traditionally been a matter of interest in transport economics, and numerous studies have been conducted in the last decades to identify the key parameters influencing travel patterns (Khademi and Timmermans, 2011; Dargay, 2007; Joksimovic et al., 2006). However, existing research on the evolution of traffic has focused on light vehicle demand, while road freight traffic has received less attention. Basically, the responsiveness of road demand with respect to different factors is measured through the concept of elasticity, by definition the relative change in travel demand induced by a relative change in a certain explanatory variable.

An overview of previous research studies aimed at analyzing and modeling road freight demand are briefly summarized in the following subsection. Then results specifically focusing on freight traffic analysis in toll roads are commented.

2.1. Previous research for free roads

The existing literature concerning road freight demand has mainly focused on modeling commodity or vehicle movements in terms of certain explanatory variables. Demand modeling has been used for different purposes, such as testing transport policy measures, forecasting transport demand, or predicting the impacts of the provision of new infrastructure (Ben-Akiva and de Jong, 2008). According to Nuzzolo et al. (2013), two main technical approaches have been adopted to that end: behavioral models and macro-economic models (both joint and partial share specifications). An overview of their basic characteristics is included in Table 1. Furthermore, a detailed literature in this field can be found in de Jong et al. (2013) and Chow et al. (2010).

Behavioral models simulate mode and route choice, and generally employ disaggregate information, so more detailed policy-relevant variables can be covered (Nuzzolo et al., 2013). By contrast, macro-economic models, which use aggregate information, are aimed at estimating the level and spatial distribution of goods or traffic flows. Within macro-economic models, partial share specifications progressively calculate consecutive steps of transport modeling (generation, distribution, etc.), while direct models simultaneously consider the whole process.

Some interesting findings have been concluded from disaggregate and partial share models. According to Abdelwahab (1998) and Oum et al. (1990), truck price elasticities significantly vary across commodity groups, so elasticities tend to be larger for lower-value commodities compared to higher-value goods. Nuzzolo et al. (2009) identified statistically significant variables for both import and export freight flows. Rich et al. (2011) assessed the extent to which mode substitution in freight transport was affected by lack of alternative freight networks from origin to destination. Additionally, Bröcker et al. (2011) and Meersmann and Van de Voorde (2013) approached the importance of globalization on road freight flows.

Table 1

Overview of the main approaches to model road freight transport. Source: Authors' elaboration based on Nuzzolo et al. (2009).

Type of model	Subtype	Level of detail of the data	Aims of the analysis	Examples	Methods employed
Disaggregate models		Individual shipments	Estimate route and/or mode choice	Abdelwahab (1998)	Mixed discrete/continuous choice
		Individual cargo companies		Beuthe et al. (2001) Rich et al. (2011) Yang et al. (2011)	Travel costs minimization Weighted nested logit Intermodal network optimization
Aggregate models	Partial share models	Macro national/regional parameters	Estimate the traffic volume	Nuzzolo et al. (2009) Bröcker et al. (2011) Kveiborg and Fosgerau, (2007)	Category regression, multinomial logit, etc. Gravity modeling Decomposition analysis
	Joint/direct models	Production of economic sectors	Estimate the amount and spatial distribution of goods	Agnolucci and Bonilla (2009) Li and Hensher (2009) Matos and Silva (2011)	ARDL, ECM ARIMA, VAR, BVAR, etc. OLS

Furthermore, other previous research developed aggregate models through direct macro estimates. These studies were aimed at calculating the relationship between heavy goods vehicle demand and certain macro explanatory variables. Gately (1990) employed an econometric analysis of US data to examine the explanatory variables for road freight traffic. He found statistically significant elasticities for both fuel prices (-0.37) and GDP (1.23). More recently, Li and Hensher (2009) identified the key drivers associated with growth of road freight traffic in Australia, and established several time series models to forecast future demand. Matos and Silva (2011) investigated energy efficiency in the road freight transportation sector in Portugal. They adopted an Ordinary Least Square (OLS) estimator and calculated a statistically significant elasticity (0.96) of heavy vehicle demand with respect to national GDP. Nevertheless, both the explanatory variables chosen and the results derived should be approached with caution since many countries – particularly, European ones – have in recent years experienced a decoupling of the growth in road freight traffic from economic growth (Kveiborg and Fosgerau, 2007). Such recent experiences as that in the UK (Agnolucci and Bonilla, 2009; Mc Kinnon, 2007) thus suggest that the relationship between GDP and heavy goods vehicle demand may not be as enduring as often supposed.

Finally, other studies not focused on demand modeling have analyzed additional aspects of road freight transport. Cherry and Adelakun (2012) and Kawamura (2000) calculated perceived value of time and comparative willingness-to-pay for truck operators. Allen et al. (2012) addressed the relationship between heavy vehicle demand, facility location and urban form, while Forkenbrock (1999) estimated external costs for intercity freight trucking. Furthermore, Winebrake et al. (2012) calculated the *rebound effect*, that is, the additional mileage driven as a result of increased fuel efficiency, specifically for heavy vehicle demand.

2.2. Previous research for toll roads

Literature regarding road freight demand for toll roads is still limited and mainly concentrates on aggregate models to estimate the level of traffic. The focus on direct macro-economic models for analyzing these types of roads may be due to two main aspects. First, toll roads are relatively scarce at the international level, what reduces the opportunity of collecting detailed information. Second, the operator of the toll road is especially interested in the traffic volume as a way to anticipate future financial requirements, equipment acquisition, etc., as pointed out by Nuzzolo et al. (2013).

Different research studies can be identified for urban and metropolitan areas. Hirschman et al. (1995) calculated toll elasticities estimates for several tolled bridges and tunnels in New York City. Holguín-Veras et al. (2006) assessed the impact of the Port Authority of New York and New Jersey's time-of-day pricing initiative on the behavior of commercial carriers. Moreover, Arentze et al. (2012) examined how sensitive are truck drivers for possible pricing policies by focusing on short-distance road freight transport, and identified the weight of the vehicle as a key variable. Liang et al. (2009) explored the effects of a toll-by-load policy on the vehicle type constitution pattern. Furthermore, Gupta and Vadali (2008) pointed out the influence that an existing tolling culture on the responsiveness of road freight with respect to tolls.

By contrast, only a very few papers can be found regarding heavy vehicle demand in interurban toll roads and focused on experiences in just a few nations, mainly the United States. They estimated road freight traffic volume through a direct modeling process by using macro variables. We summarize the main results of toll roads from the literature, sorted by country. In the case of the United States, the most consistent research was conducted by Burris and Huang (2013), who analyzed a sample of 12 interurban and metropolitan toll roads throughout the nation during an 11-year period (2000–2010). They established an approach based on time series ADL models, including population, unemployment rate, gas prices, and toll rates as explanatory variables. They found statistically significant results for heavy vehicle demand elasticities with respect to tolls, averaging -0.35 . Concerning fuel price elasticities, values ranged from -0.22 to $+0.14$ (with a mean of -0.03), although user's responsiveness increased (-0.23) when only considering the period during the economic crisis. As for the socioeconomic variables in the model, elasticities with respect to unemployment rate were negative (with a mean of -0.03), likely as a result of the economic downturn. On the other hand, Taft (2004) estimated a toll elasticity of -0.59 for truck volume on

the Ohio Turnpike. Furthermore, [Swan and Belzer \(2010\)](#) estimated diversion of trucks in the Ohio turnpike caused by changes in toll rates applied. Based on an OLS technique, they also forecasted the impact of toll rates on heavy vehicle revenue. [Holguín-Veras et al. \(2003\)](#) analyzed toll lanes for exclusive use by heavy trucks, focusing particularly on Southern California. Finally, [Zhou et al. \(2009\)](#) conducted a survey to quantify the impact of incentives on toll road use by truck drivers in Austin, Texas.

Regarding Norway, [Odeck and Brathen \(2008\)](#) calculated the elasticity of travel demand in 19 Norwegian toll road projects, including cordon toll rings, tolled trunk roads between cities, and tolled roads in peripheral regions. Detailed results provided by type of vehicle show an average toll elasticity of -0.51 for heavy goods vehicles. As for Australia, [Hensher et al. \(2013\)](#) investigated the response of road freight operators to price signals under different access charging schemes, defined by combinations of distance, mass and location. For the case of Spain, [Álvarez et al. \(2007\)](#) estimated the value of time and travel elasticities for both a Spanish toll motorway and for its free parallel road, finding statistically significant elasticities for tolls (-0.39) and fuel prices (-0.09).

As can be seen, the existing literature on interurban toll roads leaves some important aspects to be investigated. First, previous studies have focused on light vehicle demand, so that little attention has been paid to road freight traffic in tolled infrastructure. Furthermore, statistic models hardly established a macro approach to identify the key explanatory variables of heavy vehicle traffic, especially concerning the economic growth. In this respect, it is necessary to assess to what extent GDP constitutes a suitable explanatory variable for heavy goods vehicle demand in toll roads, and to explore possible alternatives. It is also important to include new econometric techniques to analyze heavy vehicle demand for the specific case of toll roads. In this respect, we use a panel data specification, combining both time series and cross-sections observations, which provides different advantages such as more variability and efficiency, and is better suited to study the dynamics of change ([Gujarati and Porter, 2004](#)). Finally, few studies ([Burris and Huang, 2013](#)) have analyzed the impact of an economic crisis on toll road freight demand. For the case of Spain, no previous studies have been undertaken specifically to investigate heavy vehicle traffic evolution over time.

3. Methodology

This section presents the data collected for the analysis of heavy vehicle demand on Spanish toll roads, as well as the methodology we followed to develop the dynamic panel data approach.

3.1. Previous data analysis

In order to estimate the demand equation for heavy vehicle traffic, we establish a dynamic panel data corresponding to 14 Spanish toll roads observed between 1990 and 2011. The sample includes those toll highways whose traffic data series are long enough for the statistical approach adopted in this paper, which is described below. Other existing tolled sections in Spain – those toll highways belonging to the second phase of tender in the Spanish toll network, whose operation started after 1998 – have traffic data series too short to be included in the analysis. Every toll highway included in the sample has a free parallel conventional road competing with it. The analysis thus focuses on toll roads with a free alternative of lower quality.

The dependent variable of the demand equation is the total veh-km travelled (VKT) for heavy vehicles in each toll road. These data have been collected from the statistics of the Spanish Ministry of Transportation ([Ministerio de Fomento, 2012](#)). Although traffic data from shorter tolled sections were available – each approximately 20 km in length – we have only considered average data for entire toll roads in order to avoid spatial correlation problems in the models, since data from short sections in the same highway are highly dependent on each other. That is, traffic volumes from consecutive road sections are very similar and clearly not independent. In this respect, we should note that more detailed information regarding road freight demand could not be included, since Origin–Destination data is not available for the Spanish road network. Nevertheless, the macro data available is suitable for the type of analysis initially pursued.

Three kinds of explanatory variables have been included in the demand equation (see [Table 2](#)): demand volume of previous years, socioeconomic variables, and generalized cost parameters. The demand variable (VKT_{t-1}) consists of a lag of the traffic volume, a term needed due to the dynamic nature of the panel. Within socioeconomic variables, we have considered several alternatives. Firstly, we take GDP since it is the most common socioeconomic variable used to explain road freight traffic growth. Secondly, we consider combined GDPs only of highly transport-intensive activities (GDP_{TI}). These sectors have been selected among those activities with the highest road freight transport intensity (RFTI) in Spain according to [Alises et al. \(2014\)](#), as well as their data availability. Particularly, we include Industry, Agriculture and Construction, which also comprises mining activities according to the Spanish statistical accounts. As can be seen, GDP_{TI} excludes those sectors with little or no impact on road demand, such as financial services, public administration, and education.

Finally, GDP of the industrial sector alone (GDP_{ind}) is included, as greater influence on toll road traffic can be expected from this variable. Industry generally comprises high value-added commodities, at which heavy vehicle transport generally show lower toll elasticities according to [EPA \(2011\)](#). Therefore, trucks carrying industrial products tend to show less reluctance to pay tolls when compared to heavy vehicles transporting lower-value-added goods. Furthermore, industrial commodities are usually moved over long distances, at least in the case of Spain, where manufacturing centers are

Table 2
Explanatory variables included in the analysis.

Dependent variable	Explanatory variables			
	Previous demand	Socioeconomic	Generalized cost	
			Toll	Fuel
VKT (Heavy Vehicles)	VKT (−1)	<ul style="list-style-type: none"> • GDP (provincial) • GDP (national) • GDP transport-intensive sectors (prov.) • GDP transport-intensive sectors (national) • Industry GDP (prov.) • Industry GDP (national) 	Toll prices (heavy vehicles)	Fuel cost (€/km): Diesel prices & efficiency

concentrated in certain regions. In these conditions, toll roads become a more attractive option when compared to the available free alternative of lower quality. By contrast, construction activities in Spain are mainly of an intra-regional nature (Vassallo et al., 2013) and generate medium- and short-distance trips, so that a smaller impact on toll road traffic can be expected. Data have been collected from the Spanish National Statistics Institute (INE).

Total or national traffic in the country is also an explanatory variable sometimes included in aggregate models (Swan and Belzer, 2010) with the aim to consider the ups and downs of overall demand. At least in the case of Spain, traffic in toll roads has not empirically shown the same trend from free roads in the country, especially concerning high capacity roads. While the core of the current toll road network started its operation during the mid-sixties, free highways were built much later, by gradually expanding high capacity sections (+363.7%) between mid-1980s and mid-2000s. As a result, each kind of roads experienced a far different trend over time. For instance, traffic in free roads grew by 299.0% between 1990 and 2007, mainly due to the extension of the network and improved accessibility in this period, while increases of traffic in toll roads (+128.8%) were significantly smaller (Ministerio de Fomento, 2013). Therefore, the gradual and meaningful expansion of free highways in Spain during the period analyzed does not make national VKT a suitable variable to consider the ups and downs experienced by overall road demand in the country.

As an alternative to capture the effect of free roads, we have considered total VKT in the corridor where the toll road is located because the infrastructure in these corridors has remained stable over the period of analysis. This method requires the inclusion of traffic data regarding the free parallel routes competing with the toll roads selected. A suitable technique to analyze this situation is a Seemingly Unrelated Regression (SUR) model, since it enables to evaluate the potential simultaneous relationship between demand in both roads – toll and free ones –, which may be affected by the same or different explanatory variables. As pointed out by Zellner et al. (2006), SUR models establish a system of equations related to each other, in which the error terms are correlated across equations, that is, the variance–covariance matrix is not diagonal. This joint estimation of demand volume in both toll and free roads leads to unbiased and more precise estimates of the regression coefficients. The SUR approach also allows us to test the magnitude of the relationship between traffic of competing roads through the Breusch–Pagan (BP) test. The results obtained in our sample for the BP test make it clear that, from a statistical point of view there is no difference between a SUR model and the dynamic panel data technique we propose in this paper, so the latter is the approach we finally followed in this research.

Other socioeconomic variables available in the Spanish statistical accounts, such as population or size of the vehicle fleet, have been discarded for two main reasons. Firstly, they are highly correlated with other socioeconomic variables included in the model. Secondly, weaker relations with traffic evolution were observed when compared to other explanatory variables considered in the model, especially after the beginning of the economic crisis of 2008. Due to the macro nature of the analysis, transport-specific variables such as type of commodity carried, and type of trip, have not been included in the model.

As mentioned before, three kind of explanatory variables are included in the demand equation: previous demand, socioeconomic and generalized cost variables. Specifically, the equation incorporates a lag of the traffic volume ($AADT_{(-1)}$), a Socioeconomic variable and two Generalized cost parameters (Toll and Fuel), what results in a total of 4 categories:

$$VKT = f(VKT_{(-1)}, \text{Socioeconom.}, \text{Toll}, \text{Fuel}) \quad (1)$$

According to Table 2, we consider several alternatives within these four categories, particularly in the socioeconomic one. This methodology then allows us to calibrate several versions of the model just by taking one variable from each of the groups of the demand equation. Therefore, by running all the available combinations of variables, we can establish up to 6 different versions of the model specification we propose. This variability improves the analytical capability of the methodology applied. Further details of the demand equation and the methodology specification are provided in Section 3.2. Additionally, a precise definition of each variable included in Table 2 is presented in the Appendix.

Regarding socioeconomic variables, two levels of data have been considered in the analysis: provincial level and national level. With the aim of better measuring the influence of local socioeconomic characteristics on heavy vehicle demand, data

have been collected at the provincial level. In Spain, a province is a geographical and political subdivision of a region. In this respect, each toll road is assigned the socioeconomic data from the provinces it crosses, as detailed in [Appendix A](#). Furthermore, data at the national level have also been tested since the panel analysis is applied to different toll roads spread throughout the country. In this respect, national parameters are expected to constitute a good proxy of socioeconomic data, not for any particular road but for the panel as a whole. Furthermore, national data may be a satisfactory explanatory variable, as some regions in Spain bear a noticeable volume of pass-through road freight traffic, generally less related to local activities. Monetary socioeconomic variables (total GDP and combined GDPs of certain sectors) have been deflated by the Consumer Price Index (CPI) to reflect their real value over time.

With regard to Generalized cost variables, historical toll rates – expressed in euro/km – were collected from the statistics of the Spanish Ministry of Transportation ([Ministerio de Fomento, 2012](#)). As for fuel cost, we assume some simplifications when including this parameter in the analysis. A *Fuel cost* variable is established by taking into account not only diesel prices – expressed in euro/liter – but also fuel consumption (liter/km) for heavy vehicles. It allows us to reflect real fuel costs when driving (euro/km) and include the *rebound effect* due to the progression in fuel efficiency experienced by trucks over time. Furthermore, this procedure clearly constitutes a more realistic approach, since taking into account only diesel prices could lead to a misestimate of the fuel influence on travel demand. For calculating fuel consumption over the 1990–2011 period, we introduce linear improvements in fuel efficiency, from average 1990 values pointed out by the Ministry of Transportation ([MOPU, 1990](#)), to current levels made available by the Ministry of Industry ([Idae, 2011](#)). Both toll rates and fuel costs have been adjusted to inflation by using the CPI.

Additionally, several subsamples have been proposed for this dynamic panel data approach. Apart from working with the whole sample, separate analyses have been conducted for coastal and interior roads in Spain. Traditionally, road freight traffic near the coast has been highly dependent on local activities such as construction, which experienced a great boom during the 1990s and early 2000s due to the development of new residential areas promoted by local governments. Furthermore, some regions near the coast (Catalonia, Valencia, the Basque Country) are among the most industrialized areas in the country. By contrast, toll roads in the inner part of the peninsula generally pass through less developed areas, with less economic activity. Then, it may be expected that heavy vehicle demand in coastal roads responds to provincial socioeconomic variables, whereas demand in interior roads should be considered in the light of national, rather than regional, data. This distinction leads to the attempt to evaluate whether road freight traffic in coastal and interior toll roads show different behavior responses with respect to both national and provincial socioeconomic data.

At this point, we want to emphasize the analytical capability of our methodology. Given the explanatory variables considered as displayed in [Table 2](#), the panel data allows us to construct up to 18 versions of the model, if we take into account the 3 possibilities (all, coast, interior) regarding the size of the sample. Thus, many and rapid cross-comparisons can be conducted in order to identify the most suitable socioeconomic explanatory variables for heavy vehicle demand.

[Table 3](#) provides an overview of the evolution of some of the provincial socioeconomic variables for all the toll roads selected before and after the economic recession. It shows the information for three special years in the sample: the starting point (1990), the peak reached just before the economic crisis (2007), and the last year (2010) where socioeconomic data is available at the provincial level. The data shows the long and strong economic growth experienced in Spain during the 1990–2007 cycle, when national GDP increased by 78.0%. For the provinces crossed by the toll roads selected, the data displayed shows average growth rates of 76.5% for total GDP, 44.9% for GDP_{TI}, and 34.6% for GDP_{Ind}. This period of prosperity has been followed by a significant deterioration, since 2008, of the nation's economic performance. National GDP fell by 7.4% between 2007 and 2011. Provincial socioeconomic data also shows significant average reductions from 2007 to 2010 for total GDP (–5.2%) as well as for GDP_{TI} (–15.9%) and GDP_{Ind} (–15.2%).

Table 3

Average heavy vehicle demand for Spanish tolled motorways considered and provincial socioeconomic data (1990–2010).

Tolled roads	VKT			GDP			Intensive transport GDP			Industry GDP		
	1990	2007	2010	1990	2007	2010	1990	2007	2010	1990	2007	2010
Montmeló–La Jonquera	251.4	528.1	406.8	49.7	89.9	84.7	18.3	25.1	21.1	14.3	16.8	14.6
Barcelona–Tarragona	256.8	481.0	336.4	50.3	90.5	85.4	18.6	25.5	21.4	14.5	17.0	14.8
Zaragoza–Mediterráneo	180.9	179.9	111.8	16.8	30.3	28.9	6.5	9.5	8.0	3.9	4.9	4.5
Villalba–Adanero	54.9	121.58	87.2	54.8	105.2	101.5	12.8	20.3	16.5	8.5	9.9	8.1
Sevilla–Cádiz	16.1	69.0	46.4	17.5	30.6	28.6	6.0	7.4	5.9	2.5	3.1	2.6
Tarragona–Valencia	180.2	448.5	265.9	27.1	47.5	44.1	9.9	13.9	11.4	6.3	7.5	6.5
Valencia–Alicante	53.2	131.9	74.4	26.5	48.2	44.2	8.5	12.6	10.2	5.4	6.3	5.4
Bilbao–Zaragoza	107.7	203.1	155.6	23.4	40.9	39.3	8.6	13.1	11.3	6.0	8.3	7.3
Burgos–Armiñón	41.2	173.8	124.1	6.3	10.9	10.2	2.9	4.3	3.7	2.1	3.0	2.5
León–Campomanes	22.3	52.4	45.7	11.5	18.1	17.2	3.4	5.6	4.3	1.8	4.5	2.0
Montgat–Mataró	9.8	21.0	15.7	44.4	79.5	74.9	16.3	22.2	18.7	13.1	15.4	13.3
Bilbao–Behobia	86.1	188.6	171.9	17.5	29.8	28.9	6.1	9.4	8.4	4.6	6.4	6.0
Tudela–Iruzun	25.2	180.1	151.8	5.5	9.6	9.6	2.4	3.5	3.3	1.7	2.3	2.2
San Cugat–Manresa	4.5	26.7	16.8	44.4	79.5	74.9	16.3	22.2	18.7	13.1	15.4	13.3
Units	M veh-km			10 ³ M€ (constant)			10 ³ M€ (constant)			10 ³ M€ (constant)		

Heavy vehicle demand has experienced trends similar to those of socioeconomic variables. For the selected toll roads, road freight traffic rose on average by 188.1% over the period 1990–2007, in line with the economic growth in the country. Trends have changed since the beginning of the crisis, and demand levels in 2010 were 27.7% lower than the peak reached in 2007. These sharp variations observed in the tolled network during the last 20 years make Spain an interesting case to be analyzed as well as useful in testing the robustness of the models.

3.2. Dynamic panel data methodology specification

In this section we present a dynamic panel data methodology for studying the evolution of heavy vehicle demand in toll roads. It allows us to estimate demand elasticities with respect to explanatory variables included in Table 2. The form proposed for the estimation models is:

$$\ln \text{VKT}_{it} = \eta_i + \lambda \ln \text{VKT}_{i,t-1} + \beta_1 \ln \text{Fuel}_t + \beta_2 \ln \text{Toll}_{it} + \beta_3 \ln \text{Socioec}_{it} + \varepsilon_{it}$$

With provincial socioeconomic data : $t = 1990, \dots, 2010$; $i = 1, \dots, 14$

With national socioeconomic data : $t = 1990, \dots, 2011$; $i = 1, \dots, 14$

(2)

where $\ln$ refers to natural logarithm. Given the dynamic nature of the analysis, the equation includes a lag of the demand variable ($\text{VKT}_{i,t-1}$). *Fuel* denotes fuel costs assumed by trucks in euro/km. *Toll_{it}* denotes toll rate (euro/km) applied in road *i* for year *t*. Finally, *Socioec_{it}* denotes different socioeconomic data (total GDP, GDP_{C+I} and GDP_{Ind}) assigned to road *i*, either at the provincial or national level. Regarding the rest of the parameters, β_k is the short-run elasticity of road demand with respect to explanatory variable *k*; λ measures possible autocorrelation in traffic data series; η_i denotes unobserved individual effects, that is, constant and specific factors for each tolled road, not accounted for by any of the other variables in the models; finally, ε_{it} is the residual or idiosyncratic error.

Regarding initial conditions, we assume (Blundell and Bond, 1998) that η_i and ε_{it} are independently distributed across *i* and have the familiar error components. As pointed out by Graham et al. (2009), the main issue to be addressed in the context of dynamic panel estimation is correlation between the lagged dependent term ($\text{VKT}_{i,t-1}$) and the unobserved cross-section individual effects (η_i). This fact greatly limits estimators to be applied. The Ordinary Least Squares (OLS) estimator for λ is then inconsistent (Bond, 2002; Hsiao, 1986) and biased upwards, at least in large samples (Nickell, 1981; Blundell et al., 2000). The Within Groups (WG) estimator eliminates this source of inconsistency by transforming the equation to eliminate η_i , but gives an estimate of λ that is biased downwards, especially in short panels (Bond, 2002; Blundell and Bond, 1998). Therefore, a consistent estimate of λ can be expected to lie between the OLS and WG estimates (Arellano and Bond, 1991; Bond et al., 2001).

Better estimates can be calculated with a Generalized Method of Moments (GMM) approach, proposed by Larsen (1982). Within this technique, Eq. (2) is differenced to eliminate the individual effects:

$$\Delta(\ln \text{VKT}_{it}) = \lambda \Delta(\ln \text{VKT}_{i,t-1}) + \beta_1 \Delta(\ln \text{Fuel}_t) + \beta_2 \Delta(\ln \text{Toll}_{it}) + \beta_3 \Delta(\ln \text{Socioec}_{it}) + \Delta \varepsilon_{it}$$
(3)

In this expression, we find that $\Delta(\text{VKT}_{i,t-1})$ is correlated with $\Delta \varepsilon_{it}$, since $\text{VKT}_{i,t-1}$ and $\varepsilon_{i,t-1}$ are clearly correlated. To solve this problem, Arellano and Bond (1991) adopted the so-called difference GMM estimator (GMM-DIFF), which includes an instrumental variables (IV) approach. The GMM-DIFF estimator assumes that values of the dependent variable lagged two periods or more ($\text{VKT}_{i,t-s}$, for $s \geq 2$) are valid instruments for the lagged dependent variable in the differenced equation, $\Delta(\text{VKT}_{i,t})$. Then, we can establish a set of *moment conditions* that would be satisfied by the true values of the parameters to be calculated (Elhorst, 2012):

$$E(\ln \text{VKT}_{i,t-s} \Delta \varepsilon_{it}) = 0 \text{ for } t = 3, \dots, T \text{ and } s \geq 2$$
(4)

In this respect, if we assume an absence of serial correlation, in the differenced Eq. (3) it can then be easily seen that an additional valid instrument is available with each additional time period. Nevertheless, due to some problems that can arise when too many instruments are considered (Roodman, 2009), we have opted for using only the first lag available in each time period. Furthermore, according to Judson and Owen (1999), limiting the number of instruments does not materially reduce the performance of this technique.

The GMM-DIFF approach generates consistent and efficient estimates of the parameters (Rey et al., 2011), among other attractive properties noted in the literature (Graham et al., 2009). However, it suffers from very low precision as the value of λ increases towards unity (Blundell and Bond, 1998), particularly at values around 0.8 and above. In these cases, lagged levels $\text{VKT}_{i,t-s}$ become weak instruments in the differenced Eq. (3), which can result in serious bias problems.

To overcome the *weak instrument* problem for persistent series, Arellano and Bover (1995) and Blundell and Bond (1998) suggested a system GMM estimator (GMM-SYS), where the instruments used in the levels equations are lagged first differences of the series. It allows yielding $(T - 2)$ additional moments:

$$E[\varepsilon_{it} \Delta(\ln \text{AADT}_{i,t-1})] = 0 \text{ for } t = 3, \dots, T$$
(5)

Exploiting these additional moment conditions can produce some advantages in terms of precision, efficiency, etc., in cases where the autoregressive parameter is only weakly instrumented (Arellano and Bover, 1995). However, despite being smaller, the finite sample bias of the GMM-SYS estimator is generally upwards, in the direction of OLS levels (Blundell and Bond,

1998). Finally, it must be noted that the most suitable technique in each case can change depending on the size of the panel (Judson and Owen, 1999).

The most widely used tests to check the validity of hypotheses assumed in GMM estimators are the m1 and m2 tests, as well as the Sargan test (González and Marrero, 2011). The m1 and m2 tests, proposed by Arellano and Bond (1991), check that no first and second-order serial correlations are observed in the estimated residuals ε_{it} , by meeting some requirements (see more details in Section 4.4). Not fulfilling the needed requirements in m1 and m2 tests can reveal inconsistency of estimates (Garín-Muñoz, 2006) or the possibility of improving the instruments chosen (Rey et al., 2011).

Additionally, the Sargan test checks the validity of the instruments used in the model by detecting possible correlation between the instruments and differenced residuals $\Delta\varepsilon_{it}$. As noted by Böckerman et al. (2009), the Sargan test can have extremely low power when using too many instruments in the GMM model, so that results from the test should be interpreted with care (Graham et al., 2009). In order to limit this problem, we have adopted the alternative procedure proposed by Roodman (2009) that consists of using only the first lag instead of all available lags for instruments in the demand equation.

Further details about validity tests used in this paper are displayed in Section 4.4 which analyzes robustness of results.

4. Modeling results and discussion

This section summarizes the main findings from the analysis of heavy vehicle demand evolution over time applied to Spanish toll roads. First, general aspects of the panel data approach adopted in this paper are shown. Next, we present the main results of road freight demand elasticities and discuss the suitability of explanatory variables included in the models. Finally, the robustness of results is discussed.

4.1. General aspects

This paper develops an original approach to identify the key socioeconomic explanatory variables influencing road freight traffic. This research is based on estimates of demand elasticities with different panel data specifications. We have included some new aspects in our analysis:

- Stability of results is checked by gradually calibrating new runnings of the model with a longer time period considered in the analysis. Then, the traditional static approach that presents elasticity results for a specific period has been exchanged for a time-dependent approach which includes the calculation of demand elasticities over time when the period of analysis is extended. In this respect, those variables with significant variations in their demand elasticities over time cannot be considered as suitable to explain the evolution of road demand. Then, this paper presents a different approach from that one proposed by Holguín-Veras et al. (2011), one of the few papers studying temporal stability of parameters. Based on an Origin–Destination survey in Colombia, these authors developed a panel formulation to analyze road freight demand, and included time-dependent parameters in the model specification to check for temporal stability.
- As mentioned in Section 3, the methodology includes a noticeable variety of explanatory variables with regard to socioeconomic data, period of time considered, size of the sample, etc. This variety enables a direct and deeper comparison of available alternatives, and makes it easier to identify which variables explain road demand evolution in a better way.
- Very little research (Burris and Huang, 2013) on toll road demand has included the period of economic crisis – from 2008 on – in the analysis. Studying such an interesting case as the Spanish tolled network, with a significant reduction of heavy vehicle demand since 2008, allows us to test the robustness of the results when the economic outlook changes dramatically.

The great diversity of models presented in the methodology does not make it possible to show the results for each and every one of the alternatives available. In this paper, we focus on the behavior of some variables, especially socioeconomic ones due to their great explanatory potential for road demand. Furthermore, different figures summarize the evolution of demand elasticities as described above, in order to make the analysis more appealing and easier to grasp. The following subsection presents and discusses the most interesting results from all the models considered in the analysis.

4.2. Analysis of explanatory variables influencing heavy vehicle demand

This subsection summarizes the estimates of heavy vehicle demand elasticities by using the panel data methods described before (OLS, WG and GMM), when taking into account all the variables considered according to Table 2. Results are sorted by socioeconomic variables (total GDP; GDP of highly transport-intensive sectors, GDP_{TI}; and Industry GDP, GDP_{Ind}), as they may be the key explanatory variables of demand evolution.

Table 4 includes detailed results for a certain demand model applied to e.g. the 1990–2007 period, characterized by long and deep economic growth in Spain. The model considers provincial GDP, toll rates and fuel cost (€/km) as explanatory variables for heavy vehicle traffic. According to Arellano and Bond (1991) and Bond et al. (2001), the λ estimates for OLS-pool (0.992) and WG (0.212) are biased upwards and downwards, respectively. This fact automatically invalidates the demand results obtained for the rest of the explanatory variables, since they are also biased. Regarding the GMM-DIFF estimator,

Table 4

Estimation of travel demand elasticities for the 1990–2007 period, through different panel data estimators.

	OLS-pool		WG fixed effects		GMM-DIFF		GMM-SYS	
	Estimate	p-value	Estimate	p-value	Estimate	p-value	Estimate	p-value
VKT (–1)	0.992	0.0000	0.212	0.0000	0.393	0.0004	0.952	0.0000
GDP (prov.)	–0.013	0.1307	2.021	0.0000	1.003	0.0000	0.007	0.2365
Fuel cost	0.136	0.5455	–0.098	0.3775	–0.387	0.0017	–0.034	0.4465
Toll	–0.017	0.1288	–0.224	0.0000	–0.333	0.0064	–0.069	0.0011
R ²	0.9922		0.2845					
m1-test					–1.524	0.0477	–1.966	0.0492
m2-test					–0.070	0.7438	–1.794	0.0726
Sargan test					14.0	0.5255	14.0	0.9990

the elasticity result for $VKT_{(-1)}$ (0.393) comfortably falls between that of OLS and WG, and is significantly different from zero, so demand elasticities calculated through this technique are not biased. However, the λ estimate for the GMM-SYS estimator (0.952) is very close to that from the OLS-pool, which again suggests some kind of bias in the results. This has been a circumstance frequently met with in conducting the analysis, so in the end we have chosen the GMM-DIFF approach for the forward analysis. Several reasons support this choice. In this particular case, problems regarding persistence of series are not found with GMM-DIFF estimators, as λ estimates for all the models developed below range from 0.263 to 0.647, that is, clearly lower than 0.8. Furthermore, the period of time is fairly long, with at least $T = 20$. Finally, choosing a GMM-DIFF approach rather than a GMM-SYS method limits some problems arising when robustness tests are applied (see Section 4.4). Then, the GMM-DIFF is ultimately the panel estimator chosen to develop the analysis of heavy vehicle demand evolution.

For the particular case shown in Table 4, as well as for the results presented below, detailed comments addressing the robustness of the estimates are displayed in Section 4.4.

Previous studies often conclude their research at this point. We now introduce some variability in the analysis by calibrating new models with time periods progressively extended over time. An illustrative example can be seen in Fig. 1. It shows elasticity results from models including toll rates, fuel cost and total GDP either at a provincial level (sub Fig. 1a) or at a national level (sub Fig. 1b) as explanatory variables. Furthermore, each subfigure reveals how demand elasticities vary when the time period considered changes over time. The y-axis measures demand elasticities obtained through the panel estimator that we ultimately selected (GMM-DIFF). The x-axis indicates the last year considered in the time period, taking 1990 as the starting point, so it allows for the analysis of the evolution of travel elasticities when an additional year is included in the model. Therefore, subfigures show how elasticities change when the time period gradually varies from 1990–2000 to 1990–2010. It can be easily seen that results shown in Table 4 are displayed in sub Fig. 1a (provincial data) in the right-hand side, specifically for $x = 2007$. As can be noted, all the elasticities have the expected sign: negative for both Toll and Fuel costs and positive for GDP, except in the period since 2010. This circumstance is discussed below.

We want to draw the attention to the analytical capability of Fig. 1. As can be seen, it enables quick and simultaneous comparisons of results for 23 different runnings of the model (11 and 12 models for provincial and national socioeconomic data, respectively), which makes it easier both to observe trends and to identify key explanatory variables. It is then a different approach to study temporal stability of parameters when compared to Holguín-Veras et al. (2011), in which an additional time-dependent coefficient was estimated.

In analyzing the results from Fig. 1, some questions arise. Firstly, results are very similar when considering socioeconomic data either at the provincial or at the national level. Secondly, if we observe the evolution of demand elasticities with respect to GDP, different periods are identified:

Fig. 1. Demand elasticities when considering provincial GDP (left) and national GDP (right) as the socioeconomic variable in the model.

- Until 2003, demand elasticity moves around 2.0–2.5, which is above the usual values found in the literature. We should note that these results correspond to the peak in the economic growth experienced by Spain during the 1990s and early 2000s.
- Next, GDP elasticities significantly decrease when including the 2004–2008 period. Results range from 0.63 to 1.16, which is in line with previous studies for road freight traffic (Matos and Silva, 2011; Gately, 1990). The decline observed may be caused by two main effects. On the one hand, these years coincide with the last part of the long period of economic growth in Spain. Then, the decrease of GDP elasticities makes clear that, once a certain level of economic development is reached, further growth causes smaller increases in road traffic. On the other hand, a reduction in demand elasticities may reflect some kind of *decoupling effect* resulting from aspects such as: the use of larger vehicles, an increase of average load (Kveiborg and Fosgerau, 2007), a declining share of transport-intensive activities in GDP such as Construction (Liimatainen and Pöllänen, 2013), etc.
- Finally, GDP elasticities fall sharply after the beginning of the economic crisis, with values near zero or even negative. These inconsistent results seem to show that the models are not able to provide a satisfactory explanation for the road freight traffic reduction in Spain, when total GDP is the socioeconomic variable chosen.

Fig. 1 shows that demand elasticity with respect to total GDP experiences great variability over time. As pointed out by Matas et al. (2012), it is often unrealistic to assume a constant elasticity for certain explanatory variables. However, the huge variability of results for total GDP greatly weakens its capability to explain heavy vehicle demand, as both variables show no stability over time. GDP elasticities move from -0.22 to 2.34 when considering provincial data, and range from -0.47 to 2.44 when choosing GDP data at the national level. This makes clear that total GDP does not represent a suitable explanatory variable to be considered as useful in predicting road freight traffic evolution in toll roads.

Results for toll and fuel elasticities are briefly summarized, since including total GDP as an explanatory variable in the models does not lead to good estimates. Toll elasticities present a fairly continuous trend over time, noticeably increasing when we include the crisis. Values range from -0.21 to -0.43 , with a mean of -0.30 . Elasticities with respect to fuel costs, moving between -0.03 and -0.51 , show higher variability. Detailed results for toll and fuel elasticities are commented upon below, when we present more consistent models.

Fig. 2 includes estimates when considering the GDP of highly transport-intensive sectors (GDP_{TI}), either at the provincial (sub Fig. 2a) or the national level (sub Fig. 2b), for the socioeconomic variable in the model. Unlike total GDP, results for GDP_{TI} show significant stability when gradually varying the time period. Demand elasticities move between 0.74 and 1.28 with provincial data, and range from 0.55 to 0.99 when taking national data.

Stability of demand results, even when incorporating the period of the economic crisis, demonstrates that GDP_{TI} is a more suitable explanatory variable. It contrasts with the results shown for GDP elasticities, where there is greater variability over time. There seems to be some reasons for this. While total GDP consists of the aggregation of different heterogeneous sectors of the economy, GDP_{TI} could be a better proxy for road freight mobility. It only refers to transport-intensive sectors (mainly Construction and Industry) and excludes those activities with little effect on road demand, such as public administration, and financial services.

Fig. 2 also demonstrates that changes in heavy vehicle demand trends on Spanish toll roads during the economic crisis cannot be considered an anomalous fact, despite sharp reductions suffered since 2007. GDP_{TI} elasticities in recent years move in the usual range of values of previous years and, therefore, nothing can be concluded in this respect. It makes clear that, if proper explanatory variables are chosen, elasticity estimates show a fairly continuous trend despite dramatic changes in the economic outlook. Furthermore, we want to point out that sub Fig. 2a and b present quite similar results. We could initially expect better performance for provincial data, as they have a stronger relationship with local, specific factors for each road. Nevertheless, GDP_{TI} data at the national level have also been shown to be a good proxy for the whole tolled

Fig. 2. Demand elasticities when considering provincial GDP of transport-intensive sectors (left) and national GDP of transport-intensive sectors (right) as the socioeconomic variable in the model.

network. This good performance of national GDP_{TI} as an explanatory variable for road freight transport can be attributed to the high proportion of long trips in the tolled high capacity network in Spain, as goods – mainly industrial commodities and agricultural products – need to be transported from the industrialized and agrarian regions near the coast and distributed throughout the inner part of the peninsula.

Next, results concerning demand elasticities with respect to toll rates and fuel costs are discussed. Toll elasticities show a quite stable trend, with values moving from -0.24 to -0.41 and a mean of -0.31 , which is consistent with previous research (Burris and Huang, 2013; Álvarez et al., 2007). This behavior is likely caused by the fact that real toll rates in the sample remain quite stable, as toll rates in Spain are usually adjusted through inflation. It is also noted that toll elasticities increased slightly over time, especially since the beginning of the economic crisis. Regarding fuel elasticities, greater variations are observed. Estimates move from -0.01 to -0.49 , averaging -0.21 , very close to the value provided by de Jong et al. (2010). A wide variety of results are also observed in the literature, as fuel elasticity estimates range from -0.41 (Gately, 1990) to values near zero (Álvarez et al., 2007) or even positive (Burris and Huang, 2013). Our values are in line with previous results, as they usually fall between the highest and lowest estimates found in the literature review. Although the relative position of toll and fuel curves can change over time, both elasticities show values of the same order of magnitude.

Fig. 3 includes elasticity results when Industry GDP (GDP_{Ind}) is the socioeconomic variable adopted in the model. It constitutes the most solid alternative, as all demand elasticities – socioeconomic, tolls and fuel costs – present very constant results over alternative. GDP_{Ind} turns out to be a very stable socioeconomic variable. Elasticities run from 0.91 to 1.16 with provincial data, and from 0.50 to 0.87 with national data. Despite some volatility experienced for particular years, the behavior of GDP_{Ind} can be considered very satisfactory.

Elasticities with respect to toll rates and fuel costs also show significant stability. Trends for toll elasticities are very constant and values move around -0.25 , while those for fuel elasticities are generally lower and lie between 0.0 and -0.28 . These results reinforce the notion that the perception of tolls by potential users is slightly higher than that of fuel costs.

As previously mentioned, heavy vehicle demand evolution in coastal and interior toll roads has also been individually analyzed. Results are quite similar to those previously calculated for the whole sample. The most relevant point has to do with different behaviors often observed in each kind of road (see Fig. 4). As expected, models for coastal roads better fit with socioeconomic provincial data, while interior roads better perform with national data. For instance, GDP_{Ind} elasticities for interior roads move between 0.91 and 1.07 when considering data at the national level, but a larger range of values (from 0.71 to 1.73) is observed with provincial data. As for coastal roads, despite showing solid results in both cases, elasticity estimates with provincial data (0.96–1.41) are more consistent than those with national data (0.16–0.65). These results can be explained by the strong relationship between road freight demand in coastal roads and local activities such as construction and industry, as well as the high proportion of long trips – less related to local effects – on interior roads.

4.3. Summary of results

Finally, Table 5 summarizes the main elasticity estimates calculated through this panel data approach. As the analysis over time has evidenced, a range of figures seems a more complete and fairer way to present results for demand elasticities, rather than the traditional approach of simply showing a single value for each variable. It gives essential information for traffic forecasts, since it can be generally assumed that the shorter the range of elasticities, the greater its usefulness as an explanatory variable.

Regarding socioeconomic variables, we found that GDP does not show a stable behavior over time, as elasticity values greatly vary in parallel with economic cycles. However, variables such as GDP_{TI} and GDP_{Ind} have a shorter range of values, at both the provincial and the national level, which makes them more reliable explanatory variables to explain heavy vehicle

Fig. 3. Demand elasticities when considering provincial Industry GDP (left) and national Industry GDP (right) as the socioeconomic variable in the model.

Fig. 4. Demand elasticities when considering provincial Industry GDP (left) and national Industry GDP (right) as the socioeconomic variable in the model, for both coastal (above) and interior roads (below).

Table 5

Summary of elasticity estimations concluded from the analysis for the whole panel.

Variables	Range of elasticities
Provincial socioeconomic variables	
GDP	−0.22 to 2.34
GDP of highly transport-intensive sectors	0.74 to 1.28
Industry GDP	0.91 to 1.16
National socioeconomic variables	
GDP	−0.48 to 2.44
GDP of highly transport-intensive sectors	0.55 to 0.99
Industry GDP	0.50 to 0.87
Toll	−0.43 to −0.19
Fuel costs (€/km)	−0.56 to −0.01

demand. Significant variability of range for fuel costs and tolls responds to the numerous models calibrated because these variables generally show a fairly constant trend in each single model.

4.4. Robustness of results

With regard to robustness of estimations, we have opted for showing one case in detail, displayed in Table 4, and briefly summarize results for the rest of the models calculated. Detailed results for the 69 models included in Figs. 1–3 are very

similar to those from the example commented upon and almost all of them fully meet the requirements pointed out in Section 3.2.

Next, robustness of results regarding m1 and m2 tests is noted. According to González and Marrero (2011), two main conditions must be fulfilled in order to test that no serial correlation is observed in the estimated residuals ε_{it} . First, there should be evidence of negative first-order serial correlation of differenced residuals ($\Delta\varepsilon_{it}$), so that the value of the statistic m1 must be negative, with a p -value preferably below 0.05. Second, there should not be evidence of second-order correlation of differenced residuals, so that the p -value associated to the statistic m2 should be greater than 0.05. Regarding the example detailed in Table 4, results for m1 and m2 tests are consistent with absence of serial correlation in the residuals. As can be noted, the value of the statistic m1 is negative (−1.55) with a p -value of 0.049 (<0.05), while the p -value for the m2 test is 0.495 (greater than 0.05). Robustness of estimates for the rest of the models presented in Figs. 1–3 is very similar to the example from Table 4. The value of statistic m1 moves from −1.893 to −1.109, with an associated p -value ranging between 0.033 and 0.052 (≤ 0.05). Furthermore, the p -value for the m2 test runs from 0.055 to 0.776 (>0.05). Thus the requirements needed for the Arellano and Bond tests of serial correlation are fully met for all the alternatives shown.

With regard to the Sargan test, the validity of instruments used in the demand equation is checked when the null hypothesis is not rejected. Specifically, González and Marrero (2011) pointed out the convenience of having an associated p -value greater than 0.10. For the case detailed in Table 4, we can observe that the p -value in the Sargan test for GMM-DIFF (0.525) is far above the reference value. Although GMM-SYS also presents a p -value greater than 0.10, values near 1.0 are clear symptoms of low power of the test in that case, since the null hypothesis may exhibit almost zero rejection frequency of the validity of instruments null hypothesis (Baum et al., 2007). These results for the Sargan test support the choice of a GMM-DIFF approach for the analysis rather than a GMM-SYS one. Robustness estimates for the rest of the models are very similar to this case, as the associated p -value for the Sargan test moves from 0.233 to 0.783, again greater than the reference value (0.10) and also not close to 1.0.

5. Conclusions and further research

This paper has developed a panel data methodology to analyze which variables explain heavy vehicle demand evolution over time in toll roads. It establishes a feasible and original alternative, which consists of gradually varying the time period in the model, to analyze the stability of elasticities over time. This approach adds some advantages to the traditional procedure. On the one hand, it enables the identification of those parameters which exhibit a more constant and solid relationship with the dependent variable and, therefore, are more suitable to be chosen as explanatory variables. On the other hand, it makes the analysis more complete, objective, and rigorous. The paper has provided some interesting conclusions.

The first conclusion is that, despite the traditional approach, total GDP does not seem to be the most suitable socioeconomic explanatory variable for heavy goods vehicle demand. The significant variability of GDP elasticities, especially when changes in the economic environment happen, weakens its ability to explain traffic behavior and make long-term traffic forecasts. However, more solid estimates can be made if we take into account only transport-intensive sectors such as construction or industry. Thus excluding from the analysis those activities with low impact on road demand, such as financial services, public administration, and education, clearly improves the performance of total GDP as a socioeconomic variable.

Some comments can be made concerning the socioeconomic variables chosen to forecast heavy vehicle demand evolution. Although better results can be estimated when considering only transport-intensive activities, GDP forecasts for specific sectors of the economy are rarely provided, particularly in the long-term. By contrast, international financial institutions focus their economic projections on total GDP, which makes heavy vehicle traffic forecasts more complicated. In this respect, it would be helpful and desirable that these institutions provide disaggregated GDP projections for the most significant economic sectors. In any case, the results arrived at in this research are useful for understanding the limitations of relying on GDP, in case that is the socioeconomic variable chosen to forecast road freight demand.

The second conclusion points out that traffic decreases experienced in Spanish toll roads in the last years cannot be considered an anomalous fact given the trends shown by socioeconomic data. When proper explanatory variables are chosen for the analysis, elasticity estimates show a fairly continuous behavior despite dramatic changes in both road freight demand and economic growth.

From the results of this paper, some aspects can be highlighted as calling for further research. First, the analysis can be extended to heavy vehicle demand in free high capacity motorways in Spain, in order to check whether each type of road exhibits a different behavior. Furthermore, a trans-national analysis would be of great value to compare the influence that the key explanatory variables studied for heavy vehicles – total GDP, as well as GDP of transport-intensive sectors – can have on toll road demand in different countries. Finally, it would be very useful to include the analysis of the *decoupling effect* in order to improve the performance of total GDP as an explanatory variable.

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Appendix A. Description of explanatory variables included in the methodology

AADT (heavy veh./day): annual average daily traffic volume for heavy goods vehicles in each toll road, as recorded in the statistics of the Spanish Ministry of Transportation.

AADT₍₋₁₎ (heavy veh./day): lag of the annual daily traffic volume for heavy goods vehicles in each toll road.

GDP, national (M€): Gross domestic product at the national level, as recorded in the Spanish National Statistics Institute (INE) database. In constant euros.

GDP, provincial (M€): sum of the GDPs from the K provinces crossed by each toll road:

$$GDP_{provincial} = \sum_{i=1}^K GDP_i$$

GDP of highly transport-intensive sectors, national (M€): Gross domestic product of jointly the construction, industry and agriculture sectors at the national level, as recorded in the Spanish National Statistics Institute (INE) database (in constant euros):

$$GDP_{highly\ transport - intensive\ sector, national} = GDP_{constr.} + GDP_{indust.} + GDP_{agric.}$$

GDP of highly transport-intensive sectors, provincial (M€): Gross domestic product of jointly the construction, industry and agriculture sectors from the K provinces crossed by each toll road, as recorded in the Spanish National Statistics Institute (INE) database (in constant euros):

$$GDP_{highly\ transport - intensive\ sectors, provincial} = \sum_{i=1}^K GDP_{constr,i} + \sum_{i=1}^K GDP_{indust,i} + \sum_{i=1}^K GDP_{agric,i}$$

Industry GDP, national (M€): Gross domestic product of the industrial sector at the national level, as recorded in the Spanish National Statistics Institute (INE) database. In constant euros.

Industry GDP, provincial (M€): Gross domestic product of the industrial sector from the K provinces crossed by each toll road, as recorded in the Spanish National Statistics Institute (INE) database (in constant euros):

$$Industry\ GDP, provincial = \sum_{i=1}^K GDP_{indust,i}$$

Toll rate (euro/km): average toll rate applied to heavy goods vehicles in each toll road, as recorded in the Spanish Ministry of Transport statistics. In constant euros.

Fuel cost (euro/km): product of Diesel price and Fuel consumption:

$$Fuel\ cost = Diesel\ price\ (euro/liter) \times Fuel\ consumption\ (liter/km)$$

Diesel prices are collected from the statistics of the Spanish Ministry of Transportation. In constant euros.

Fuel consumption is assumed as a linear progression from average 1990 levels according to the Spanish Ministry of Transportation to 2011 values by the Spanish Ministry of Industry.

Appendix B. Generalized costs for heavy vehicle demand in the Spanish toll network considered (1990–2010)

Variable Units	Toll road	1990	2007	2010
Toll rate €/km (constant)	Montmeló–La Jonquera	0.078	0.070	0.072
	Barcelona–Tarragona	0.088	0.080	0.082
	Zaragoza–Mediterráneo	0.070	0.069	0.071
	Villalba–Adanero	0.164	0.135	0.144
	Sevilla–Cádiz	0.133	0.056	0.058
	Tarragona–Valencia	0.107	0.064	0.066
	Valencia–Alicante	0.108	0.064	0.066
	Bilbao–Zaragoza	0.132	0.082	0.084
	Burgos–Armiñón	0.122	0.064	0.065
	León–Campomanes	0.136	0.079	0.081
	Montgat–Mataró	0.117	0.059	0.061
	Bilbao–Behobia	0.145	0.090	0.091
	Tudela–Iruzun	0.079	0.020	0.021
	San Cugat–Manresa	0.151	0.109	0.111
Fuel price €/liter (constant)		0.400	0.531	0.553
Fuel consumption liter/km		0.400	0.319	0.305
Fuel cost €/km (constant)		0.160	0.169	0.168

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3. A MICRO APPROACH ON ROAD DEMAND BEHAVIOR: UNDERSTANDING USERS' PERCEPTIONS AND WILLINGNESS TO PAY IN INTERURBAN TOLL ROADS

This chapter conducts a micro approach on interurban toll roads demand by exploring users' perceptions and willingness to pay. These two concepts have not generally been analysed simultaneously in the existing literature. Although willingness to pay has been widely studied for interurban roads, researches mainly comprised high-occupancy toll (HOT) lanes, a different concept in practice to purely toll facilities. Furthermore, perceptions towards tolls were mainly studied for urban pricing schemes, with scarce contributions at the interurban context. This research analyses users' perceptions and willingness to pay in interurban roads, as well as the relationship between both of them. It is aimed at identifying to what extent users' choices are influenced by individual characteristics or road-related attributes, the latter considered as context-specific factors.

To that end, the research exploits the results from a nationwide survey conducted to road users in interurban toll roads. Two different choice models (binomial logit and tobit specifications) are adopted to analyse users' responses. The research covers an interesting case in the international context in terms of users' experiences towards tolls, given the marked asymmetry of the Spanish toll road network across regions.

Figure 3.1. Analysis on users' perceptions and willingness to pay

From the results of the previous analysis, this chapter also conducts a special focus on analysing regional differences in users' perceptions towards toll roads. Since some researches have concluded that context-specific factors may greatly influence users' perceptions towards tolls, analysing the singular case of a toll network asymmetrically distributed becomes of great interest. As well as the identification of potential differences among respondents according to their region of residence or the toll road frequently used, the modelling approach is aimed at determining the reason of such differences.

To fulfil this objective, a multilevel model has been adopted since it is an econometric technique ideally suited for measuring differences across groups of individuals, as well as avoiding the so-called "*athomistic fallacy*". The network analysed represents a very interesting case given its heterogeneity in terms of different explanatory factors such as toll roads density, level of the toll rate, quality of the free alternative road, etc.

Figure 3.2. Analysis exploring regional differences in users' perceptions towards toll roads

This chapter includes two papers that has been published as:

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Users' perceptions and willingness to pay in interurban toll roads: identifying differences across regions from a nationwide survey in Spain

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Abstract Users' acceptability is considered one of the key drivers for the successful implementation of transport policy measures. This is especially crucial in the case of toll roads since they are financed through drivers' contributions. Previous literature in this field has mainly focused on measuring users' attitudes towards urban congestion pricing strategies. However limited research has been developed concerning interurban toll roads. Previous research shows that socioeconomic variables are not conclusive to explain users' perceptions towards tolls. By contrast, other drivers such as regional differences seem to play a more important role, especially when charging conditions within the same nation greatly vary across regions. This paper analyzes regional differences in users' attitudes within an asymmetrical distribution of the toll road network across regions. Based on a nationwide survey conducted to road users in interurban toll roads in Spain, we develop both a binomial logit and a censored regression (tobit) model to explore drivers' perceptions and willingness to pay. The research concludes that users from regions with a more extensive tolled network generally show a more negative attitude towards charges, but not necessarily a lower willingness to pay. The paper also points out that an asymmetrical distribution of toll roads across regions may result in negative perceptions among those users perceiving to be unfairly treated when compared to citizens in other regions.

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Keywords Users' perceptions · Willingness to pay · Toll roads · Logit model · Tobit model · Spain

Introduction

Budgetary restrictions faced by national governments in the last decades have led them to limit their expenditure in public policy priorities, such as road infrastructure, and seek alternative funding mechanisms. As a result, tolls and road user fees have increasingly become a common option to collect stable resources for funding road projects (Matas and Raymond 2003), both in the United States and many European countries. Road charging represents a powerful means to raise funds, but may also change travel conditions and users' choices in the transport network. In this respect, it is generally agreed that users' acceptability is one of the key drivers to achieve a successful transport policy (Kockelman et al. 2009), especially when it comes to road pricing strategies. Policy makers must seek to recommend options that not only have strong public support, but are also desirable in terms of equity, ability to generate stable revenues, capacity to encourage environmentally responsible choices, etc. (Dill and Weinstein 2007).

Despite the increasing literature on attitudes towards tolls and acceptability of road user charges, several research gaps can be identified. Firstly, there is limited previous research focusing on interurban contexts, what contrasts with the broad literature on urban areas. Secondly, stated-preference surveys on free roads are often employed, with a limited usefulness since potential users are asked about choices they may have not experienced or are not easy for them to imagine (Odeck and Kjekreit 2010).

Existing literature on users' perceptions towards tolls has traditionally analyzed the influence of socioeconomic factors (age, income, trip purpose, etc.), but has not generally got to conclusive and coincident results about their influence on attitudes (Yusuf et al. 2014). Additionally, some authors (Rienstra et al. 1999; Schade and Schlag 2000) have pointed out that socioeconomic factors may have a somewhat lesser impact on acceptability than do attitudinal factors. In certain occasions, the latter may be rather determined by features scarcely analyzed in the literature, such as the quality of the alternative free road, if available, and regional differences on toll roads within the same nation. In this respect, regional approaches to road transport have mainly focused on very few specific topics such as road safety (Tolon-Becerra et al. 2013; Eksler et al. 2008).

Spain can be considered a representative case of an interurban highway network asymmetrically distributed across regions. While a significant percentage of the high capacity network is tolled in certain territories, other areas are provided with free high quality roads. This heterogeneity has generated negative sentiments towards road charging in those regions especially enduring the burden of tolls. This fact makes Spain an interesting case to analyze potential differences in toll road users' attitudes across regions.

The aim of this paper is to establish a first approach to explore regional differences on road users' perceptions towards toll roads. Particularly, it seeks to identify potential differences on users' attitudes and willingness to pay (WTP) as a result of an asymmetrical distribution of toll roads across regions. Furthermore, the relationship between users' perceptions and their declared WTP is addressed. Based on a nationwide survey conducted in interurban toll roads in Spain, we develop both a binomial logit and a censored regression (tobit) model to explore users' perceptions and WTP. This research has some noteworthy aspects. To our knowledge, this is one of the few nationwide surveys —jointly

with those ones developed for Norway in Odeck and Brathen (2008; Odeck and Kjekreit 2010)—conducted in interurban toll roads already in operation. The network considered, with a total of 2264 km, is also among the longest interurban toll road systems ever surveyed in the literature. Furthermore, the model specification we use includes some explanatory variables barely analyzed to measure users' perceptions towards toll roads, such as the quality of the free parallel road. This paper focuses just on perceptions and attitudes among road drivers. Consequently, potential influences coming from the existence of alternative modes (rail, air) have not been considered. Finally, the research covers an interesting case in the international context, given the marked heterogeneity of toll roads across regions in Spain.

This paper is organized as follows. After this introductory chapter, “Literature review” section summarizes the state of knowledge regarding users' perceptions towards tolls, and provides some brief insight about the history and main characteristics of the Spanish interurban toll network. “The Spanish toll road network” section outlines the methodology of this research. “Methodology” section makes a description of the survey conducted to road users. “The data: a nationwide survey in Spanish toll roads” section presents and discusses the results. Finally, “Choice modeling results and discussion” section sets out the main conclusions and points out further research.

Table 1 Overview of the influence of different socioeconomic parameters on attitudes towards tolls

Author (year)	Podgorski and Kockelman (2006)	Dill and Weinstein (2007)	Odeck and Brathen (2008)	Odeck and Kjekreit (2010)	Chen and Wen (2014)
Context	Texas residents	California residents	Road users in Norway	Road users in Norway	Road users in Taiwan
Explanatory variables included					
Trip length	N.s.s.	N.s.s.	–	N.s.s.	–
Travel frequency	–	–	–	–	–
Age	N.s.s.	++	N.s.s.	++	
Gender	S.s.	S.s.		N.s.s.	
Education	++	++			
Employment	S.s.				
Income		N.s.s.	N.s.s.	++	
Political leaning		S.s.			
Level of information			++	++	
Type of vehicle			S.s.		
Travel purpose			N.s.s.		S.s.
Who pays the toll			N.s.s.		

++ Statistical positive influence; – statistical negative influence

S.s statistically significant differences, N.s.s. non statistically significant differences

Literature review

Previous studies on attitudes towards tolls have mainly focused on urban contexts, with special attention to the implementation of congestion charging systems in city centers (Furst and Dieplinger 2014; Gehlert et al. 2011; Kottenhoff and Freij 2009; Gaunt et al. 2007). By contrast, the literature analyzing users' perceptions on interurban areas is limited and primarily deals with American High Occupancy/Toll (HOT) lanes, such as Zmud et al. (2007) and Golob (2001). The terms 'perceptions' and 'attitudes' have both been used in the literature as almost synonyms to address users' view towards tolls. These terms are different to users' behavior, which reflects the choice actually followed by the respondents.

The acceptability of toll road pricing constitutes a complex matter that can be approached in a number of ways (Di Ciommo et al. 2013). Previous research studies in this field have analyzed the influence of socioeconomic factors (age, income, trip purpose, etc.) on users' perceptions towards tolls. The results of these studies are useful to target specific user market segments as well as predict future behavior of citizens. Nevertheless, they have not generally led to conclusive and coincident results about the influence of these variables on users' attitudes (Odeck and Kjekreit 2010; Gehlert et al. 2011), as can be seen in Table 1.

In this respect, some authors (Rienstra et al. 1999; Schade and Schlag 2000) have pointed out that socioeconomic factors may have a somewhat lesser impact on acceptability than do attitudinal factors. The latter may be determined by aspects such as the use of toll revenues (Schuitema and Steg 2008; Jaensiriak et al. 2005), the perceived fairness of charges (Bonsall et al. 2007; Schade and Baum 2007), existing community values or political leanings (Yusuf et al. 2014). All these factors can lead to regional differences on users' perceptions towards tolls, especially when charging conditions greatly vary across territories within the same nation.

Previous research studies addressing regional differences on road transport are scarce and mainly limited to analyze specific topics such as road safety (Tolon-Becerra et al. 2013; Eksler et al. 2008; Lassarre and Thomas 2005). Regarding acceptability towards road charges, only differences between residents in urban and rural areas have been addressed. According to Podgorski and Kockelman (2006), rural areas in Texas are more supportive for tolling when compared to urban contexts, likely because residents might be thinking of tolls not applied to roads in their areas. Also focusing in Texas, Kockelman et al. (2009) identified regional differences in terms of supporting different proposed congestion pricing policies. In the same line, the study by Dill and Weinstein (2007) in California found more support for tolling in rural or smaller urban areas. As can be noticed, these papers did not specifically focus on users' attitudes but on public perceptions in general.

For the case of Europe, the research on users' acceptability in the Norwegian toll network by Odeck and Brathen (2008 and Odeck and Kjekreit 2010) can be considered the most relevant study, and also the only study addressing users' attitudes towards tolls nationwide. These authors underlined the importance of the level of information supplied to users prior to the implementation of road charging. With regard to Spain, no previous studies have been undertaken specifically to investigate users' perceptions towards toll roads.

On the other hand, literature regarding WTP in toll roads is extensive and typically focuses on managed lanes. A comprehensive review of the existing research can be found in Li et al. (2010). Many of the previous studies have addressed behavioral and travel

characteristics influencing the value of time (VOT) (Rose and Hensher 2014; Burris et al. 2012; Amador et al. 2005). However, to our knowledge no effort has been made to analyze potential differences in WTP across regions. In Spain, Asensio and Matas (2008) and Álvarez et al. (2007) calculated the VOT in specific road corridors made up of a toll motorway and a free parallel road, but they did not make a nationwide analysis.

This paper aims to contribute to the existing literature in the following aspects. First, along with the studies conducted by Odeck and Kjekreit (2010) in Norway, to our knowledge, this is one of the few nationwide surveys that analyze users' attitudes in interurban toll roads already in operation. Second, it constitutes a first insight concerning regional differences on users' attitudes and WTP caused by an asymmetrical road transport policy. Finally, we include variables barely used in previous studies to explain users' perceptions towards tolls, such as the quality of the free alternative road.

The Spanish toll road network

With a total of 16,582 km, Spain has currently one of the longest high capacity road networks within Europe. Given the scarcity of quality roads in the nation until the mid-1960s, a great effort was made over the last decades to build an extensive road network to promote economic growth and territorial cohesion among regions. As of 2013 toll road concessions were 18.2 % of the high capacity network currently in operation (Ministerio de Fomento 2014), what also makes Spain one of the longest national tolled networks in the world.

Since the early 1970s, more than 3000 km of toll highway concessions have been put in operation (Matas et al. 2012). Nevertheless, Spanish toll roads are far from constituting a homogeneous network throughout the country. They were built in different periods, and are asymmetrically distributed over the territory. According to Vassallo et al. (2012), three different periods can be identified in the development of the road network in Spain:

- First period (1962–1975): Despite the aim of the government to provide the nation with a modern high capacity network, the budgetary resources were not enough to finance the program through public funds. In order to develop these high investment road projects, several toll highways were granted by the government to private concessionaires. The toll highways built during this period were mainly located in the most industrialized regions such as Catalonia, the Basque Country, Valencia, etc.
- Second period (1975–1995): The petroleum crisis in the 1970s destabilized the Spanish economy and postponed further extensions of the high capacity network. Later, the socialist government elected in 1982, which was politically opposed to road charging, promoted new road projects in the country fully financed through the public budget. The program built free highways, many of them connecting Madrid with the most important Spanish cities. The new program aimed at alleviating the deficit of road infrastructure in less developed regions, not served in the previous period.
- Third period (1996–2008): The need to contain the public deficit, as a prerequisite for joining the Eurozone, moved the central government towards using again the toll concession approach to build new roads. New projects primarily aimed at tackling the increasing road congestion near the city of Madrid, by promoting 5 toll roads parallel to the existing free radial highways. New concessions awarded in this period followed different approaches, not always based on road user charging, such as shadow tolls, availability payment mechanisms, etc.

Consequently, the current situation in Spain is a tolled network asymmetrically located throughout the country. As can be seen in Table 2 and Fig. 1, great contrasts can be found in the Spanish high capacity network. While regions such as Catalonia, Valencia or Galicia have an extensive tolled network (above 300 km), other territories such as Extremadura, Cantabria or Asturias have few, or even no, tolled kilometers. As we mentioned above, this is a result of the historical evolution of road policy in the country (see Fig. 1). At the beginning of the 1980s, high capacity roads in Spain were scarce and mainly comprised tolled sections concentrated in few regions. It was not until the 1990s and early 2000s that the high capacity network significantly increased and spread over most of the territory, generally financed through the public budget.

The current national toll network comprises two different types of toll roads. Firstly, few of the toll sections are tunnels, where a fixed toll is charged for crossing them. In terms of unitary values, toll rates for light vehicles in this type of infrastructure are quite expensive, lying from 0.143 Euro/km (Eje Aeropuerto tunnel) to 0.49 Euro/km (Arxanda tunnels). However, the vast majority of the toll network surveyed is made up of interurban road stretches (99.6 % of tolled km), where users are charged per km driven. Toll rates within this group are lower—they range between 0.07 and 0.10 Euro/km for light vehicles—, and fairly homogeneous over the territory. Furthermore, tolls in Spain vary across

Table 2 Evolution of the interurban high capacity and toll road network in Spanish regions (1990–2010)

Region	Surface (10 ³ km ²)	1990			2010		
		High capacity network (km)	% Tolled	Tolled network (km)	High capacity network (km)	% Tolled	Tolled network (km)
Andalusia	87.6	726	24.2	176	2642	9.1	241
Aragon	47.7	330	58.2	192	781	20.1	157
Asturias	10.6	80	76.3	61	408	5.4	22
Balearic Islands	4.9	42	0.0	0	183	0.0	0
Basque Country	7.2	359	62.1	223	598	41.5	248
Canary Islands	7.4	198	0.0	0	308	0.0	0
Cantabria	5.3	42	57.1	24	220	0.0	0
Castilla-La Mancha	79.4	435	0.0	0	1809	13.2	239
Castilla y León	94.2	501	41.3	207	2303	11.9	275
Catalonia	32.1	838	68.4	573	1336	47.2	631
Extremadura	41.6	17	0.0	0	744	0.0	0
Galicia	29.6	141	83.7	118	1055	31.1	328
Madrid	8.0	472	20.1	95	973	14.9	145
Murcia	11.3	82	14.6	12	630	18.3	115
Navarra	10.4	172	88.4	152	380	36.6	139
La Rioja	5.0	129	91.5	118	165	72.1	119
Valencia	23.2	561	68.6	385	1427	25.7	367

Fig. 1 Evolution of the interurban high capacity network in Spain (1990–2010)

vehicle types, with toll rates applied to heavy vehicles being around 50 % higher than to light vehicles.

The regional asymmetry of the tolled network has been one of the reasons why people in certain regions have a sentiment of unfairness for enduring the burden of tolls. While drivers in Catalonia or Valencia have been paying tolls for decades, regions such as Castilla y León, Castilla-La Mancha or Andalusia have been provided with many free high capacity roads in the last 20 years (see Table 2). Territorial inequity in this respect is an issue repeatedly claimed and proposed in the political agenda by nationalist parties in regions such as Catalonia. Furthermore, social movements and associations have recently appeared at the regional level to coordinate protests and actions towards tolls, claiming for undergoing charging unfairness compared to the rest of Spaniards. This is the case of the so-called *No vull pagar* (in Catalan, “not wanting to pay”) movement, present in the region of Catalonia and, to a lesser extent, in Valencia. Since 2012, this movement has occasionally organized protests in existing toll roads, encouraging drivers to cross tollgates without paying the toll and collapsing toll plazas for hours.

Methodology

In order to measure users’ perceptions and WTP in interurban toll roads, we develop both a binomial logit and a censored regression model. The main characteristics of each statistical specification are summarized below. The predictors to calibrate these models were obtained from a survey that will be described in the following section.

Binary choice models to measure users’ perceptions

The study employs binary choice models in order to measure the effect of certain socio-economic factors and regional characteristics on users’ attitudes and choices towards the use of toll roads. Particularly, respondents were asked in the survey (see “[Methodology](#)” section) whether they considered tolls as an appropriate mechanism to fund roads. This answer represented the dependent variable of the binary choice specification.

Binary choice models fall into the category of utility maximization models and they incorporate the micro-economic theories of consumer behavior and psychological choice

behavior. Rational choice models assume that a person chooses the alternative with the higher utility (Ben-Akiva and Lerman 1995; Train 2003) among all the options available. The utility of each choice can be determined by a number of parameters related to both personal attributes of the individual (X) and characteristics of the alternative itself (S), which are described below (see “Methodology” section). Then the utility in the model is approached as follows:

$$U_{ik} = f(X_{ik}, S_{ik}) \quad (1)$$

where U_{ik} is the utility gained by individual k for choosing alternative i . U_{ik} is considered a random variable and therefore consists of a sum of observed variables V_{ik} —systematic or representative component of the utility—and random components ε_{ik} :

$$U_{ik} = V_{ik} + \varepsilon_{ik} = \beta_k X_{ik} + \varepsilon_{ik} \quad (2)$$

where is X_{ik} a vector of measurable characteristics that define utility, such as age, income, trip frequency, etc.; and β_k is a vector of parameters to be estimated (Louviere et al. 2006).

Economic theory assumes that the individual k will choose the option with the highest utility ($U_{ik} > U_{jk}$). In the general form of a binary choice model, the probability that respondent k will choose alternative i is expressed as (Ben-Akiva et al. 1985):

$$P_i = \frac{e^{V_{ik}}}{\sum_j e^{V_{ij}}} \quad (3)$$

Then, the binary logistic regression predicts the logit of the odds ratio, L_i , given multiple explanatory variables X_i (Peng and So 2002):

$$L_i = \ln \frac{P_i}{1 - P_i} = \alpha + \beta_1 X_1 + \beta_2 X_2 \dots + \beta_k X_k \quad (4)$$

As a result of this linearization process, the interpretation of the β_i coefficients is different compared to the ones from lineal regression models. In this case, the slope coefficient suggest that for a unit increase in a certain explanatory variable X_k , the weighted log of the odds in favor of a certain alternative ($Y = 1$) increases by e^{β_k} . More appealingly, for a unit increase in a certain explanatory variable X_k , the odds ratio in favor of happening $Y = 1$ increases by e^{β_k} .

Logit models adopt several distributional assumptions that differ with the usual regression models. Apart from the independence of the error terms and lack of multicollinearity problems in the sample, this specification assumes linearity of independent variables and logs of the odds ratio. Furthermore, the model resort to nonlinear estimating procedures using the method of maximum likelihood (Gujarati and Porter 2004), so a quite large sample size is required.

Tobit specification to measure users' willingness to pay (WTP)

Censored regression (tobit) models are employed in situations where the information on the dependent variable is available only for some observations (Gujarati and Porter 2004). This is the case of our survey, where users were asked about hypothetical situations in order to assess their WTP for specific scenarios (see “Methodology” section). In this respect, we found two types of users: those willing to use toll roads by paying a certain amount of money, and those users who will never use toll roads either because of income

constraints or personal beliefs. In case we wanted to calculate a regression including the whole sample, we would find that no information would be available related to the WTP (from now on WTP) for the second group of users, so we have a censored sample.

In order to deal with the data from respondents not willing to use toll roads, we adopted a censored regression (tobit) model. According to Nolan (2002), the formulation of the underlying model would be:

$$Y_i^* = \beta X_i + \varepsilon_i \quad (5)$$

where Y^* is a continuous latent variable, X_i is a matrix of explanatory variables, β is a vector of coefficients to be estimated, and ε_i is a vector of normally distributed error terms. On the other hand, the observed variable (Y_i) is defined by:

$$\begin{cases} Y_i = Y_i^* & \text{if } Y_i^* > 0 \\ Y_i = 0 & \text{if } Y_i^* \leq 0 \end{cases} \quad (6)$$

It is important to highlight that the β coefficients represent the effect of X_i on the latent variable Y^* , but not on the observed variable Y , which is the difference with the linear regression model. As can be seen, the explanatory variables (X_i) in the tobit model affect both the decision of individuals to choose/not to choose a specific alternative, as well as the intensity of their choice (Tsekeris and Dimitriou 2008). In contrast with logit models, tobit specifications adopt the same distributional assumptions as standard regression models so coefficients of these models should be interpreted in the usual way.

The combination of logit and tobit models for analyzing users' perceptions and WTP, respectively, constitutes a noteworthy methodological point of this research. In strict terms, it should be acknowledged that distinguishing attitudes from actual behavior and WTP can be better estimated through revealed preference (RP) Surveys. Nevertheless, a comparison between perceptions and stated-preference choices from real users of the toll network can also be a valuable approach to address such an issue. This procedure will allow a better understanding of the modeling results, which will lead to more efficient policy recommendations.

The data: a nationwide survey in Spanish toll roads

The data used in this research was collected from a nationwide survey developed in several Spanish interurban toll roads in 2010. It was addressed to users of interurban toll roads, both frequent and occasional ones, though also comprised potential users living close to the existing tolled infrastructure. The survey was conducted between October and November, 7-days a week with the aim to get a representative sample in terms of trip purpose. Depending on the type of user and the characteristics of the toll road, the data was collected from either phone questionnaires or personal interviews at service areas or petrol stations. We stratified the sample in order to achieve sufficient representation at the regional level. Further details about this survey can be found in Gomez and Vassallo (2014).

The paper is primarily aimed at identifying regional differences with regard to two main questions: users' perceptions towards toll roads and their WTP in interurban contexts. The questionnaire, divided into two main parts (see details in Appendix 1), was especially designed to that end. In the first part, drivers were asked about their socioeconomic characteristics (age, income, trip frequency, trip purpose, etc.), and also additional information regarding the toll road. These data mainly comprised the explanatory variables for

the choice model described above. For the case of potential users, trip purpose was not asked since this subgroup in the sample never used toll roads before. Further comments about the explanatory variables in the questionnaire are included below.

The second part of the survey was related to drivers' attitudes regarding toll roads. In order to estimate general acceptability towards tolls, users were asked whether they considered tolls as an appropriate way to finance road infrastructure, in a similar way as in Odeck and Brathen (2008). This has been an approach previously adopted in the literature to account for users' perceptions towards road charges.¹ Their answers at this point formed the dependent variable for the binary choice model detailed in subsection 3.1. Additionally, they reported their perceptions towards current toll rates. In this respect, it is important to note that it is a requirement that every toll concession in Spain has a free parallel road available in the corridor.

Finally, the questionnaire concluded with a simple stated-preference choice to measure users' WTP in different scenarios. Respondents were presented a corridor made up of a free road and a parallel toll highway which allows the driver to save travel time (TT). For a given 60- and 180-min trip in the free road, drivers were asked in open answer about the amount they would be willing to pay for specific TT savings (TT_{sav}) in the case of using the toll road. Therefore, respondents directly reported their WTP in different scenarios, what is particularly interesting in the case of frequent and occasional users. This information became the dependent variable for the tobit model described in subsection 3.2.

As this paper is mainly focused on identifying regional differences in users' attitudes, respondents in the sample were surveyed in a balanced way (see Table 3 below) from some of the regions with the largest toll road network. The survey focused on regions with mature toll roads, where user charging was implemented decades ago, and those ones with a more modern toll network. We also included some variability regarding the quality of the free parallel road (see Appendix 2). Catalonia, Madrid, Valencia, the Basque Country and Galicia were the cases ultimately selected for this research. Other regions with a significant length tolled (Andalusia, Castilla-La Mancha, Castilla y León) were not included because toll roads are not spread in a homogeneous way throughout the territory, but are concentrated on specific areas. This makes the analysis more difficult in these cases, since users' perceptions towards tolls may widely vary over the same region. A constant specific variable for each region was included in the model in order to identify potential regional differences and capture the influence of region-specific factors, such as the presence of an anti-toll atmosphere in certain territories.

The network included in the survey comprises all the interurban toll roads starting and/or ending in the 5 regions selected. With a total of 2264 km, this sample can be considered representative of the Spanish toll network, as it includes around 75 % of total tolled km in the country. We would like to note that it is an extensive network when compared to other toll systems previously analyzed, both interurban toll networks (Odeck and Kjekreit 2010; Zmud et al. 2007) or toll point facilities, such as bridges or tunnels (Yusuf et al. 2014; Gordon and Peters 2011).

The quality of the free parallel road available may constitute a significant explanatory factor to determine users' perceptions, since it increases the ability to avoid tolls. For the network surveyed, great asymmetry can be observed regarding this point (see Appendix 2). Tolled sections competing with free highways are numerous in regions such as Madrid, while in the Basque Country or Catalonia the alternative route is generally formed by a

¹ In this research, we use the terms "users' perceptions" and "users' attitudes" interchangeably as it has usually been done in the literature.

Table 3 Summary of characteristics in the sample

Variable	Subgroup	Respondents	% Sample
Gender	Male	1645	51.3
	Female	1559	48.7
Age	Under 24	173	5.4
	From 24 to 34	513	16.0
	From 35 to 49	1335	41.7
	From 50 to 64	900	28.1
	Above 64	283	8.8
	Not responding	602	18.8
Income	Under 20,000 Euro	916	28.6
	From 20,000 to 30,000 Euro	1116	34.8
	From 30,000 to 50,000 Euro	462	14.4
	Above 50,000 Euro	108	3.4
	Not responding	602	18.8
Type of vehicle	Car	2847	88.9
	Light van	232	7.2
	Truck	103	3.2
	Moto	12	0.4
	Bus	11	0.3
	Not responding	602	18.8
Frequency/type of user	Frequent	2210	69.0
	Occasional	705	22.0
	Potential	288	9.0
Trip purpose	Commuting	890	27.8
	Business	349	10.9
	Weekend leisure	783	24.4
	Holiday leisure	562	17.5
	Other	332	10.4
	Not included (potential users)	288	9.0
	Not responding	602	18.8
Region	Catalonia	640	20.0
	Madrid	634	19.8
	Valencia	652	20.3
	Basque country	636	19.8
	Galicia	642	20.0
Quality of the alternative	Conventional road	2596	81.0
	Highway	608	19.0

conventional (two-lane) road, with poor characteristics. The research also measures the influence of additional variables on users' attitudes, such as unitary toll rates applied (taking into account the type of vehicle driven by the user) and the type of tolled infrastructure (interurban road/tunnel), since each one follows a different charging scheme. This research does not consider the potential influence of alternative transport modes (rail, air) on users' attitudes, since the survey is addressed to people who mostly travel by car.

Table 3 summarizes the main characteristics of the sample used for the two analyses conducted in this research: users' perceptions and WTP. A balanced proportion of men and women can be observed, as well as the distribution of respondents across regions.

Furthermore, we identify a higher presence of people aged between 35 and 49, whose income typically lies below Euro 30,000, and a vast majority of cars (88.9 %) regarding the type of vehicle used. It is noticeable the high proportion of respondents (18.8 %) not reporting their income. Commuting (27.8 %) and weekend leisure (24.4 %) are the most common trip purposes in the sample, with a high proportion of respondents (69.0 %) making more than 8 trips per month (frequent users). These variables mainly comprise the explanatory parameters considered for this research, apart from some minor additions commented below.

Choice modeling results and discussion

This section reports the main findings from the analysis. Subsection 5.1 presents the results of modeling users' perceptions towards toll roads through a binomial logit specification. Estimates of the tobit model measuring drivers' WTP are displayed in Subsection 5.2.

Users' perceptions towards interurban toll roads

Before showing the estimates calculated through the binomial logit specification described in "[The Spanish toll road network](#)" section, some preliminary results are presented (see Table 4) for certain explanatory variables. Concerning the general perception on toll roads, the majority of respondents (52.8 %) were positive towards the application of tolls to finance road infrastructure. Nevertheless, this attitude does not seem to be homogeneous throughout the country when we disaggregate the results by regions.

Table 4 Users' perceptions towards toll roads and toll rates

	Perception towards toll roads (%)		Perception on toll rates (%)		
	Positive	Negative	Cheap	Medium	Expensive
Total sample	52.8	47.2	0.9	13.0	86.1
Region					
Catalonia	41.4	58.6	0.2	5.9	93.9
Madrid	65.1	34.9	1.8	26.4	71.8
Valencia	48.5	51.5	0.5	13.4	86.1
Basque country	54.5	45.5	0.1	10.2	89.7
Galicia	54.9	45.1	1.1	10.2	88.7
Income					
Below 20,000 Euro	51.4	48.6	0.1	13.0	86.9
From 20,000 to 30,000 Euro	53.7	46.3	0.5	11.9	87.6
From 30,000 to 50,000 Euro	56.0	44.0	1.5	16.5	82.0
Above 50,000 Euro	59.7	40.3	1.6	24.2	74.2
Not responding	45.8	54.2	0.5	11.1	88.4
Quality alternative					
Conventional road	50.4	49.6	0.8	10.3	88.9
Highway	63.1	36.9	1.4	24.6	74.0

Preliminary results in percentage

As can be seen, users' acceptability in Catalonia is low (41.4 %), while in Madrid is particularly high (65.1 %) when compared to other regions in the sample. Furthermore, drivers' attitudes towards toll roads appear to be more positive as income increases. We can also observe that the level of acceptability is higher for those drivers using a toll road competing with a high quality alternative.

Regarding users' perceptions on toll rates, not modeled afterwards, we find that the majority of users (86.1 %) considered that toll rates applied are too high. Catalonia is the region with the most negative perception towards the level of toll rates (93.9 %), while Madrid is again the least negative (71.8 %). Given the fairly homogeneous toll rates applied throughout the country, the reason behind regional differences may be the asymmetrical density of toll roads and existence/absence of high quality free alternatives when compared to other territories. The network in some regions forces drivers, in a certain way, to use toll roads to save TT.

It can also be observed that, the higher the income (particularly above 50,000 Euro), the less negative users' attitudes towards toll rates. This is in line with other previous results referred to in the literature (Odeck and Kjekreit 2010). Finally, focusing on the influence of the alternative road, we notice that users are less negative to toll rates when the free parallel road happens to be a highway.

In order to check the validity of these preliminary findings, a binomial logit specification has been calibrated. The model estimates the probability of being positive towards toll roads—that is, to consider tolls as an appropriate mechanism to fund roads—and measures the influence of different explanatory variables on this attitude. Before setting up the logit model, some tests for checking multicollinearity between the explanatory variables modeled were applied, showing no significant interactions.

The majority of explanatory variables in the model are categorical, so a base case needs to be chosen as a reference to better identify potential differences in users' perceptions (see Table 5). With regard to the region parameter, we have selected the Basque Country as the base case, since it seems to represent an intermediate position in terms of users' attitudes, given the preliminary results in Table 4. Then, it allows us to approach whether users' perceptions in the rest of the regions, either positive (Madrid) or negative (Catalonia, Valencia), are statistically significant when compared to the base case.

In order to properly calculate the influence of each variable on users' perceptions, two different models have been calibrated. The first one (Model 1) includes the whole sample, and is mainly aimed at calculating how attitudes may vary depending on the type of user: potential, occasional and frequent. However, Model 1 is not able to estimate all the explanatory variables, since data related to e.g. trip purpose are not available for potential users. Consequently, a second logistic specification (Model 2) has been calculated for actual users—frequent and occasional ones—of the tolled network: In this case, it is possible to include two additional explanatory variables: toll rates and type of tolled infrastructure.

Table 5 includes empirical results from both models. As can be seen, coefficients remain fairly constant for those parameters simultaneously included in models 1 and 2. The results confirm that, as pointed out in the literature (Rienstra et al. 1999; Schade and Schlag 2000), users' acceptability is often more influenced by attitudinal factors than by individual socioeconomic characteristics. Despite a more positive perception observed in the case of females, no statistically significant differences can be found throughout the subgroups established in terms of age, type of vehicle or income.

A less negative attitude towards toll roads is found with age, but the relationship is not statistically significant (p value > 0.05) neither for the variable as a whole nor for any of

Table 5 Users' perceptions towards interurban toll roads: estimation results

Variables	Model 1: all respondents			Model 2: excluding potential		
	Coefficient	Standard error	p-value	Coefficient	Standard error	p-value
Age						
Under 25 (base case)						
From 25 to 34	−0.462	0.294	0.116	−0.495	0.309	0.110
From 34 to 49	−0.496	0.281	0.077	−0.512	0.295	0.083
From 50 to 64	−0.226	0.293	0.439	−0.249	0.309	0.420
Over 64	−0.122	0.970	0.900	−0.172	0.982	0.861
Gender						
Male (base case)						
Female	0.279	0.079	0.000	0.264	0.084	0.002
Type of vehicle						
Car (base case)						
Light van	−0.287	0.145	0.048	−0.257	0.153	0.0902
Truck	−0.170	0.214	0.628	−0.141	0.221	0.523
Moto	1.082	0.796	0.174	2.073	1.515	0.799
Bus	−0.750	0.655	0.253	−0.750	0.661	0.257
Region						
Basque Country (base case)						
Catalonia	−0.641	0.119	0.000	−0.735	0.128	0.000
Madrid	0.183	0.149	0.218	0.095	0.210	0.651
Valencia	−0.325	0.116	0.005	−0.380	0.129	0.003
Galicia	−0.059	0.117	0.615	−0.038	0.129	0.766
Type of user						
Frequent user (base case)						
Occasional user	−0.046	0.091	0.616	0.066	0.092	0.477
Potential user	0.198	0.133	0.136			
Quality of alternative						
Conventional (base case)						
Highway	0.331	0.129	0.010	0.412	0.153	0.007
Type of tolled infrastructure						
Road (base case)						
Tunnel				0.133	0.212	0.530
Toll rate				−0.645	0.987	0.514
Income						
Under 20,000 Euro (base case)						
20,000 to 30,000 Euro	0.118	0.124	0.340	0.078	0.131	0.554
30,000 to 50,000 Euro	0.156	0.161	0.331	0.144	0.169	0.396
Over 50,000 Euro	0.278	0.287	0.334	0.233	0.299	0.435
Trip purpose						
Commuting (base case)						
Business				0.254	0.136	0.061

Table 5 continued

Variables	Model 1: all respondents			Model 2: excluding potential		
	Coefficient	Standard error	p-value	Coefficient	Standard error	p-value
Weekend leisure				0.164	0.109	0.134
Holiday leisure				0.084	0.121	0.487
Other				−0.046	0.146	0.751
Constant	0.881	0.256	0.001	0.545	0.248	0.028
−2 log likelihood	−4094			−2805		
ρ^2	0.066			0.087		
No. of observations	2601			2353		

the intervals established. Regarding the type of vehicle, no statistically different attitudes are found between truck and car users, despite the different percentage that tolls may represent in the total generalized cost for each case.

We can also see that the perception becomes more positive as the income increases, but a statistically significant influence cannot be concluded from this analysis, as in Dill and Weinstein (2007) and Odeck and Brathen (2008), among others. Frequency of trips does neither have an impact on users' perceptions towards toll roads, even though a more positive attitude, not statistically significant, is observed for potential users. This result, in line with Jaensiriak et al. (2005), may be caused by their expectancy of not using toll roads in the future and, consequently, not being affected by road pricing.

Regarding actual users of toll roads (Model 2), no differences are identified in terms of trip purpose when compared to the base case (commuting). The more positive perception for business trips, not far from being statistically significant, may be caused by the fact that in some cases the employer pays for this kind of trips. Finally, interurban trips related to leisure activities also show a higher level of acceptability, likely due to the less frequency of these trips.

In contrast with the limited influence of socioeconomic variables, users' perceptions towards toll roads in Spain seem to be more affected by attitudinal factors related to the specific context of each region. Even excluding the influence of the quality of the alternative road, we can observe that users from Valencia, and especially from Catalonia, significantly show a more negative perception towards toll roads. As mentioned above, this opinion can be explained at the light of the historical evolution of the road network in Spain and the anti-toll atmosphere in certain regions, which is amplified by nationalist parties. While regions such as Catalonia and Valencia took advantage of the early implementation of toll roads in the early 1970s, the subsequent development of free highways in the rest of the country in later years has made the former regions to feel unfairly treated. The current asymmetry of the Spanish toll network, whereby some users have to pay tolls while other ones can drive for free in high quality roads, seems to be the reason behind the negative perception in Catalonia and Valencia.

Despite having a high density of toll roads, no meaningful results are found in the case of Galicia, since this region shows a quite similar perception than users from the Basque Country. On the other hand, people in Madrid have a more positive attitude when compared to the base case. Although this result is not statistically significant, it appears to be strongly connected with the fact that toll roads in this region generally have a free quality

Table 6 Users' willingness to pay: estimation results

Variables	Model 1: all respondents			Model 2: excluding potential		
	Coefficient	Standard error	p-value	Coefficient	Standard error	p-value
Age						
Under 25 (base case)						
From 25 to 34	−0.305	0.239	0.201	−0.310	0.254	0.222
From 34 to 49	−0.687	0.220	0.001	−0.754	0.235	0.001
From 50 to 64	−1.457	0.225	0.000	−1.697	0.240	0.000
Over 64	−1.853	0.299	0.000	−2.204	0.321	0.000
Gender						
Male (base case)						
Female	−0.889	0.105	0.000	−1.010	0.114	0.000
Type of vehicle						
Car (base case)						
Light van	−0.715	0.200	0.000	−0.663	0.212	0.001
Truck	0.025	0.288	0.930	0.255	0.301	0.396
Moto	0.029	0.784	0.969	0.524	0.849	0.537
Bus	0.321	0.922	0.727	0.283	0.936	0.762
Region						
Basque Country (base case)						
Catalonia	−0.118	0.166	0.478	−0.254	0.175	0.146
Madrid	1.342	0.201	0.000	1.314	0.213	0.000
Valencia	0.744	0.161	0.000	0.726	0.171	0.000
Galicia	0.250	0.161	0.120	0.216	0.171	0.205
Type of user						
Frequent user (base case)						
Occasional user	−0.112	0.122	0.359	−0.202	0.125	0.106
Potential user	−0.750	0.187	0.000			
Quality of alternative						
Conventional (base case)						
Highway	−0.495	0.174	0.004	−0.524	0.184	0.004
Income						
Under 20,000 Euro (base case)						
20,000 to 30,000 Euro	0.191	0.167	0.254	0.213	0.178	0.232
30,000 to 50,000 Euro	−0.024	0.218	0.911	0.068	0.230	0.765
Over 50,000 Euro	1.347	0.374	0.000	1.547	0.385	0.000
Trip purpose						
Commute (base case)						
Business				0.524	0.181	0.003
Weekend leisure				0.662	0.145	0.000
Holiday leisure				0.867	0.164	0.000
Other				0.795	0.195	0.000
Travel time (TT)	0.022	0.003	0.000	0.022	0.004	0.000

Table 6 continued

Variables	Model 1: all respondents			Model 2: excluding potential		
	Coefficient	Standard error	p-value	Coefficient	Standard error	p-value
Travel time saving (TT_{sav})	0.185	0.022	0.000	0.186	0.023	0.000
$TT * TT_{sav}$	−0.001	0.000	0.000	0.001	0.000	0.000
Constant	−3.211	0.567	0.000	−3.415	0.604	0.000
−2 log likelihood	−21,108			−19,468		
No. of observations	10,053			9190		

alternative. Unlike other regions, toll roads in Madrid are not perceived by the users as a burden, but an additional option to choose when the free parallel highway gets congested.

Finally, we can observe that users of toll roads competing with free highways show a more positive attitude —statistically significant— towards tolls. It seems reasonable given the fact that, in these situations, users dismiss the opportunity to drive by a free quality road, probably seeking further benefits offered by toll roads, such as TT reliability or congestion avoidance. No statistical influence is found for other explanatory variables, such as toll rates, probably because they remain fairly homogeneous throughout the network surveyed.

Regarding the goodness of fit of the estimated results, the models present a rho-squared coefficient of 0.066 and 0.088, respectively, which may be considered acceptable for logit specifications according to Henser and Johnson (1981). Furthermore, the signs of the regression coefficients and their statistical and practical significance are in line with the expected results. This is actually important for binary regression models according to Gujarati and Porter (2004).

Users' willingness to pay (WTP)

Next, we analyze the second source of data obtained from the survey, referring to users' WTP according to the stated-preference choice they were presented. As previously done, we point out some preliminary findings before displaying the results estimated through a censored regression (tobit) specification.

For the whole sample (all respondents), Fig. 2 shows the distribution of users' WTP depending on different TT when driving in the free road, as well as TT savings (TT_{sav}) offered by the parallel toll road. We present the cumulative percentage of respondents in the sample (y-axis) willing to pay the toll rate reported in the x-axis. The curves show a descending trend, since a lower percentage of the sample is willing to pay as the toll rate increases.

As seems reasonable, WTP tends to increase as TT and TT savings do. However, some results can be quite curious. The majority of the people surveyed with a positive perception towards tolls (52.8 %) do not seem to be in line with a high, or even moderate, WTP. As can be seen in the figure, for short trips ($TT = 60$ min) around 40–50 % of respondents are not willing to pay at all for saving time, and around 60–80 % are not willing to pay more than 1 euro. What seems to be even more surprising is that only around 50 % of respondents are willing to pay more than 1 Euro for saving TT in interurban long trips ($TT = 180$ min). Although these results are not purely based on a revealed-preference

Fig. 2 Willingness to pay distribution in the sample depending on the travel time and travel time savings

analysis—but on a stated-preference model to actual users of toll roads—, they show the lack of connection that somehow exists between users' attitudes and real behavior in the field of road charging (Fifer et al. 2014; Burris et al. 2012).

Further relationships in the sample have been explored. WTP is generally lower for potential users when compared to actual users of toll roads (both frequent and occasional), especially in the case of short trips. Regarding the level of income, respondents earning above 50,000 Euro seem to have a higher WTP, particularly for long trips, while the rest of the sample present a fairly homogeneous behavior.

Figure 3 displays the distribution of WTP in the sample depending on the region selected. Findings are not conclusive, but some trends may be identified. If we exclude the results for low tolls (left-hand side of the figures), a quite homogeneous distribution is perceived in Catalonia, the Basque Country and Galicia. By contrast, WTP seems to be somewhat higher in the case of Madrid and Valencia.

Again, the validity of these preliminary findings is further explored through a censored regression (tobit) model (see Table 6). When compared to the previous logit specification (see Subsection 5.1) the explanatory variables *toll rate* and *type of tolled infrastructure* have been removed since they were not specifically determined in the stated-preference choice designed. On the other hand, the variable *quality of the alternative* here is not referring to the quality of the free road in the stated-preference case, but to the trip made by the respondent when she/he was surveyed. This allows us to explore whether statistical differences in users' WTP can be identified depending on the characteristics of the toll road she/he used. Furthermore, three additional explanatory variables were added to the choice model: TT in a certain scenario (TT), TT saving offered by the toll road (TT_{sav}), and the interaction between these two parameters ($TT * TT_{sav}$). As it happened in Subsection 5.1, two different models have been calculated due to the lack of data available for potential users with regard to trip purpose.

From the results of the tobit model in Table 6, some trends can be identified. It must be noted that, again, coefficient estimates remain fairly constant in models 1 and 2. As Table 6 shows, WTP tends to increase as TT and TT savings provided by the toll road (TT_{sav}) do. The results show that users are willing to pay, *ceteris paribus*, around 0.02 Euro for using the toll road as the TT increases 1 min, and around 0.18 Euro as the TT_{sav} rises 1 min. Despite being statistically significant, the interaction term ($TT * TT_{sav}$) showed a very weak influence on WTP, because the value of the coefficient estimated was very close to zero.

Fig. 3 Willingness to pay distribution in the sample depending on the region

With regard to the socioeconomic variables included in the model, we can observe that WTP significantly tends to decrease with age, particularly for respondents aged above 50. As well as this, women are willing to pay between 0.8 and 1.0 Euro less than men. This behavior is inconsistent with women's more positive attitude towards tolls identified in the logit specification (see Table 5). No statistical differences can be identified regarding the type of vehicle.

Unlike results for users' perceptions towards toll roads, WTP sometimes vary with income and type of user. Respondents belonging to the interval with the highest income ($<50,000$ Euro) are statistically more willing to pay when compared to the base case, in line with previous research (Zmud et al. 2007; van den Berg 2014; Borjesson et al. 2012), according to which the VOT increases with income. With regard to the type of user, potential ones significantly show a lower WTP (-0.7 Euro) when compared to actual users (frequent and occasional). Again, this contrasts with the higher acceptability by these types of users, probably because they do not expect to use toll roads very often. Additionally, WTP remarkably increases when the trip purpose is different from commuting. In the case of business trips, it should be caused by the fact that it is not always the employee, but in some cases the employer, who pays for the toll. Regarding leisure trips, the higher WTP may be influenced by the lower frequency of these kinds of trips, as pointed out by Cantos and Álvarez (2009).

Finally, we discuss the results concerning potential differences in users' WTP depending on the region and the quality of the free alternative. In this respect, a higher WTP is observed for respondents from Madrid ($+1.3$ Euro) and Valencia ($+0.7$ Euro), when compared to the base case. By contrast, respondents from the Basque Country, Galicia and Catalonia do not show statistically significant differences. If we compare these results with the estimates obtained for users' perceptions, two different cases come up. First, some regions such as Madrid and Catalonia have a comparatively high (low) WTP, which is in line with a general positive (negative) perception towards toll roads. By contrast, it is quite surprising that the WTP reported in Galicia and Valencia follows the opposite direction as the general perception towards tolls in these regions. Again, these results reinforce the idea that perceptions reported and WTP do not necessarily come together. They also show that a road transport policy asymmetrically developed over time does not need to clearly influence users' WTP, as it happens in the case of Valencia.

Finally, we can observe that those users driving in a toll road competing with a free highway are significantly more reluctant to pay (-0.5 Euro) compared to toll roads in

which the alternative is a conventional road. This result makes sense because the users of the toll road competing with a free highway do not value that much the benefits offered by the toll road given that the free alternative already provides high quality services. By contrast, the poor characteristics of conventional roads make drivers to be more willing to pay for using toll roads.

Conclusions and further research

In this paper we have developed both a binomial logit and a tobit model to explore users' attitudes and WTP on interurban toll roads. The analysis yielded some interesting conclusions.

The first conclusion is that a positive perception towards tolls is not always related to a higher WTP, but often to the low expectancy of using the tolled infrastructure. In this respect, it should be pointed out that, while acceptability may only reflect an overall sentiment of fairness towards tolls, WTP seems to be more closely related to the users' own experience and expected behavior. This idea may provide useful insights for future research objectives.

The second conclusion is that users' perceptions and WTP seem to be, in certain cases, only slightly determined by personal socioeconomic characteristics. This paper has made it clear that other variables barely explored in the literature, such as regional differences or the quality of the free alternative route, may play a more important role regarding toll roads perceptions.

The third conclusion shows that those regions comparatively suffering a higher burden of tolls or subjected to anti-toll campaigns generally have a more negative perception towards toll roads, but not necessarily a lower WTP. This is especially clear in cases such as Spain, with a heterogeneous toll implementation process across regions.

Finally, the fourth conclusion, strongly related to the third one, concerns the consequences of continually developing an asymmetrical road transport policy within the same nation. A coordinated and—as possible—homogeneous implementation of road transport policies within a nation is advisable in order to avoid that some regions perceive to be treated unfairly. A more balanced implementation across regions of pricing strategies and road accessibility provision can contribute to better distribute the burden of road financing, as well as to avoid negative perceptions in certain territories. Nevertheless, this fact needs to be complemented with further alternative analysis. Particularly, the consequences that changes in the current pricing policy may have on regional development and territorial cohesion within the same country are additional aspects to be taken into account.

From the results of this paper, some aspects can be pointed out for further research. First, the influence of attitudinal variables on users' choices and perceptions need to be explored more deeply, likely through a structural equation approach. Furthermore, differences on acceptability towards road charging across groups of respondents, i.e. across regions, should be analyzed in greater detail by adopting more suitable econometric specifications such as multilevel models. The influence of alternative transport modes may also be considered when analyzing users' perceptions on road interurban trips. Additionally, further efforts are needed to estimate differences between attitudes reported by users and their revealed behavior. Finally, a cross-comparison of users' perceptions in urban/metropolitan and interurban toll roads would be useful to identify the issues to be improved regarding road charging policies in each context.

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Appendix 1

See Table 7.

Table 7 Variables measured and questions addressed in the survey

Variable	Question addressed	Options provided
Socioeconomic characteristics		
Gender		Male; Female
Age	Where do you place your age in the following intervals?	Under 25; From 25 to 34; From 35 to 49; From 50 to 64; Above 64
Income	Where do you put your personal income in the following intervals?	Under 20,000; From 20,000 to 30,000; From 30,000 to 50,000; Above 50,000
Type of vehicle		Car; Light van; Truck; Moto; Bus
Region		Catalonia; Madrid; Valencia; Basque Country; Galicia
Frequency/type of user	How often do you use toll roads, considering the following intervals?	More than 8 trips per month (frequent user); Less than 8 trips per month (occasional user); Never used it before (potential user)
Trip purpose (only for frequent and occasional users)	What is the most common trip purpose when you use toll roads?	Commuting; Business/Work related activities; Weekend leisure; Holiday leisure; Other
Characteristic of the toll road		
Quality of the free alternative		Conventional road; Highway
Toll rate		Expressed in Euro/km
Tunnel		Tunnel; interurban road
Attitudes towards tolls		
Perception towards toll roads	Do you think that tolls are an appropriate mechanism to fund roads?	Yes; No

Table 7 continued

Variable	Question addressed	Options provided
Perception on toll rates	In your opinion, current toll rates are...	Expensive; Medium; Cheap
Perception on time savings	In your opinion, using toll roads makes you save...	A considerable amount of travel time; Not so much travel time; No travel time at all
Willingness to pay	Given a certain corridor formed by a free road and a parallel toll road which allows you to save time, how much would you pay for using the toll road if... ?	
	Travel time is 60 min & toll road saves 15 min	Open answer (Euro)
	Travel time is 60 min & toll road saves 25 min	Open answer (Euro)
	Travel time is 180 min & toll road saves 30 min	Open answer (Euro)
	Travel time is 180 min & toll road saves 45 min	Open answer (Euro)

Appendix 2

Table 8.

Table 8 Main characteristics of the toll roads included in the sample

Region	Toll road	Year of start	Length (km)	Toll rate, light vehicle (Euro/km)	Regions crossed by the toll road	High capacity alternative road
Catalonia	Montmeló–La Jonquera	1972	135.6	0.089	Catalonia	Partly (3.0 %)
	Montmeló–Papiol	1978	26.6	0.092	Catalonia	No
	Barcelona–Tarragona	1975	96.6	0.089	Catalonia	Partly (9.7 %)
	Zaragoza–Mediterráneo	1976	215.5	0.095	Catalonia, Aragon	Partly (6.6 %)
	Barcelona–Montmeló	1972	14.2	0.100	Catalonia	Yes
	Montgat–Palafolls	1969	43.1	0.087	Catalonia	No
	Castelldefels–El Vendrell	1992	56.3	0.163	Catalonia	No
	San Cugat–Manresa	1990	43.1	0.147	Catalonia	No
	Vallvidriera Tunnels	1992	16.7	0.206	Catalonia	No
	Cadí Tunnel	1986	29.7	0.392	Catalonia	No
	Tarragona–Valencia	1978	225.3	0.096	Catalonia, Valencia	Partly (19.8 %)
Madrid	Madrid–Guadalajara	2003	64.1	0.099	Madrid, Cast.-La Mancha	Yes
	Madrid–Arganda	2003	33.1	0.096	Madrid	Yes
	Madrid–Ocaña	2003	53.0	0.104	Madrid, Cast.-La Mancha	Yes
	Madrid–Navalcarnero	2003	29.0	0.109	Madrid	Yes
	Eje Aeropuerto	2005	8.8	0.143	Madrid	Yes
	Villalba–Adanero	1977	69.6	0.144	Madrid, Castilla y León	No
	Madrid–Toledo	2006	60.0	0.092	Madrid, Cast.-La Mancha	Yes
Valencia	Tarragona–Valencia	1978	225.3	0.096	Valencia, Catalonia	Partly (19.8 %)
	Valencia–Alicante	1976	148.5	0.097	Valencia	Partly (9.2 %)
	Circunvalación Alicante	2007	28.5	0.101	Valencia	Yes
	Alicante–Cartagena	2001	76.6	0.061	Valencia, Murcia	No

Table 8 continued

Region	Toll road	Year of start	Length (km)	Toll rate, light vehicle (Euro/km)	Regions crossed by the toll road	High capacity alternative road
Basque Country	Artxanda Tunnels	2003	3.0	0.492	Basque Country	No
	Bilbao–Ermua	1976	36.2	0.087	Basque Country	Partly (5.3 %)
	Ermua–Behobia	1976	87.6	0.107	Basque Country	No
	Maltzaga–Arrasate	2003	35.6	0.107	Basque Country	No
	Bilbao–Zaragoza	1978	294.4	0.092	Basque Country, La Rioja, Aragon	Partly (18.0 %)
Galicia	Ferrol–Front. Portuguesa	1979	218.9	0.089	Galicia	Partly (14.4 %)
	Santiago–Alto Sto. Domingo	2003	56.6	0.094	Galicia	No
	La Coruña–Carballo	1998	32.6	0.068	Galicia	No
	Puxeiros–Val Miñor	1999	25.2	0.060	Galicia	No

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Measuring regional differences in users' perceptions towards interurban toll roads

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ABSTRACT

Public acceptability is crucial to achieve the successful implementation of certain policy initiatives. In the transport sector, this is especially relevant for toll roads since they entail a burden to the users. Previous literature in this field has mainly focused on analyzing the influence of different individual characteristics on attitudes towards road charges, without clear results. However, other context-specific drivers such as regional parameters may also play an important role to explain users' attitudes, especially when the implementation of tolls within the same nation varies throughout regions. The goal of this paper is to analyze regional differences in users' perceptions with regard to tolls as an appropriate way to finance the provision of road infrastructure. Based on a nationwide survey conducted to road users in interurban toll roads in Spain, we develop a multilevel logit model to explore regional differences in drivers' perceptions. The research concludes that differences identified seem to be more influenced by context-specific variables, related to either the characteristics of the toll road or the region, than by the characteristics of the individuals. The paper also underlines the negative effects of an asymmetrical distribution of toll roads across regions on users' perceptions, since those territories especially suffering the burden of tolls show a more negative attitude towards road charging.

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1. Introduction

Public acceptability has traditionally been identified as one of the key drivers to achieve a successful implementation of different policy initiatives (Marciano et al., 2014; Aitken et al., 2014). Regarding the transport sector, this is especially relevant in the case of road charging strategies (Zheng et al., 2014; Kockelman et al., 2009), that is being a policy increasingly adopted by governments to collect stable resources to face budgetary constraints. In this respect, Dill and Weinstein (2007) claim that policy makers must seek to recommend options that not only have strong public support, but are also desirable in terms of equity, ability to generate stable revenue, capacity to encourage environmentally responsible choices, etc.

Despite the increasing literature on attitudes towards tolls and acceptability of road user charges, there is a need for a more comprehensive approach (Kallbekken et al., 2013). The existing literature has traditionally analyzed the influence of individual characteristics (age, income, trip purpose, etc.) on perceptions towards toll roads, leading to inconclusive results (Gehlert et al., 2011). By contrast,

no previous efforts have been made to include explanatory variables at the regional level or specifically address regional differences on toll road acceptability. This approach may be crucial when road charging characteristics greatly vary across regions within the same nation.

Spain constitutes an interesting case in the international context to explore regional differences on users' attitudes towards toll roads. While the current Spanish high capacity road network is one of the longest ones within Europe, it is made up of both tolled and free roads asymmetrically distributed across regions. As pointed out by Vassallo et al. (2012), this is due to the changes over time of the road transport policy implemented by different governments. As a result, while some regions such as Catalonia or Valencia have a dense toll motorway network, the percentage of free high capacity roads is significantly higher in other areas of the country. As pointed out by Gomez et al. (2015), this heterogeneity has provoked negative sentiments towards road charging in certain regions along with political complaints. In fact, protest groups and associations have recently appeared in some regions of Spain (such as Catalonia) to coordinate actions against tolls because of the sentiment of unfairness perceived when compared to the rest of Spaniards.

The aim of this paper is to analyze regional differences in users' perceptions towards financing the provision of roads through toll mechanisms, given an asymmetrical distribution of toll infrastructure

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facilities across regions. Based on a nationwide survey conducted in interurban toll roads, we develop a multilevel logit model to measure the influence of individual, road-related and regional variables in users' perceptions.

This paper is organized as follows. After this introductory chapter, [Section 2](#) summarizes the state of knowledge on perceptions towards road charges and identifies some research gaps in the literature. [Section 3](#) describes the data collected from a survey conducted to road users and the explanatory variables included in this research. [Section 4](#) outlines the multilevel methodology adopted to explore regional differences in drivers' attitudes, and [Section 5](#) presents and discusses the results. Finally, [Section 6](#) shows the main conclusions and points out further research.

2. Literature review

Previous studies on attitudes towards road charging have been mainly focused on urban contexts, with special attention to the implementation of congestion charging systems in city centers ([Furst and Dieplinger, 2014](#); [Schuitema et al., 2010](#); [Gaunt et al., 2007](#)). By contrast, the literature analyzing perceptions on interurban areas is still limited and primarily concerns residents' perceptions rather than users' ([Kockelman et al., 2009](#); [Dill and Weinstein, 2007](#)).

Till now, research efforts have been mainly directed towards measuring the influence of individual socioeconomic factors (age, gender, income, etc.) on road pricing attitudes. These studies—potentially useful to target specific user market segments—have not generally led to conclusive and coincident results about the influence of these types of variables on attitudes as noted by [Yusuf et al. \(2014\)](#) and [Odeck and Kjekreit \(2010\)](#). Because of this lack of evidence, some authors ([Schade and Schlag, 2000](#); [Rienstra et al., 1999](#)) have pointed out that socioeconomic factors might have a somewhat lesser impact on acceptability than other drivers such as attitudinal factors.

The study of the acceptability of toll road pricing constitutes a complex issue that can be approached from different perspectives ([Zheng et al., 2014](#)) such as the perceived fairness of charges ([Cools et al., 2011](#); [Fujii et al., 2004](#)), political bias ([Hårsman and Quigley, 2010](#)) or existing community values ([Yusuf et al., 2014](#)). Particularly, [Smirti et al. \(2007\)](#) acknowledged that the level of acceptability may sometimes be highly context-specific, so attitudes may change across roads or, at an upper level, even across territories with different characteristics. Despite the fact that the literature admits this problem, as of today, little effort has been made to incorporate the regional perspective in the acceptability analysis, or to measure regional differences on users' perceptions towards road charging.

There are some research studies dealing with regional differences in certain transport modes such as air transport ([Alberts et al., 2009](#)) or maritime ([Castillo-Manzano and Fageda, 2014](#); [Oosterhaven et al., 2001](#)). However regional differences have scarcely been addressed for road transport issues, and when analyzed they have been limited to specific areas such as road safety ([Tolon-Becerra et al., 2013](#); [Eksler et al., 2008](#); [Lassarre and Thomas, 2005](#)), or spillover indicators ([Condeço-Melhorado et al., 2011](#)). The papers by [Sandow \(2008\)](#) and [Abane \(2011\)](#) are among the few studies in the literature incorporating the geographic perspective in the analysis of travelers' behavior.

Regarding acceptability towards road charging, some research studies made a preliminary approach to regional differences. [Podgorski and Kockelman \(2006\)](#) analyzed public support for toll roads in Texas, and found that those regions with small urban areas were more receptive to road charging. According to the authors, this result may be influenced by the fact that residents could be thinking of tolls not applied to roads in their areas. Also focusing on Texas, [Kockelman et al. \(2009\)](#) identified a higher support in those regions having past positive experiences with toll roads. In the same line, the study by [Dill and Weinstein \(2007\)](#) in California pointed out that regional experience with toll facilities appeared to increase support for tolling.

Despite the interest of these findings regarding road charging acceptability, there is still room for a different types of analysis that models users' instead of residents' perception. In addition, when focusing on regional differences, it is possible to use hierarchy in the survey data to properly address differences among respondents and therefore avoid the so-called may “atomistic fallacy” (see more comments in [Section 4](#)), present in some of the researches previously mentioned.

To sum up, some research gaps can be identified concerning the current state of knowledge in this topic. First, further explanatory variables than individual characteristics—such as regional parameters or tolling infrastructure attributes—need to be addressed to have a more thorough picture. Second, the existing literature has not specifically focused on users' attitudes but on public perceptions in general. And third, we are not aware of any previous research mainly focusing on regional differences on users' perceptions towards toll roads that use specific modeling techniques for this purpose.

3. The data: a nationwide survey in Spanish toll roads

In order to measure users' perceptions towards interurban toll roads and explore potential differences across regions, we develop a multilevel binary logit analysis. To that end, we collected data from a nationwide survey (see [Appendix 1](#)) developed in several Spanish interurban toll roads in 2010. With the aim to identify potential regional differences not in public acceptability but in drivers' perceptions, the questionnaire was specifically addressed to users of interurban toll roads. It was conducted between October and November, 7-days a week in order to get a representative sample in terms of users' trip purpose, since its distribution generally vary during the week. The data was collected from personal interviews at service areas or petrol stations near the existing tolling infrastructure. We stratified the sample in order to achieve sufficient representativeness at the regional level.

As this paper is mainly focused on identifying regional differences in users' attitudes, the network covered in the survey includes the Spanish regions with a toll road network homogeneously distributed over the territory. The network surveyed combines regions with mature toll roads, where user charging was implemented decades ago, along with regions with a more recent toll network. Catalonia, Madrid, Valencia, the Basque Country and Galicia were the cases ultimately selected for this research. Other potential regions (Andalusia, Castilla-La Mancha, Castilla y León) were not included in the end because toll roads are located only in specific areas of the region. This may result in users' perceptions towards tolls widely varying over the same region, making the analysis more difficult.

Then, the network ultimately surveyed comprises all the interurban toll roads starting and/or ending in the 5 regions selected. The sample includes respondents selected in a balanced way from the regions chosen (see [Appendix 2](#)). The data size is large enough to be considered representative for each region. In total, 2769 users from 30 toll roads were surveyed. The resulting sample, made up by 2264 km, can be also considered representative of the Spanish toll network, as it includes around 75% of total tolled km in the country. We would like to note that it is among the longest interurban toll road systems ever surveyed in the literature.

The data was collected through face-to-face questionnaires especially designed for research purposes. In order to capture respondents' attitudes towards toll roads, the questionnaire requested them to report whether they considered tolls as an appropriate way to finance the provision of road infrastructure. This is an approach previously adopted to measure respondents' road charging acceptability such as in [Odeck and Brathen \(2008\)](#). Their answers at this point are the dependent variable to be modeled through the multilevel logit specification detailed below.

In order to model users' perceptions on toll roads, three levels of explanatory variables were included in this research (see [Table 1](#)). Firstly, individual characteristics—the first level of data—were collected

Table 1
Description of variables included in the research.

Variable		Subgroup	Respondents	% Sample
Dependent variable				
User perception towards toll roads		Positive	1451	52.4
		Negative	1318	47.6
Explanatory variables				
Individual characteristics	Gender	Male (base reference)	1454	52.5
		Female	1315	47.5
	Age	Under 24 (base reference)	148	5.3
		From 24 to 34	453	16.4
		From 35 to 49	1153	41.6
		From 50 to 64	773	27.9
		Above 64	242	8.7
	Type of vehicle	Car (base reference)	2452	88.6
		Light van	201	7.3
		Truck	96	3.5
		Moto	9	0.3
		Bus	11	0.4
	Income	Under 20,000 Euro (base reference)	725	26.2
		From 20,000 to 30,000 Euro	926	33.4
		From 30,000 to 50,000 Euro	394	14.2
		Above 50,000 Euro	95	3.4
		Not responding	629	22.7
	Frequency/type of user	Frequent (base reference)	2099	75.8
		Occasional	670	24.2
	Trip purpose	Commuting (base reference)	845	30.5
		Business	331	12.0
		Weekend leisure	744	26.9
		Holiday leisure	534	19.3
		Other	315	11.4
Infrastructure characteristics	Quality of the alternative route	Toll roads		%
		Conventional road (base reference)	22	74.2
	Unitary toll rate	Highway	8	25.8
		(Euro/km)	Mean: 0.13	Sd: 0.09
	Type of toll infrastructure	Road (base reference)	26	87.1
Regional parameters		Tunnel	4	12.9
	GDP per capita	(1000 Euro/person)	Mean: 25.87	Sd: 5.07
	Political beliefs	% votes for left-wing parties	Mean: 46.3	Sd: 3.6
	Nationalist/regionalist feelings	% votes for nationalist/regionalist parties	Mean: 27.3	Sd: 25.8
	Abundance of toll roads	% high capacity km being tolled	Mean: 32.1	Sd: 12.8

through personal interviews. Secondly, we incorporated a set of explanatory variables regarding the attributes of tolling infrastructure. This represents the second level in the model. Finally, a group of regional parameters made up the third level of data. As can be seen, although the main objective of the research was to identify potential regional differences on users' perceptions, the inclusion of an intermediate level concerning the characteristics of the toll infrastructure was necessary to properly take into account the existing hierarchy in the data. In this respect, potential heterogeneity may appear in users' perceptions among toll roads, given some differences observed in terms of physical or charging attributes.

Individual characteristics of users, as well as attitudes towards toll roads, were collected through face-to-face questionnaires (see details in [Appendix 1](#)). In the first part, drivers were asked about their socioeconomic and transport-related characteristics (age, level of income, type of vehicle used, trip purpose, etc.), generally grouped into different categories as shown in [Table 1](#). Among further explanatory variables potentially determining individuals' perceptions towards tolls, the political beliefs can be identified as a relevant one. However, due to the objection frequently shown by respondents to report ideological concerns in some regions of Spain, the current research approached this issue at the regional level by analyzing the political atmosphere of each region.

The second level of data in the model was made up of infrastructure attributes, including physical and charging characteristics with regard to the toll road used. Although it is acknowledged that the level of acceptability towards road pricing may be highly context-specific ([Smirti et al., 2007](#)), the characteristics of the tolling infrastructure

have not been explicitly incorporated as explanatory variables in previous modeling approaches. They are expected to have a significant influence on users' attitudes, and also to be useful to explain potential differences among users of different types of toll roads.

Among the road infrastructure variables, we firstly included the quality of the free parallel road available in each case, since it increases the possibility for users to skip tolls and therefore might be a significant explanatory factor to determine users' perceptions. It is important to note that in Spain it is a requirement that every toll concession has a free parallel road available in the same corridor. The binary variable adopted distinguishes between toll roads whose free alternative route is a conventional (two-lane) road, generally with poor quality, and those ones competing with high capacity roads (highways). Additionally, we included the toll rate per kilometer charged in each road as an explanatory variable, in order to capture the potential effect of the charging level on users' perceptions. This parameter was collected from the Spanish Ministry of Transportation database ([Ministerio de Fomento, 2011a](#)). Finally, a binary variable was considered to differentiate between purely interurban toll roads and tolled point sections (tunnels).

Finally, the third level of data is made up of a set of independent variables at the regional level in order to explain potential differences in users' attitudes across regions. Firstly, GDP per capita—expressed in 1000 Euro/person—intends to capture the influence of the average standard of living within each region on toll road acceptability, in a similar way as other papers measuring public acceptability ([Karlsdotter et al., 2009](#)). Moreover, an explanatory variable referring to the abundance of toll roads in each region is inserted in the model. This variable is

measured as the percentage of high capacity road km being tolled within each particular region, according to the Spanish Ministry of Transportation database (Ministerio de Fomento, 2011b). The regions considered in the research show significant variability at this point given that a great proportion of the high capacity network is tolled in regions such as Catalonia (47.2%) or the Basque Country (41.2%), while this percentage is much lower in other regions such as Madrid (14.9%). In that respect, we may expect that those regions with a higher presence — in relative terms — of toll roads might show a more negative attitude.

Political beliefs have also been identified as a driver potentially influencing perceptions towards road charging (Hårsmann and Quigley, 2010). We approach the effect of the political atmosphere in each region by considering the general support obtained by either right- or left-wing parties. Notwithstanding the fact that a complementarity with data at the individual level would have been highly desirable, analyzing the effect of the political climate on users' perceptions remains a relevant issue given the key role played by the regional governments of Spain in social and economic beliefs. Specifically, we included the percentage of votes obtained by left-wing parties in the last regional elections in the country. We may expect that the political climate may be less supportive of tolls in regions governed by socialist/communist parties, while a higher presence of conservative parties would favor more positive attitudes towards toll roads. In addition, we include an explanatory variable concerning the support for nationalist/regionalist parties (those parties supporting more independence from the central government or even full independence) within each region, with the aim to measure the influence of nationalist feelings on general attitudes towards tolls. The reason behind that is the great opposition against tolls by nationalist parties in certain regions such as Catalonia.

Table 1 summarizes the main characteristics of the data sample. A balanced proportion of men and women were surveyed, with a higher presence of people aged between 35 and 49 (41.6%). Furthermore, we observe users' income typically lying below Euro 30,000, and a vast majority of cars (88.6%) regarding the type of vehicle used. The high share of respondents (22.7%) not reporting their income is also noticeable. Commuting (30.5%) and weekend leisure (26.9%) are the most common trip purposes in the sample, with a high proportion of respondents (75.8%) making >8 trips per month (frequent users).

Concerning toll infrastructure, a significant percentage of the sample drives in interurban toll roads competing with conventional roads. It can be noted that, for the network surveyed, there is a great asymmetry across regions regarding the alternative to the toll road (see Appendix 2). Tolloed sections competing with free highways are numerous in regions such as Madrid, while in the Basque Country or Catalonia the alternative route is generally made up of a conventional (two-lane) road. Some variability is also found in other explanatory variables such as the toll rate applied, nationalist/regionalist feelings or abundance of toll roads across regions. Finally, we would like to note the balanced proportion of respondents in the sample from the 5 regions surveyed: Catalonia (20.1%), Valencia (20.3%), Madrid (19.8%) the Basque Country (20.1%), and Galicia (19.6%). The sample reached a data size large enough to be representative of toll road users in each territory. Further details about the survey conducted to collect the data for this research can be found in Gomez et al. (2015).

4. Methodology

In order to measure users' perceptions towards interurban toll roads and explore potential differences across regions, we develop a multilevel binary logit model. This type of specification represents an extension of the classical regression models, in the sense that they take into account potential correlation between data observations due to hierarchical or nested structures in the data.

When hierarchically/nested structured data are present in the sample, classical regression models become not valid since the assumption of independent observations is violated (Koppelman and Bhat, 2006).

In this case, we can expect that observations belonging to the same group may share common characteristics while being also different from other existing groups. Failing to account for these differences may lead to the so-called “atomistic fallacy”, with important negative consequences in the results. Firstly, a misinterpretation of estimates is commonly associated, since inferences regarding variability across groups are drawn based on the individual level of data (Hox, 2002). Secondly, it may lead to spurious statistical significances of parameter estimates in the model, due to an underestimation of the standard errors calculated. As underlined by Goldstein (2003), these limitations can be overcome by using multilevel (or hierarchical) models, since they recognize the existence of such data hierarchies.

Based on a more complex structure, multilevel specifications consider a different model for each level of data. This also allows exploring inter-group variability at different levels. Among other advantages, these models make possible not only to quantify the relationship between variables within the same level, but also to estimate their influence on other levels defined in the data.

For our research, we apply the standard multilevel approach, based on random coefficients, that has been widely described in the literature (de Leeuw and Meijer, 2007). In order to model users' acceptability towards toll roads, this technique is combined with a logit specification given the binary nature of the dependent variable (see Section 3). Particularly, we model the probability that respondents consider tolls as an appropriate mechanism to finance the provision of roads.

Binary choice models fall into the category of utility maximization models, assuming that a person chooses the alternative with the higher utility (Ben-Akiva and Lerman, 1995; Train, 2003) among all the options available. The utility of each choice (U_{ijk}) is a random variable that can be determined by a number of explanatory parameters X_p . The binomial logit approach developed in this research follows the standard procedure so for further detail the reader is referred to Gujarati and Porter (2004); Koppelman and Bhat (2006) or Train (2003).

Simultaneously, the model accounts for the hierarchical level of the data by adopting the multilevel technique. The data needed for the research were collected from different toll roads, which can be subsequently grouped into regions (see an illustrative example in Fig. 1; the specific application to the case study selected is included in Appendix 3). Therefore, the modeling framework was assigned a three-level structure (i – j – k). Subscript i is related to individuals, while j and k refer to the toll road and regional level, respectively. As in every multilevel approach, higher levels of the hierarchy (toll roads and regions) are considered themselves a sample from a general population of toll roads and regions.

The model comprises random effects at both intercepts and slope parameters, allowing random variations among toll roads (j) and regions (k), as shown below in a general form:

$$Y_{ijk}^* = \beta_{0(n)jk} + \beta_{1(n)jk} X_{1ijk} + \dots + \beta_{p(n)jk} X_{pijk} + \varepsilon_{ijk} \quad (1)$$

$$\beta_{0(n)jk} = \beta_{0(n)} + u_{jk} + u_k; \quad \beta_{p(n)jk} = \beta_{p(n)} + u_{jk} + u_k$$

where $\beta_{0(n)jk}$ is the model intercept, consisting of a fixed intercept $\beta_{0(n)}$, a random variation u_{jk} of this intercept across toll roads and a random variation u_k of this intercept across regions, in a similar way as in Papadimitriou et al. (2014). Then, it allows intercepts to vary randomly at each different level (toll roads and regions). In a similar way, $\beta_{1(n)jk}$ is the coefficient for explanatory variable X_1 , also allowing variability across toll roads (j) and regions (k). Finally, ε_{ijk} is the common idiosyncratic error. Therefore, it is possible to structure the total variation in the model into three different error terms:

$$E_{ijk} = u_k + u_{jk} + \varepsilon_{ijk} \quad (2)$$

where random variations defined above are independently distributed: $u_k \sim N(0, \sigma_k^2)$; $u_{jk} \sim N(0, \sigma_{jk}^2)$; $\varepsilon_{ijk} \sim N(0, \sigma^2)$. In this respect, a significant random intercept with regard to regions (toll roads) indicates that

Fig. 1. Hierarchy in users' perceptions considered in the multilevel model adopted: illustrative example.

divergences between responses are due to unobserved regional (toll road) differences, and not to differences across respondents. Additionally, a significant random slope with regard to regions (toll roads) means that the influence of a certain explanatory variable X_p does significantly vary across regions (toll roads).

The explanatory variables in the model comprise individual characteristics (X_{ijk}), toll road attributes (X_{jk}) and regional parameters (X_k), as it was explained more deeply in Section 3. Given the different level of the independent variables, the hierarchical analysis followed the traditional stepwise procedure, developed in greater detail by Murillo (2008), among others. Through this method, subsequent models are generated by gradually incorporating the explanatory variables into the analysis:

- Model 0: only including intercepts and random effects (no explanatory variables).
- Model I: incorporating individual characteristics to the model.
- Model II: adding toll road attributes to the analysis.
- Model III: including regional parameters in the model.

Throughout this process, the model repeatedly evaluates the improvement in the fitting of the model that is achieved due to the gradual inclusion of new explanatory variables. Along with this, the methodology makes possible to check the statistical significance of the random effects included, in both intercepts and slope coefficients, for the different levels of data.

5. Choice modeling results and discussion

5.1. Definition of the model and preliminary findings

This section reports the main results coming out from the multilevel analysis modeling users' perceptions towards toll roads. Before showing the estimates calculated through the binomial logit specification described in Section 4, some preliminary findings for certain explanatory variables, particularly categorical ones, are presented in Table 2. Concerning the whole sample, the majority of respondents (52.4%) were positive towards financing the provision of road infrastructure through a toll mechanism. Although at first glance this attitude seems to be fairly homogeneous throughout certain subsamples, noteworthy differences can be identified in some cases, especially when we disaggregate the results by region.

With regard to individual characteristics, we observe that users' perceptions do not vary too much depending on gender. Positive attitudes towards toll roads for men (52.5%) are only slightly higher when compared to women (52.2%). The same distribution is also found in the sample concerning trip frequency of use, with a slightly more positive perception for frequent users.

Furthermore, toll road acceptance seems to increase to some extent with age, if we exclude respondents under 24. The survey shows that

49.4% of users between 24 and 34 consider that tolling is an adequate mechanism to finance the provision of roads, while this percentage increases up to 59.9% for respondents aged above 64. It can also be found that, the higher the income (particularly above 50,000 Euro), the more positive the users' attitudes towards toll roads. This finding is in line with other previous results referred to in the literature (Odeck and Kjerkreit, 2010).

Table 2

Users' perceptions towards toll roads. Preliminary results in percentage for categorical variables.

Level of data		Dependent variable	
		Perception towards toll roads (%)	
	Explanatory variables	Positive	Negative
Total sample		52.4	47.6
Individual	Gender		
	Men	52.5	47.5
	Women	52.2	47.8
	Age		
	Under 24	54.7	45.3
	From 24 to 34	49.4	50.6
	From 35 to 49	50.7	49.3
	From 50 to 64	53.9	46.1
	Above 64	59.9	40.1
	Type of vehicle		
	Car	53.5	46.5
	Light van	45.9	54.1
	Truck	49.0	51.0
	Moto	81.8	18.2
	Bus	40.0	60.0
	Income		
	Below 20,000 Euro	51.2	48.8
	From 20,000 to 30,000 Euro	52.9	47.1
	From 30,000 to 50,000 Euro	56.1	43.9
	Above 50,000 Euro	60.7	39.3
	Not responding	51.6	48.4
	Frequent	52.5	47.5
Road infrastructure	Frequency/Type of user		
	Occasional	52.2	47.8
	Trip purpose		
	Commuting	49.8	50.2
	Business	55.3	44.7
	Weekend leisure	54.6	45.4
	Holiday leisure	52.6	47.4
	Other	50.8	49.2
	Type of tolled infrastructure		
	Interurban road	52.2	47.8
	Tunnel	61.6	38.4
	Quality alternative		
Region	Conventional road	49.8	50.2
	Highway	63.4	36.6
	Catalonia	39.6	60.4
	Madrid	65.5	34.5
	Valencia	47.7	52.3
	Basque Country	54.9	45.1
	Galicia	54.7	45.3

If we focus on the influence of road infrastructure characteristics, some heterogeneity on users' attitudes can be noticed depending on the quality of the alternative road. Drivers are significantly more positive towards toll roads (63.4%) when the free parallel road happens to be a high capacity road. This contrasts with a lower support (49.8%) in the case that the competing road was of low quality. These results may reflect that the absence of high quality free alternatives forces drivers, in a certain way, to use toll roads to save travel time thus influencing their attitudes towards tolling.

Some heterogeneity is also observed regarding users' attitudes when we analyze the results by region. As can be seen, users' acceptability in Catalonia is low (39.6%), while in Madrid is relatively high (65.1%). Other regions such as the Basque Country or Galicia show a more moderate position, with positive attitudes being around 55%. The asymmetrical density of toll roads throughout the nation might be one of the reasons explaining regional differences because it causes a perceived sentiment of unfairness. In fact, only 14.9% of the high capacity network is tolled in Madrid, while this percentage is significantly higher in other regions surveyed, such as the Basque Country (41.2%) and specially Catalonia (47.2%).

In order to check the validity of these preliminary findings, a multi-level logit specification has been calibrated. The model estimates the probability of being positive towards toll roads—that is, to consider tolls as an appropriate way to finance the provision of roads—and measures the influence of different explanatory variables on this attitude. As pointed out above, the multilevel specification is a suitable econometric technique for exploring regional and inter-road differences from the sample.

Before setting up the multilevel model, some tests for checking multicollinearity between the explanatory variables were applied. The analysis showed that the regional parameters *nationalist/regionalist feelings* and *abundance of toll roads* (see Table 1) were highly correlated and thus statistically not independent of each other (correlation coefficient = 0.98). Despite the fact that these variables refer to very different aspects, such a high multicollinearity level does not make possible to separate the partial effect of each explanatory parameter (Gujarati and Porter, 2004) and thus one of them needs to be removed from the model. Given its expected greater influence to explain regional differences in users' perceptions, we opted for keeping the abundance of toll roads within a region as an explanatory variable in the model.

Following the usual procedure for exploring regional differences through a multilevel specification, we developed a stepwise analysis. Firstly, a so-called Model 0 or “empty model” was run to test whether random variation across regions (level 3) and toll roads (level 2) are a significant part of the total variation between responses. After that, subsequent models were generated by gradually incorporating explanatory variables concerning individual characteristics (level 1), road infrastructure attributes (level 2) and regional parameters (level 3). Throughout this process, random variation across groups (regions and toll roads) was tested not only for intercepts but also for slope coefficients. In order to make the paper more concise, only results from the initial

and final models are displayed in the paper. The intermediate results produced (Models I and II) can be checked in the Appendix section.

Table 3 includes different estimates for the zero model. Firstly, Model 0.A allows random intercepts for both the regional and toll road level. As can be seen, the standard deviation of random intercepts for regions is highly significant (p -value = 0.004), while no significant toll road group effect is found in the sample (p -value > 0.05). In order to check the statistical significance of the toll road level, we estimated an alternative Model 0.B, only including random effects across regions. By testing the hypothesis of Model 0.B being nested in Model 0.A, differences between likelihood ratios resulted not significant (p -value = 0.145). Therefore, there is no evidence of statistically significant disparities among users from different toll roads. In line with Murillo (2008) and Train (2003), we decided to remove random coefficients related to the toll road level (u_{jk}) from the model, and continue the analysis from now on under the assumption of users' differences with a two-level specification. These authors point out that low or non-significant random effects evidence that groups are not internally homogeneous, so the grouping act has no consequences on the results and observations can thus be considered independent in this case. Random coefficients at the toll road level are then removed in order to avoid false complexity in the model, not supported by the data.

Next, the different explanatory variables were incorporated to the multilevel model, generating Models I to III as set in Section 4. Estimation results from Model III—including all the explanatory variables considered in the research—are displayed in Table 4, and discussed below sorted by the type of explanatory parameter: individual, road-related and regional. Estimation results from the intermediate models generated (Models I and II) are shown in Appendix 4.

5.2. Analysis of individual characteristics and road infrastructure attributes

The influence of individual characteristics and road infrastructure attributes on users' perceptions was gradually incorporated in the analysis through Models I and II respectively (see Appendix 4 for more details). Given the small variability of results during the stepwise modeling process, we display the empirical results for the final multilevel specification in Table 4.

Estimates for Model III confirm the relatively low influence of individual socioeconomic characteristics on acceptability towards road charging, as sometimes identified in the literature (Schade and Schlag, 2000; Rienstra et al., 1999). Despite a less positive perception towards toll roads observed in the case of women, no statistically significant differences are found throughout the categories established in terms of age, income or type of vehicle.

We can observe that users' perception becomes less negative as the age increases, but the relationship is not statistically significant (p -value > 0.05) for any of the intervals established. Frequency of trips does neither have an impact on users' perceptions towards toll roads, even though a lower acceptability, not statistically significant, can be observed for occasional users. Concerning the type of vehicle, no statistically different attitudes are found between e.g. truck and car drivers, despite the distinct effect that tolls may have in the generalized cost for each case. Nevertheless, the type of vehicle revealed to be overall a significant variable to explain users' attitudes towards toll roads, at the light of the results for the LR-test.

A more supportive attitude towards toll roads is found for higher income levels, but again a statistically significant influence cannot be concluded from this analysis, as in Odeck and Brathen (2008) or Bhatt et al. (2008), among others. With regard to trip purpose, almost statistical differences are identified for business trips when compared to the base case (commuting). This more positive perception may be caused by the fact that, in some occasions, it is not the employee but the employer who pays for the toll in this type of trips. Furthermore, the LR-test indicates that trip purpose is overall an explanatory variable statistically significant to explain users' attitudes towards toll roads.

Table 3
Users' perceptions towards interurban toll roads: estimation results. Model 0.

Model	Model 0.A			Model 0.B		
Variables	Coeff.	Std. error	p -value	Coeff.	Std. error	p -value
Fixed effects						
Intercept	0.109	0.162	0.499	0.102	0.157	0.519
Random effects						
Toll road	0.137	0.083	0.099			
Region	0.346	0.119	0.004	0.341	0.115	0.003
– 2 log likelihood	– 1883.20			– 1884.28		
Likelihood-ratio test (0.B nested in 0.A)			Prob > χ^2 = 0.145			

Table 4

Users' perceptions towards interurban toll roads: estimation results. Model III (including individual, toll road and regional parameters).

Level of data	Explanatory parameters	Modeling estimates			Overall significance (LR test)
		Coeff.	Std. error	p-Value	p-Value
	Fixed effects				
	Intercept	− 4.297	0.881	0.000	
Individual	Gender (base reference: male)				0.001
	Female	− 0.279	0.085	0.001	
	Age (base eference: under 24)				0.197
	From 24 to 34	− 0.249	0.219	0.255	
	From 35 to 49	− 0.178	0.207	0.391	
	From 50 to 64	− 0.013	0.214	0.952	
	Above 64	0.176	0.277	0.525	
	Type of vehicle (base reference: car)				0.011
	Light van	− 0.251	0.153	0.101	
	Truck	− 0.137	0.221	0.537	
	Moto	1.494	6.486	0.982	
	Bus	− 0.767	0.664	0.248	
	Income (base reference: under 20,000 €)				0.317
	From 20,000 to 30,000 €	0.080	0.131	0.541	
	From 30,000 to 50,000 €	0.146	0.169	0.388	
	Above 50,000 €	0.235	0.299	0.431	
	Frequency (base reference: frequent user)				0.476
	Occasional user	− 0.066	0.092	0.476	
	Trip purpose (base reference: commuting)				0.008
	Business	0.266	0.136	0.051	
	Weekend leisure	0.162	0.110	0.140	
	Holiday leisure	0.087	0.122	0.476	
	Other	− 0.049	0.146	0.739	
Toll road	Type of tolled infrastructure (base reference: road)				0.061
	Tunnel	0.429	0.229	0.061	
	Toll rate	− 1.481	0.985	0.133	0.133
	Quality of the alternative route (base reference: conventional)				0.029
	Highway	0.296	0.136	0.029	
Region	Regional GDP per capita	0.049	0.010	0.000	0.000
	% Left-wing parties	− 0.081	0.015	0.000	0.000
	% High capacity roads tolled	− 0.012	0.004	0.008	0.008
	Random effects				
	Region	1.77 e-06	0.040	0.999	
	− 2 log likelihood	− 1847.04			

Despite the fact that many of the individual explanatory variables included in the model were not statistically significant, a likelihood-ratio test does not reject the hypothesis of Model 0 being nested in Model I (see [Appendix 4](#)). Therefore, a statistically significant improvement in the fitting of the model was achieved when including individual characteristics as explanatory variables. Additionally, we can observe that the standard deviation of random intercepts for regions remains significant but in the same order of magnitude when compared to Model 0. This fact evidences that, from a practical point of view, individual characteristics do not contribute to explain unobserved differences on users' perceptions across regions. This issue will be further explored by testing not only the potential influence of individual characteristics on random intercepts, but also coefficient variations across regions (see comments regarding [Appendix 5](#) below).

Regarding the influence of road infrastructure attributes on users' perceptions, some trends can be identified from the estimates displayed in [Table 4](#). As pointed out by [Smirti et al. \(2007\)](#), the role of context-specific parameters on users' perceptions seems to be of greater importance than the characteristics of individuals. Regarding the type of toll infrastructure, we can observe that setting tolls in specific spots such as tunnels have for users a higher acceptability than regular interurban roads. According to the estimation results, odds ratio in favor of being positive towards toll roads increases by 53.6% for users of tunnel facilities. This result, very close to be statistically significant, may be due to the shorter length and consequently smaller toll payments associated to this type of road infrastructure.

As it is expected the level of the toll rate has a negative influence on users' perceptions towards toll roads. Despite not being statistically significant, those users driving in more expensive toll roads have a lower acceptability towards road pricing. Finally, the quality of the alternative free route represents a highly significant parameter to explain users' perceptions, in line with [Smirti et al. \(2007\)](#). We can observe that drivers are 34.4% more supportive of being charged in toll roads competing with free highways than in toll roads competing with low quality alternatives. This finding seems reasonable given the fact that, when the alternative is not so good, users are more captive to use toll roads.

Again, a likelihood-ratio test confirms the statistically significant improvement (p -value < 0.05) reached in the model after the inclusion of infrastructure-specific characteristics (see [Appendix 4](#)). On the other hand, the standard deviation of the random intercepts for regions remains still significant but lower when compared to Model I. Consequently, we can see that road infrastructure attributes contribute to reduce unobserved regional differences on users' acceptability, mainly by taking into account the current heterogeneity across regions in terms of quality of the alternative free road (see [Appendix 2](#)). As pointed out above, in regions such as Catalonia or the Basque Country the alternative route is generally a conventional (two-lane) road, while in Madrid tolled sections competing with free highways are more numerous.

With the aim to further explore regional differences for the explanatory variables already considered (individual characteristics and infrastructure attributes), we conducted several supplementary models

allowing random slopes on predictors. The main results obtained, shown in [Appendix 5](#), make clear that no coefficient variability across regions is present in our sample. Regarding individual characteristics, gender, age or income coefficients do not significantly vary across regions, given the high *p*-value obtained in all cases for both the standard deviation of random slopes and the likelihood-ratio test. Similarly, the analysis does not suggest any regional variation in the slope coefficients concerning infrastructure attributes, such as quality of the alternative route or the toll rate charged.

5.3. Analysis of regional parameters

Finally, estimation results are discussed for the three explanatory variables included at the regional level concerning political beliefs, share of toll roads and average wealth. We should point out again that, due to multicollinearity problems, it was not possible to incorporate the variable related to nationalist/regionalist feelings (measured through the vote to nationalist/regionalist parties) in each territory.

As can be seen in [Table 4](#), despite being statistically significant, the wealth of each region measured through the GDP per capita has very limited influence on users' perceptions. According to the results, for a 100 Euro-increase in the regional GDP per capita, the odds ratio in favor of being positive towards tolling increases by only 0.5%, so toll acceptability remains quite similar for different levels of regional wealth. This is also in line with the results we obtained regarding the influence of the individual level of income on users' attitudes. Therefore, the average standard of living within a region seems to play a minor role on toll roads acceptability, at least for the case of Spain. These results contrast with findings in other areas such as health services ([Karlsdotter et al., 2009](#)).

Attitudes towards toll roads are however more noticeably affected by the political atmosphere within the region. This result confirms the conclusions by [Hårsman and Quigley \(2010\)](#) regarding the influence of political bias on road charging acceptability. Given the negative sign of the coefficient in the model, an increase in the vote to left-wing parties at the regional level reduces the support for toll roads. This finding makes sense, since Spanish socialist and communist parties promote a greater involvement of the government in the economy, typically associated in Spain to publicly-funded services. This attitude is then politically opposed to paying a toll for using roads. We can also note that this conclusion deserves to be complemented with an analysis of the influence of political beliefs at the individual level.

Additionally, as might be expected the density of toll roads within a region significantly influences users' perceptions towards toll roads. Even excluding the influence of infrastructure attributes—such as the quality of the alternative road in each case—or political beliefs, we can observe that users from regions with a higher density of toll roads have a more negative attitude towards road charging. This fact may be explained by the marked asymmetry of toll roads across regions, which is strongly connected to the influence of perceived fairness on pricing acceptability, as pointed out by [Cools et al. \(2011\)](#). In this respect, it is not strange that users from Catalonia or Valencia, very frequently obliged to pay for using high capacity roads, feel unfairly treated when compared to other regions with a more extensive free high-capacity road network.

We also find that the inclusion of regional parameters significantly improve the fitting of the model, given the results obtained for the likelihood-ratio test (*p*-value < 0.05). It is also worth noticing how unobserved effects across regions almost disappear in Model III. As can be seen in [Table 4](#), random coefficients become very close to zero and non-statistically significant after including regional parameters in the model. Then, we may conclude that regional differences initially identified on users' attitudes towards toll roads can be appropriately explained by the variables already included in the model. Finally, [Table 5](#) refines the results by removing overall non-significant explanatory variables such as age or income, with no effect on the fitting of the model according to the likelihood-ratio test.

Table 5
Users' perceptions towards interurban toll roads: refining results.

Level of data	Explanatory parameters	Modeling estimates		
		Coeff.	Std. error	p-Value
	Fixed effects			
	Intercept	−4.441	0.863	0.000
Individual	Gender (base reference: male)			
	Female	−0.306	0.081	0.000
	Type of vehicle (base reference: car)			
	Light van	−0.276	0.152	0.070
	Truck	−0.146	0.221	0.510
	Moto	1.981	15.692	0.990
	Bus	−0.714	0.666	0.283
	Trip purpose (base reference: commuting)			
	Business	0.257	0.135	0.057
	Weekend leisure	0.196	0.105	0.062
	Holiday leisure	0.144	0.115	0.211
	Other	0.044	0.137	0.747
Toll road	Type of tolled infrastructure (base reference: road)			
	Tunnel	0.437	0.228	0.056
	Toll rate	−1.486	0.983	0.130
	Quality of the alternative route (base reference: conventional)			
	Highway	0.299	0.135	0.027
Region	Regional GDP per capita	0.048	0.010	0.000
	% Left-wing parties	−0.082	0.015	0.000
	% High capacity roads tolled	−0.011	0.004	0.011
	Random effects			
	Region	1.68 e-05	0.039	0.999
	−2 log likelihood	−1851.61		

5.4. Discussion of the results

In this subsection, we briefly discuss the results obtained in this research work with regard to unobserved differences at the regional level. To that end, we included in [Fig. 2](#) the *evolution* of random intercepts for the main models calibrated stepwise in this paper (Models 0 to III). At first glance, some trends can be identified concerning users' differences across regions. Random intercepts in Model 0 evidence that users from Valencia, and especially from Catalonia, show a more negative perception towards toll roads than the average. This contrasts with regions such as Galicia or the Basque Country, in an intermediate position, and especially with the case of Madrid, whose users shows a higher positive attitude towards road charging.

As mentioned above, this view can be explained in the light of the asymmetrical tolling conditions currently applied, resulting from a changing national road transport policy over time. This fact has caused a marked regional heterogeneity that in its turn has provoked a negative perception due to a sentiment of unfairness in the regions more widely affected by tolls. This situation, combined with political beliefs and different tolling infrastructure attributes across regions, has created a significant anti-toll atmosphere in certain parts of the country, although they were initially favored by the early implementation of toll roads.

The lack of change in random intercepts observed between Models 0 and I (see [Fig. 1](#)) evidences the limited influence of the characteristics of individuals on regional differences. Additionally, infrastructure attributes only seem to be of great importance for the case of Madrid, given that its random coefficient goes down from 0.52 to 0.33. This fact appears to be strongly connected with the fact that toll roads in this region usually have a free high-capacity alternative (see [Appendix 2](#)). Finally, we can see that undoubtedly differences across regions are more affected by regional context-specific parameters included in the model, especially the abundance of toll roads. In this respect, a more

Fig. 2. Evolution of random effects regarding region intercepts for the different models calibrated.

coordinated tolling policy would be desirable to eliminate, or at least to reduce, these regional differences and sentiments of unfairness present in certain territories.

6. Conclusions and further research

The multilevel logit model developed in this research enabled us to explore and quantify the explanatory effect of context-specific variables, not only at the regional level but also concerning road-related attributes. From the analysis we were able to obtain some interesting conclusions.

The first conclusion is that users' perceptions towards toll roads may experience substantial differences across regions within the same nation. This seems to be especially crucial in those cases undergoing a heterogeneous toll implementation process across territories.

The second conclusion is that regional differences on tolling acceptability seem to be more affected by context-specific variables, related to either toll road or regional characteristics, than by the attributes of individuals. Particularly, those regions comparatively having a higher share of toll roads or more burdensome tolling infrastructure generally show a more negative perception towards road charging. This idea provides useful insight for future research, given the fact that these types of variables have barely been modeled till now.

The third conclusion concerns the consequences of developing an asymmetrical road transport policy across regions. In parallel with the

promotion of regional development and the analysis of territorial equity, a more coordinated implementation of road transport policies across regions seems to be advisable in order to avoid the sentiments of being treated unfairly that some territories perceive. Then, a more balanced national implementation of pricing strategies and road accessibility provision can contribute to better distribute the burden of road financing, as well as to avoid negative perceptions in certain territories.

From the results of this paper, some aspects can be pointed out for further research. First, further efforts are needed to extend the current analysis to regions with a lower presence of toll roads, in order to estimate the potential consequences and acceptability of establishing a more homogeneous road transport policy throughout the nation. Additionally, a *trans*-national research would be highly desirable, especially at the European level, with the aim to evaluate public perceptions towards the current EU charging policy. Finally, the influence of further explanatory variables on users' perceptions needs to be explored more deeply, likely by incorporating political beliefs at the individual level or latent variables through a structural equation approach.

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Appendix 1. Variables measured and questions addressed in the survey

Variable	Question addressed	Options provided
Socioeconomic characteristics		
Gender		Male; female
Age	Where do you place your age in the following intervals?	Under 25; from 25 to 34; from 35 to 49; from 50 to 64; above 64
Income	Where do you put your personal income in the following intervals?	Under 20,000; From 20,000 to 30,000; From 30,000 to 50,000; Above 50,000
Type of vehicle		Car; light van; truck; moto; bus
Region		Catalonia; Madrid; Valencia; Basque Country; Galicia
Frequency/type of user	How often do you use toll roads, considering the following intervals?	>8 trips per month (frequent user); <8 trips per month (occasional user); Never used it before (potential user)
Trip purpose (only for frequent and occasional users)	What is the most common trip purpose when you use toll roads?	Commuting; business/work related activities; weekend leisure; holiday leisure; other
Characteristic of the toll road		
Quality of the free alternative		Conventional road; Highway
Toll rate		Expressed in Euro/km
Tunnel		Tunnel; interurban road
Attitudes towards tolls		
Perception towards toll roads	Do you think that tolls are an appropriate mechanism to finance the provision of roads?	Yes; no

Appendix 2. Main characteristics of the toll roads included in the sample

Region	Toll road	Year of start	Length (km)	Toll rate, light vehicle (Euro/km)	High capacity alternative road	People surveyed	
						By toll road	By region
Catalonia	Montmeló–La Jonquera	1972	135.6	0.089	Partly (3.0%)	58	558
	Montmeló–Papiol	1978	26.6	0.092	No	135	
	Barcelona–Tarragona	1975	96.6	0.089	Partly (9.7%)	78	
	Zaragoza–Mediterráneo	1976	215.5	0.095	Partly (6.6%)	18	
	Barcelona–Montmeló	1972	14.2	0.100	Yes	89	
	Montgat–Palafolls	1969	43.1	0.087	No	67	
	Castelldefels–El Vendrell	1992	56.3	0.163	No	39	
	San Cugat–Manresa	1990	43.1	0.147	No	26	
	Vallvidriera Tunnels	1992	16.7	0.206	No	40	
	Cadí Tunnel	1986	29.7	0.392	No	8	
Madrid	Madrid–Guadalajara	2003	64.1	0.099	Yes	59	548
	Madrid–Arganda	2003	33.1	0.096	Yes	91	
	Madrid–Ocaña	2003	53	0.104	Yes	59	
	Madrid–Navalcarnero	2003	29	0.109	Yes	61	
	Eje Aeropuerto	2005	8.8	0.143	Yes	103	
	Villalba–Adanero	1977	69.6	0.144	No	162	
	Madrid–Toledo	2006	60	0.092	Yes	13	
Valencia	Tarragona–Valencia	1978	225.3	0.096	Partly (19.8%)	177	562
	Valencia–Alicante	1976	148.5	0.097	Partly (9.2%)	198	
	Circunvalación Alicante	2007	28.5	0.101	Yes	49	
	Alicante–Cartagena	2001	76.6	0.061	No	138	
Basque Country	Artxanda Tunnels	2003	3	0.492	No	62	558
	Bilbao–Ermua	1976	36.2	0.087	Partly (5.3%)	162	
	Ermua–Behobia	1976	87.6	0.107	No	181	
	Maltzaga–Arrasate	2003	35.6	0.107	No	59	
	Bilbao–Zaragoza	1978	294.4	0.092	Partly (18.0%)	94	
Galicia	Ferrol–Front. Portuguesa	1979	218.9	0.089	Partly (14.4%)	264	543
	Santiago–Alto Sto. Domingo	2003	56.6	0.094	No	53	
	La Coruña–Carballo	1998	32.6	0.068	No	145	
	Puxeiros–Val Miñor	1999	25.2	0.060	No	81	

Appendix 3. Application of the multilevel specification to the case study adopted

Appendix 4. Users' perceptions towards interurban toll roads: estimation results. Models 0 (lack of explanatory variables), Model I (including individual characteristics) and Model II (including infrastructure attributes)

Level of data	Model	Model 0		Model I: Model 0 + individual characteristics		Model II: Model I + infrastructure characteristics	
	Variables	Coeff.	p-Value	Coeff.	p-Value	Coeff.	p-Value
Individual	Fixed effects						
	Intercept	0.102	0.519	0.293	0.266	0.332	0.224
	Gender (base reference: male)						
	Female			−0.271	0.001	−0.268	0.002
	Age (base eference: under 24)						
	From 24 to 34			−0.248	0.256	−0.244	0.265
	From 35 to 49			−0.182	0.379	−0.173	0.404
	From 50 to 64			−0.020	0.926	−0.104	0.961
	Above 64			0.185	0.504	0.181	0.513
	Type of vehicle (base reference: car)						
	Light van			−0.251	0.100	−0.256	0.094
	Truck			−0.165	0.457	−0.141	0.525
	Moto			1.623	0.988	1.504	0.982
	Bus			−0.753	0.253	−0.763	0.250
	Income (base reference: under 20,000 €)						
	From 20,000 to 30,000 €			0.070	0.589	0.079	0.546
	From 30,000 to 50,000 €			0.123	0.466	0.147	0.384
	Above 50,000 €			0.180	0.544	0.242	0.415
	Frequency (base reference: frequent user)						
	Occasional user			−0.070	0.449	−0.064	0.491
	Trip purpose (base reference: commuting)						
	Business			0.231	0.089	0.263	0.053
	Weekend leisure			0.146	0.182	0.164	0.136
	Holiday leisure			0.060	0.619	0.086	0.480
	Other			−0.053	0.717	−0.048	0.744
Toll Road	Type of tolled infrastructure (bc: road)						
	Tunnel					0.431	0.059
	Toll rate					−1.459	0.138
	Quality of the alternative route (bc: conventional)						
	Highway					0.335	0.014
	Random effects						
	Region	0.341	0.003	0.355	0.003	0.309	0.004
	−2 log likelihood	−1884.28		−1862.280		−1855.98	
	Likelihood-ratio test			Mod. 0 nested in Mod. I		Mod. I nested in Mod. II	
				Prob > chi ² = 0.001		Prob > chi ² = 0.006	

Appendix 5. Users' perceptions towards interurban toll roads: testing regional differences for slope coefficients

Model	Assumption	Random coefficient	p-value	Random region coefficient	Log-likelihood	Prob. nesting model I > chi2
Model I. Gender	Regional differences on gender coefficients	0.147	0.405	0.355	−1862.16	0.176
Model I. Age	Regional differences on age coefficients	0.000	0.999	0.355	−1862.28	1.000
Model I. Income	Regional differences on income coefficients	0.158	0.116	0.198	−1861.49	0.132
Model	Assumption	Random coefficient	p-value	Random region coefficient	Log-likelihood	Prob. nesting model II > chi2
Model II. Alternative	Regional differences on quality of the alternative coefficient	0.000	0.999	0.309	−1855.98	0.999
Model II. Toll rate	Regional differences on toll rate coefficient	0.000	0.999	0.309	−1855.98	0.999

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4. RECOMMENDATIONS, CONCLUSIONS AND FURTHER RESEARCH

This section summarizes the compliance with the objectives (Section 4.1), practice-oriented recommendations (Section 4.2), main conclusions (Section 4.3) and further research that could follow up (Section 4.4).

4.1 Fulfilment of research objectives

As previously explained in Chapter 1, the main objective of this thesis was to provide knowledge for explaining road demand in interurban toll roads. The research comprised two main areas:

- To identify, through a macro analysis, key explanatory variables determining road demand evolution for light and heavy vehicle demand, with a special focus on traffic reductions experienced in periods of economic slowdown.
- To explore, through a micro analysis, users' perceptions and willingness-to-pay in interurban toll roads, as well as to study potential relationships between these two concepts. A special focus on the influence of regional issues in this matter was specially sought.

In order to complete the tasks at hand, different methodologies were proposed for each level of analysis and validated for the case of Spain. Several papers were developed with a common structure: introduction, state of knowledge, methodology, description of the case study (Spanish interurban toll roads), modelling results, discussion and conclusions.

Regarding the first objective, a dynamic panel data methodology was adopted to identify key explanatory variables for light and heavy vehicle demand and applied to the case of the Spanish toll road network:

- a) The first paper (Chapter 2) developed a methodological framework to analyse light vehicle demand evolution over time and identify its main

explanatory variables. The methodology comprised three types of parameters referred to: socioeconomic context, generalized cost of the trip and location of the toll road within the country. The analysis of the evolution of both road traffic and explanatory variables was conducted by adopting a dynamic panel data specification. Through an original approach, the research estimated demand elasticities and tested their stability over time, so the most suitable explanatory variables were identified. It also enabled measuring, at a macro level, potential differences in traffic behaviour between toll roads situated in interior regions or near the coast. This methodology was applied to the Spanish interurban toll road network for the 1990-2011 period so the beginning of the economic crisis was included in the analysis. Therefore, the impact of the economic slowdown on road traffic volume was particularly explored.

- b) In the same line, the second paper (Chapter 2) applied the aforementioned methodology to the evolution of heavy vehicle traffic over time. The research particularly focused on analysing the performance of total GDP as an explanatory variable for road freight demand evolution, since it is the socioeconomic parameter most commonly used to make truck traffic forecasts. Additionally, further alternative variables were considered and tested. The results showed the reliability of the panel data methodology applied in the first two papers, as well as the consistency of the explanatory parameters identified for road demand when considering both periods of economic growth and slowdown.

Concerning the second objective, focused on the micro level approach, the research took advantage of the results from a nationwide survey conducted to users of interurban toll roads. The analysis explored users' perceptions and willingness to pay, and was divided into two main parts:

- c) In Chapter 3, a discrete choice approach was adopted to analyse users' perceptions and willingness-to-pay in interurban toll roads, developed in the third paper. Based on the information collected from a nationwide stated preference (SP) survey, the research estimated the influence of different type of explanatory variables –individual characteristics, road-related attributes, etc.– in determining users' reactions towards interurban toll roads currently in operation. Variables barely analyzed in the literature were included, such as the quality of the free alternative road or the toll rate levied. Additionally, the results obtained for users' perceptions and willingness-to-pay were compared and discussed.

To that end, two discrete choice models were developed. Firstly, a usual binary logit model studied general users' perceptions towards tolls as a way to finance interurban roads. Secondly, willingness-to-pay was addressed through a SP choice experiment in which respondents were presented different conceptual scenarios. At this point, a censored regression (tobit) model was adopted since a significant percentage of users reported a null willingness-to-pay in the SP experiment.

- d) As a continuation of the previous research, the fourth paper (Chapter 3) made a special focus on exploring potential differences in users' perceptions due to an asymmetrical distribution of interurban toll road infrastructure across regions. To properly deal with differences across users, a multilevel logit model was adopted to identify whether perceptions may significantly vary depending on the region of residence or the toll road used. Particularly, individual characteristics, road-related attributes and regional parameters were included as explanatory variables in the research. Checking the existence of significant differences across groups from a statistical point of view, as well as identifying those variables explaining such differences, could be done by inserting some random coefficients in the modelling approach.

4.2 Practice-oriented and policy recommendations

The following is a summary of some recommendations at the practice-oriented level, in the light of the research work developed in the current thesis. The main goal is to join the conclusions obtained from the previous papers in the transport planning perspective. The section is divided into two areas: methodological recommendations and achievements, more directed towards future research to be developed in this field; and practice-oriented recommendations, addressing policy recommendations and possibilities to implement in practice.

4.2.1 Methodological recommendations and achievements

Given the variety of econometric techniques used in the thesis, the following conclusions describe the main contributions in the field of methodological approaches for analysing road demand behaviour.

- Data usage. When different aspects related to road demand behaviour are to be analysed, comprising both the macro and micro level, no kind of data available should be disregarded. The current dissertation is an example of using and adapting a wide variety of data for studying road demand behaviour from different points of view.
 - For instance, the identification of the macro variables explaining road demand evolution in the long-term should be addressed by collecting aggregate data available in official data sources: national statistics services, transport institutes, etc. It should not only comprise data at the national level, since regional figures could better explain some local effects affecting the issue under analysis. In Chapter 2, the thesis collected information at a macro level including different data sources, both at the national and provincial level: average road traffic volume, GDP for the whole economy as well as for specific economic sectors, Employment, Population, toll rates, gasoline prices, etc.

In this respect, it is important to collect different types of explanatory variables specifically addressing each segment of the traffic to be analysed. We can acknowledge that macro variables such as GDP,

employment, public deficit, etc., generally show an evolution over time highly correlated to each other. However, the selection of the proper explanatory variables can have a significant influence on the ultimate estimates, as well as in the subsequent demand forecasts coming from them. For instance, it can be expected that light vehicle demand should be more influenced by variables such as total Employment or Population, while freight traffic should be better explained by GDP data or foreign trade accounts.

Additionally, some variables need to be managed in order to properly reflect the issue addressed in the analysis. For instance, among the explanatory variables regarding generalized cost of the trip, our research included tolls and fuel cost. While tolls were reported in unitary terms (Euro/km), the only information available for fuel was gasoline prices (Euro/liter). In order to reflect real fuel costs when driving (Euro/km) for the period analyzed (1990-2011), it was necessary to include linear improvements in fuel efficiency observed in the fleet over time. To that end, fuel prices for each particular year were weighted by the estimates of fuel vehicle efficiency (liter/km) in turn approached by using data from the Spanish Ministry of Transportation and the Ministry of Industry.

- Furthermore, an exploration on users' perceptions and willingness-to-pay should be based on information at the micro level, so data needs to be collected for each individual through a survey. Nevertheless, researchers should take into account that the explanatory factors collected in surveys may not be enough to properly explain individuals' behaviour. In that case, it could be useful to include information not reported in the survey, particularly the one referring to context-specific attributes. For instance, the modelling approach at the micro level included the quality of the free alternative road as an explanatory variable for users' perceptions and willingness to pay. Despite not being directly reported in the survey, this context-specific variable evidenced

to significantly influence individuals' perceptions and willingness-to-pay in our case.

- Selection of methodologies. The analytical methodologies applied in the field of transport research are highly conditioned by the data available. Given that the thesis addressed both macro and micro aspects of road demand behaviour, the proper technique should be considered for each particular case. At this point, the econometric background offers a wide range of alternatives to analyze such variety of aspects.

Regarding the macro approach, the dynamic panel data methodology adopted was especially suited for identifying the explanatory variables to better explain road demand evolution over time:

$$\left\{ \begin{array}{l} \Delta \ln(AADT_{it}) = \alpha \Delta \ln(AADT_{i,t-1}) + \beta_1 \Delta \ln(Toll_{it}) + \beta_2 \Delta \ln(Fuel_t) + \\ \quad + \beta_3 \Delta \ln(Socioec.variable_{it}) + \Delta \varepsilon_{it} \\ \text{Orthogonality conditions: } E[IMD_{i,t-s} \Delta \varepsilon_{it}] = 0, \quad t = 3, \dots, T \quad s \geq 2 \end{array} \right. \quad (1)$$

Through an original approach, the stability of elasticity results was checked by gradually calibrating new runnings of the model with a longer time period considered in the analysis. Thus, the traditional “static” approach that presents elasticity results for a specific period was replaced by a “time-dependent” approach, including the evolution of demand elasticities over time, when the time period is gradually extended. In this respect, we considered that those variables with poor stability and significant variations in their demand elasticities over time could not be considered suitable to explain the evolution of road demand in the long term. The change proposed in the methodological approach is illustrated in Figure 5.1, showing the differences between the “static” and the “time-dependent” perspective.

Figure 4.1. “Static” and “time-dependent” perspective of macro demand analysis

Regarding the micro approach to road behaviour, we explored both users’ perceptions and willingness-to-pay. Then a different econometric methodology was needed. Users’ perceptions were studied through a binomial logit specification, a common approach conducted in the literature, so no particular contribution was made in this respect. Furthermore, the analysis of willingness-to-pay was developed by using a censored regression (tobit) model, an econometric technique rarely adopted for choice modelling. The reason behind this decision was the fact that, while a great proportion of respondents were not willing to pay at all, the rest of them showed great variability in their preferences. As a result, we had a censored data sample. Then, a tobit specification was adopted due to two main advantages. Firstly, this specification avoids biased results for demand elasticities since the whole sample can be considered. Secondly, the tobit model allows capturing two effects simultaneously: the decision of individuals to choose/not to choose a specific alternative, as well as the intensity of their choice (Tsekeris et al, 2008):

$$\begin{cases} Y_i = Y_i^* = \beta X_i + \varepsilon_i & \text{if } Y_i^* > 0 \\ Y_i = 0 & \text{if } Y_i^* \leq 0 \end{cases} \quad (2)$$

Therefore, the thesis is an example of combining different methodological techniques as a way to take advantage of the data available and to the type of analysis needed. This procedure makes possible a better understanding of the issue under analysis, leading to more efficient policy recommendations.

- Identification of key explanatory factors. As previously mentioned, one of the main contributions of the research was the identification of key explanatory variables for light and heavy vehicle demand at a macro level. To that end, we adopted an original approach consisting of checking the stability over time of demand elasticities obtained through a panel data model. It allowed us to pass from a static approach of the problem to a time-dependent one.

This fact resulted to be important in order to identify those variables showing a suitable explanatory performance not only in periods of prosperity, but also when an economic slowdown arises. In the case that all the variables in the model show a trend slightly varying over time, as it happens for certain socioeconomic variables in times of economic growth, some type of spurious relationships could be present in the results. This is a situation to be avoided, since policy conclusions cannot be drawn in this case. Rather, trend variability in the data, as it is the case of a period of economic growth followed by a recession, allows testing more consistently the performance of each explanatory variable. At this point, it is important to note that, for the case of Spain, some parameters were found to be unsuitable to explain road demand evolution once the economic crisis was considered in the analysis.

- Regional analysis for users' perceptions. Given that a preliminary exploration on users' perceptions towards tolls identified significant regional differences, a special focus was conducted in this field. In this respect, the study of regional parameters on road transport research has been barely included in the literature up to date. In principle, we may suppose that those individuals living in the same context could also show a similar behaviour.

Therefore, a multilevel methodology was adopted for exploring potential differences among individuals, according to the region of residence and the toll road use.

$$Y_{ijk}^* = \beta_{0(n)jk} + \beta_{1(n)jk} X_{1ijk} + \dots + \beta_{p(n)jk} X_{pijk} + \varepsilon_{ijk} \quad (3)$$

$$\beta_{0(n)jk} = \beta_{0(n)} + u_{jk} + u_k; \quad \beta_{p(n)jk} = \beta_{p(n)} + u_{jk} + u_k$$

The model included random effects at both intercepts and slope parameters, allowing random variations among toll roads (j) and regions (k), so a misinterpretation of estimates could be avoided. Surveys conducted on transport research generally draw inferences regarding variability across groups based on the individual level of data (Hox, 2002), while relationships among groups are not properly analysed. Then, the introduction of multilevel analysis in this research is strongly encouraged to obtain more consistent and accurate results, as well as to again adapt to the structure of data collected.

4.2.2 Policy recommendations and practice-oriented possibilities to implement in practice

Some policy and practice-oriented recommendations have arisen from the asserted analysis on road demand behaviour in interurban toll roads:

1. At the macro level, the following issues can be pointed out:
 - a. Concerning the macro analysis, new variables have been identified for explaining road demand in interurban roads in the long term. Therefore, policymakers and road operators should develop a more careful analysis when making traffic forecasts analysis. Choices should be based on those explanatory variables better adjusting to the historical trend of each particular road segment after a more rigorous analysis. Hence, taking GDP as an explanatory variable for road traffic with no further reason than usual practice should be avoided.
 - b. Among the factors that should be considered when estimating traffic evolution over time, we can mention the location of the toll road. As could be identified in this research, demand volume in toll roads near the coast may show a far different behaviour from what is observed in interior roads. While coastal roads seem to be more influenced by local activities, the latter are characterized by a higher proportion of long-distance trips and, therefore, are more influenced by national parameters.
 - c. Separated analysis should be developed for each segment of the traffic, light and heavy vehicles, since they respond to different explanatory factors. While light vehicle demand seems to be more influenced by variables such

as Employment or income, road freight transport is strongly related to the evolution of transport-intensive activities, such as construction and industry. Up to date, the traditional procedure for both road operators and public administrations has been considering road traffic as a whole, without taking into account that it is formed by two heterogeneous segments.

- d. Once the suitable explanatory variables have been identified for interurban road demand, they can be used for other purposes than making traffic forecasts. In case the traffic risk of the toll concession is assumed or shared by the private partner, some legal terms could be included in the concession contract to mitigate this risk. For instance, given that Employment evidenced to be a suitable explanatory variable for light vehicle demand, some compensations for the toll operator could be included in the contract in case sharp reductions are experienced in the level of national/regional employment at a certain time.

2. At the micro level, the following issues can be pointed out:

- e. One of the main contributions of the research in the field of policy recommendations is alerting policymakers about the consequences of developing an asymmetrical road transport policy across regions. In parallel with the promotion of regional development and the analysis of territorial equity, a more coordinated implementation of road transport policies across regions, particularly tolling policies, seems to be advisable. A more homogeneous policy may avoid the sentiments perceived in some territories of being treated unfairly, especially when charging conditions greatly vary within the same nation. Then, a more balanced national implementation of pricing strategies and road accessibility provision can contribute to better distribute the burden of road financing, as well as to avoid negative perceptions in certain territories. Despite being commented particularly for road transport and tolling policies, the importance of regional issues can be extended to other transport modes for a wide variety of matters.
- f. The research showed the partial view that could be provided if policy analysis are only focused on either users' perceptions or willingness to pay.

In this respect, traditionally policy makers have paid more attention on users' perceptions, while practitioners and road operators have commonly focused on willingness to pay. By contrast, the research showed the importance of studying both concepts simultaneously, as a way to provide a more integrated view of the problem.

4.3 Conclusions and research findings

The thesis developed two main approaches (macro/micro) to analyse road demand behaviour, and applied it to the Spanish toll network. Additionally, a special focus was made to explore regional differences in users' perceptions throughout the country. The analysis yielded some interesting conclusions and contributions for the case of Spain.

1. At the macro level, from the study of road demand evolution for the 1990-2011 period:
 - a. *Regarding light vehicle demand*, the most suitable socioeconomic parameters to explain road traffic evolution over time were identified. Firstly, we concluded that GDP does not constitute the most suitable socioeconomic variable for explaining light vehicle demand evolution, despite being the most common one used in the literature. GDP elasticities experienced great variability over time, even when choosing data either at the provincial level (from 0.45 to 0.96) or at the national level (from 0.40 to 0.98). Then, the research concluded that this significant variability in GDP demand elasticities weakens its usefulness in explaining traffic behavior in the long term. It also hinders its ability to make traffic forecasts for light vehicles, since the relationship between both variables shows little stability over time (see Figure 5.2.a below). This is also the case for other variables potentially useful to explain road demand evolution such as Population. This parameter evidenced to be not strongly connected with the economic evolution and also poorly reflected the potential amount of road users in the country, given the importance of migrations observed in the country in the last decades.

- b. By contrast, other socioeconomic parameters such as Employment or GDP per capita led to more stable and consistent results. Unlike GDP, results for e.g. Employment elasticities showed greater stability when gradually varying the time period, for both national data (from 0.54 to 0.72) and provincial data (from 0.49 to 0.78). Stability of elasticity results, even when incorporating the crisis, demonstrates that Employment constitutes a suitable explanatory variable for light vehicle demand, in contrast to GDP (see Figure 5.2.b). There seems to be some reasons behind that. While GDP is made up of the aggregation of different and heterogeneous sectors of the economy, Employment could be a better proxy for income and mobility. This variable does not refer to all the potential users of a toll road –that is, the whole population– but only to those who are employed, generally with higher income and greater mobility potential.

Figure 4.2. Demand elasticities (short-run) when considering GDP (left) and Employment (right) as the socioeconomic variable to model light vehicle demand

- c. Similar results were obtained when considering GDP per capita to explain light vehicle demand evolution (see Figure 5.3). It constituted the most solid alternative, since demand elasticities showed very constant results over time: from 0.77 to 0.98 with provincial data, and from 0.94 to 1.18 with national data.

Figure 4.3. Demand elasticities (short-run) when considering GDP (left) and GDP per capita (right) as the socioeconomic variable to model light vehicle demand

- d. As for variables related to the generalized cost of the trip (toll and fuel costs), some trends could be identified. Toll elasticities showed a quite stable trend, with values moving from -0.20 to -0.41, which is consistent with previous research in the literature (Matas et al., 2012; Burris et al., 2011; Odeck et al., 2008). This behaviour is likely caused by the fact that real tolls in the sample remain constant, as toll rates in Spain are usually adjusted through inflation.

By contrast, greater variations were observed for fuel cost elasticities. Estimates moved from 0.0 to -0.37, not being far from zero in most of the cases, as in Burris et al. (2011). Thus, toll elasticities in Spain are generally above fuel ones. This result suggests that user's perception of the burden of tolls seems to be higher than that for fuel costs, at least in our country.

- e. *Regarding heavy vehicle demand*, the analysis yielded similar conclusions. Again, GDP evidenced to be an explanatory variable not particularly suitable to explain heavy vehicle demand, since elasticities showed great variability over time (see Figure 5.4a). Estimates moved from -0.22 to 2.34 when considering provincial data, and ranged from -0.47 to 2.44 when choosing national GDP. The huge variability of elasticity results for total GDP greatly weakens again its capability to explain heavy vehicle demand, as well as to predict road freight traffic evolution in toll roads.
- f. By contrast, considering only the GDP of those economic sectors with a high impact on transport demand, such as construction or industry, led to

more consistent results. Unlike total GDP, estimates concerning GDP for transport-intensive sectors showed significant stability when gradually varying the time period, even if the economic crisis is incorporated in the analysis (see Figure 5.4). Elasticities moved between 0.74 and 1.28 with provincial data, and from 0.55 to 0.99 when taking national data. Some reasons could be pointed out for this stability. While total GDP consists of the aggregation of different heterogeneous sectors of the economy, GDP of only transport-intensive sectors could be a better proxy for road freight mobility. This procedure excludes those activities with little effect on road demand, such as public administration, financial services, etc., so only economic sectors with a high impact on transport (mainly Construction and Industry), and hence with higher explanatory power, are considered.

Figure 4.4. Demand elasticities (short-run) when considering GDP (left) and GDP only from transport-intensive sectors (right) as the socioeconomic variable to model heavy vehicle demand

- g. As for variables related to the generalized cost of the trip, toll elasticities again showed a quite stable trend, with values moving from -0.19 to -0.43, which is consistent with previous research (Burris et al., 2013; Álvarez et al., 2007). Regarding fuel elasticities, greater variations were observed, with estimates in the Spanish toll network moving from -0.01 to -0.56. Averaging -0.21, these results were very close to the values provided by De Jong et al. (2010) or Matas et al. (2003). In this respect, it should be mentioned that a wide variety of results can be observed in the literature, as fuel elasticity estimates range from -0.41 (Gately, 1990) to values near

zero (Álvarez et al., 2007) or even positive (Burris et al., 2013). This research also evidence that toll and fuel elasticities present values of the same order of magnitude, in contrast to results for light vehicle demand.

- h.* Demand elasticities have been quantified for the Spanish toll network during the period 1990-2011. This elasticity results will be of great interest for those road operators and public administrations interested in estimating traffic evolution in our nation for the next years.

Table 4.1. Demand elasticities obtained for Spanish toll roads (1990-2011)

Variables		Elasticity range	
		Light vehicle demand	Heavy vehicle demand
Socioeconomic variables at the regional level	GDP	0.45 – 0.96	-0.22 to 2.34
	Employment	0.54 – 0.72	-
	GDP per capita	0.77 – 0.98	-
	GDP transp.-intensive sectors	-	0.74 – 1.28
	GDP Industry	-	0.91 -1.16
Socioeconomic variables at the national level	GDP	0.40 – 0.98	-0.48 to 2.44
	Employment	0.49 – 0.78	-
	GDP per capita	0.94 – 1.18	-
	GDP transp.-intensive sectors	-	0.55 – 0.99
	GDP Industry	-	0.55 – 0.89
Toll		-0.40 to -0.19	-0.43 to -0.19
Fuel cost		-0.37 to -0.02	-0.56 to -0.01

- i.* Regarding the influence of the location of the toll road, a different behaviour was observed for toll roads located in the interior of the peninsula when compared to those ones situated near the coast. Coastal roads better fitted with socioeconomic variables at the provincial level, while interior roads performed slightly better when considering national data (see an example for heavy vehicle demand in Figure 5.5). These results can be explained by two main factors. Firstly, the strong relationship between road traffic evolution in coastal roads and such local activities as tourism or construction. Secondly, interior roads generally show a higher proportion of long-distance trips, less related to local effects, so a greater influence of national variables can be expected in this case. Nevertheless, differences

between the evolution of demand elasticities in terms of volatility was not identified in the analysis.

Figure 4.5. Demand elasticities for heavy vehicle demand when considering provincial Industry GDP (left) and national Industry GDP (right) as the socioeconomic variable in the model, for both coastal (above) and interior roads (below)

- j. *Regarding the impact of the economic crisis on toll road traffic*, several issues can be concluded. Firstly, the panel data approach demonstrated that road demand behaviour during the economic crisis in Spanish toll roads cannot be considered an anomaly, despite sharp reductions suffered since 2007. When considering suitable socioeconomic variables, demand elasticities after including the crisis in the analysis were of the same order of magnitude as that of previous years. Therefore, sharp traffic reductions in Spanish toll roads in those years cannot be considered anomalous, but only in line with the economic context. The methodological approach explored any potential structural change in demand elasticities between periods of prosperity and economic slowdown/recession, for both light and heavy vehicle demand.

Nevertheless, no significant results were found for the explanatory variables finally selected in the model: Employment, GDP per capita and GDP of transport-intensive sectors. This fact reinforced the conclusions previously pointed out. Finally, demand responsiveness towards explanatory variables related to the generalized costs of transport (tolls and fuel costs), did not statistically changed during the economic slowdown and recession in Spain.

2. At the micro level, from the nationwide survey conducted to road users in interurban toll roads:

- k.* For the case of Spain, personal characteristics evidenced to be non-statistically significant to determine users' perceptions and willingness to pay. Slope coefficients for individual attributes such as age or income showed a p-value lower than 0.05. These results are in line with previous research, such as Odeck et al. (2008) in Norway and Dill et al. (2007) in Texas. Likely, some trip-related attributes were also found non-statistically significant. This is the case of explanatory variables such as type of vehicle, trip frequency or trip purpose.
- l.* By contrast, users' perceptions and willingness to pay seem to be more influenced by context-specific variables in the case of Spain. The quality of the free alternative road available (conventional road/high capacity road) evidenced to be a parameter significantly influencing users' responses. For instance, drivers were 44% more supportive of being charged in toll roads competing with free highways than in toll roads competing with low quality alternatives. In the same line, those users driving in a toll road competing with a free highway were significantly more reluctant to pay (-0.5 Euro) compared to toll roads in which the alternative happens to be a conventional road.
- m.* Among the context-specific variables influencing users' perceptions, the region of residence seems to play a major role when an asymmetrical distribution of the interurban toll road network is observed within the same nation. The research showed that those regions comparatively suffering a higher burden of tolls generally have a more negative

perception towards toll roads, but not necessarily a lower willingness to pay. This is especially clear in cases such as Spain, with a heterogeneous toll implementation process both across regions and over time.

4.4 Future research

This research has identified a number of issues which could be subject of future research. Given that the thesis focused on a matter scarcely studied in the literature up to date, a great variety of issues can be mentioned. The following areas should be pursued to expand the current research:

- With regard to explaining road demand evolution through a macro approach:
 - Further research is needed in order to explore the performance of additional explanatory variables, as well as their potential usefulness to determine road demand evolution over time at the macro level. Particularly, analysing the relationship between road demand and those explanatory variables traditionally identified as leading macroeconomic indicators (maritime traffic, construction licenses evolution, consumer confidence index, etc.) would be of great relevance. This contribution would be highly useful for estimating more accurate traffic forecasts and for better making traffic trends for future periods.
 - A more detailed treatment of data is required in order to capture intra-annual effects of road traffic within the analysis. While the current thesis included annual data, lower time intervals (monthly/quarterly data) might be included in the analysis to assess seasonality. Without doubt, this fact will be conditioned by the data availability for each explanatory variable in the modelling approach. Nevertheless, this contribution would increase the sample size by more than doubling the current number of observations, what would make the results more consistent; and more importantly, it would enrich the current research since potential seasonality trends of traffic could be identified.
 - A trans-national analysis would be useful to compare the results obtained for Spain with other countries in the international context. At this point, it could be expected that road demand evolution, particularly heavy vehicle

traffic, could show a different behaviour depending on different national characteristics, e.g. its geographic location or the structure of its economic system. For the case of Europe, comparing the results in Spain with other nations geographically located in the centre of the continent –therefore with a higher volume of passing traffic– or with a strong industrial sector, as it is the case of Germany or Switzerland, would be of great interest from a policy perspective. This investigation would highly enrich the analysis, since the results and conclusions here presented could be validated, confronted and –if necessary– adapted when the national context changes.

- Including the use of spatial econometric techniques in the analysis of interurban roads would be a significant contribution, since this approach has not been developed in the literature up to date. Basically, the use of spatial econometrics would take into account the potential relationships between variables in the model due to spatial autocorrelation, in the sense that location similarity would coincide with value similarity:

$$Y = \lambda W y + \beta X + u \quad (4)$$

Then, the model assumes that levels of the dependent variable Y depend on the levels of Y in the neighbouring regions. This specification would improve the current approach adopted, in which each toll road is assumed as an individual within the panel. Then, the new approach would divide toll roads into different road sections, each of whom would represent the individuals of the new panel model (see Figure 5.6). Therefore, several independent observations could be included for each toll road analyzed. As previously mentioned when suggesting the inclusion of sub-annual time periods, the introduction of spatial econometrics in the model would significantly expand the sample size and hence make the research more consistent, accurate and complete.

Figure 4.6. Illustrative example of the adoption of spatial econometric techniques to the panel data approach currently used

- A particularly valuable contribution in the field of modelling road demand through a macro approach would be the study of traffic diversion within a transport corridor formed by a toll road and its free parallel alternative. In this context, road diversion between free and toll roads has been only explored through stated preference (SP) surveys, in which respondents are asked about their choices given some particular options. This approach is of great interest in this matter, but presents some weaknesses: (i) the surveys are conducted in a specific period of time, so it represents a time-fixed picture of the problem. However, the evolution of users' choices over time can be only evaluated with a panel survey, an approach rarely adopted due to its high cost associated; (ii) in the same line, in this type of surveys the respondents are asked about hypothetical situations they may not have encountered before (Odeck et al., 2010), so the analysis is not based on choices already done; (iii) more importantly, this type of surveys explores the influence of individual characteristics (income, age, etc.) on personal choices, but it does not capture how choices are affected by the evolution of the economic environment. Therefore, while surveys can estimate the influence of e.g. individuals' level of income on drivers' choices, they are not able to address how aggregate traffic diversion behaves over time as macro variables such as Employment or GDP per capita –as a proxy for personal income– vary in the surrounding areas. Up to date, the existing macro analyses on traffic diversion have only focused on the relationship between vehicle demand and road safety (see e.g. Baumgarten et al., 2015).

This procedure would not mean disregarding the current approaches based on SP surveys, but would represent an alternative tool for analysing road diversion in interurban roads. Particularly, its usefulness would rest in estimating the influence of explanatory variables on road diversion at the macro level, as well as considering real traffic data (historic trends) in contrast to hypothetical respondents' choices from surveys. To develop this objective, different econometric techniques should be explored, such as grouped logit (glogit) specifications, seemingly unrelated regression (SUR) models, simultaneous equation models (SEM), etc.

Apart from its usefulness to identify macro variables explaining traffic diversion evolution in interurban roads, this proposed approach would estimate the average Value of Time (VOT) of users in each road. Obtaining this value would be interesting to adjust toll levels within the corridors and to estimate the change in the social welfare coming from this policy.

- Finally, all the former issues suggested could be supported by the introduction of Geographic Information System (GIS) techniques within the analysis. They constitute an ideal tool for taking into account geographical factors in the study of road demand evolution. For instance, this approach would enable considering the influence of population density or layout of urban areas in the level of road demand, as well as their impact on congestion and road traffic diversion. Among other advantages, the introduction of GIS techniques would make it possible to incorporate the different characteristics of each particular toll section, such as average speed, road safety information, road infrastructure attributes, etc.
- With regard to explaining road demand through a micro approach:
 - Modelling approaches adopted to analyse users' perceptions should be further improved. The current binomial logit specification can only be considered as a first approach on users' perceptions, since more complex econometric specifications are available for modelling users' discrete choices. Further alternatives such as e.g. mixed logit models allow taking into account potential heterogeneity of preferences within the sample, so

differences among users with regard to perceptions and willingness to pay would be studied in greater detail.

- Users' perceptions in interurban toll roads should be widely explored. In this research, general perceptions towards toll roads have been modelled, but other issues need to be addressed. For instance, exploring users' attitudes towards different pricing schemes in the interurban context would represent a matter of great interest. In this respect, the case study analysed –the Spanish interurban toll roads– presents the same tolling scheme for the whole network, consisting of a constant toll rate per km (Euro/km). By contrast, users' perceptions could be explored regarding different charging schemes to be potentially implemented: a flat-fee (*vignette*) system, a time-based scheme, or even a high-occupancy toll (HOT) lane scheme, despite being a tolling scheme only used in the United States. This analysis would yield some interesting conclusions of great value for policymakers.
- Additional explanatory variables influencing users' choices are worth to be studied. Particularly, the increasing adoption of electronic toll collection (ETC) systems worldwide makes it necessary to evaluate to what extent the use of on-board equipment (OBE) may influence toll roads use. In this respect, the impact of cashless payment methods on toll roads use should be further explored, since only some preliminary analysis (Zhou et al., 2012) have been conducted in the literature up to date, suggesting that those tolls paid electronically may be less perceived by users.
- As commented before, previous research on road users' choices and willingness to pay are based on stated preference surveys, so real choices are not analysed. This fact could bias the results, since some experiments have demonstrated that stated and revealed preferences may sometimes vary significantly. To overcome this problem, some technological developments could be used. Given the increasing penetration of wireless communication devices, and particularly the generalized adoption of smartphones, traffic data could be collected even at the individual level. This information could lead to a BigData problem to better identify those

explanatory factors determining users' behaviour. Additionally, some pilot projects could be established in order to test users' reactions to e.g. toll variations in a real case. These pilot projects would be of great interest to explain drivers' choices and traffic diversion in those corridors made up of a toll road competing with a high quality free road. For Spain, this is a case commonly observed in access roadways to metropolitan areas such as Madrid and Barcelona.

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