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Policy mix to reduce greenhouse gas emissions of commuting: A study for Barcelona, Spain

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ABSTRACT

Commuting or the journey to work makes up an important part of transport. It should therefore be a target of climate policies that aim to reduce greenhouse gas emissions from transport. To design an effective climate-transport policy package, this article constructs a framework consisting of two core aspects of commuting patterns driven by five categories of underlying factors. Policy implications are derived from this. The set of factors and policies are then studied for the Barcelona Metropolitan Region in Spain. We find that it is essential to limit dispersion of the population and provide spatially adequate public transport services. In addition, effects of imperfections in labour and housing markets, and commuter bias in transport preferences towards car use, should be addressed in policy.

Introduction

The transport sector is almost entirely dependent on fossil fuels. It is the second largest sector producing global greenhouse gas (GHG) emissions and the second fastest growing sector of emissions in general, while future projections of emissions look dim (OECD, 2008a). Policies targeting transport externalities, such as energy consumption and emissions, are often subject to rebound effects, notably increased use of vehicles, that reduce their effectiveness (Rajan, 2006; Rietveld, 2006). The policy challenge is to formulate a combination of effective supply- and demand-side policies, technology-oriented solutions and physical planning. There is a clear need for understanding what a complete, effective policy package looks like as substantially reducing GHG emissions from transport is very difficult (Gilbert and Perl, 2010; Hickman and Banister, 2014).

This study will put the spotlight on commuting transport and try to obtain such a policy package on the basis of identified core factors of commuting. Commuting or the journey to work makes up an important part of transport. It should therefore be a target of climate policies that aim to reduce greenhouse gas emissions from transport. Commuting has long been an important target of transport policy and urban planning, because of its regular pattern, its close connection with congestion problems, and its association with people's choices about locations of work and housing (van de Covering and Schwanen, 2006). Where people live influences their overall travel behaviour for extensive periods of time. In this study we use the term "commuting" to denote one-way journeys to job destinations. We concentrate on commuting at a regional scale and consider both intra- and intercity journeys. For the study of GHG emissions from commuting, we will focus on two aspects of commuting patterns and behaviour, namely commuting distance and transport mode choice. We give special attention to car use in view of its disproportional contribution to GHG emissions. In addition, the relationship between commuting distance, commuting time and transport mode is discussed. We find it advantageous to consider this relation since commuting distances, while relevant from a planning perspective, may be overlooked by travellers who may be more sensitive to variations in commuting time costs.

Many studies deal with the question concerning which factors underlie increased commuting distances and car usage. We review planning studies, economic studies, and studies from environmental and social psychology (i.e., behaviour studies). These three perspectives will be offered and from the insights gained we will identify a set of core factors, and then apply this to obtain a policy package for the Barcelona Metropolitan Region (BMR) in Catalonia (Spain). We do not consider here reducing carbon intensity of energy used for commuting since this has been analysed elsewhere (e.g., Chapman, 2007; Ison and Ryley, 2007; T&E, 2006). In 2006, commuting made up 15.8% of the total number of journeys made within the BMR. In contrast to personal-purpose journeys (e.g., for shopping or daily leisure), commuting journeys usually involve

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relatively long distances, much time, and the use of motor vehicles (either public transport or private vehicles) (Miralles-Guasch, 2011). In addition, commuting journeys are more scattered now and, thus, are not easily served by public transportation leading to an increase in the relative share of the use of the private vehicle. Changes in modal split and commuting distance have obvious repercussions in the amount of emissions. Vehicle traffic is the principal source of GHG emissions in Barcelona, being responsible for 30–35% of total emissions for the period 1987–1996; only between 3.8% and 4.2% of the total CO_2 emissions from transportation in Barcelona originates from public transportation, even though this accounts for 55% of the total number of journeys made within the city (Baldasano et al., 1999). All in all, the BMR is a relevant case for studying commuting patterns in relation to GHG emissions and environmental policy. Our contribution to the literature on commuting transport and its use of energy and related emissions is thus threefold: development of a framework based on the extensive literature on commuting and its factors; derivation of an environmental policy package addressing GHG emissions from commuting; and an application of these to Barcelona.

Similar studies to ours are found for large metropolitan areas, such as New York and London (Hickman et al., 2009, 2010, 2013; Sperling and Gordon, 2009). Hickman et al. (2013) mainly focus on reducing emissions from transport by investing in planning of, and infrastructure for, public transport in London and Oxfordshire metropolitan regions. Here we adopt a broader perspective, including a larger set of commuting determinants (factors) which allows us to derive a wider palette of policy options. Hickman et al. (2009, 2010) have a similar scope to ours, but focus on backcasting techniques, scenario-building and transport and carbon simulation models. Our study can be seen as complementary to these studies in that it aims to identify the full set of commuting factors (for the BMR). It should further be noted that the earlier studies do not deal specifically with commuting as we do, but instead address transport in general, including all personal journeys, freight transport and aviation.

The remainder of this article is structured as follows. Section 'Commuting distance and transport mode: three perspectives' contains a literature review of the factors underlying commuting, and presents three distinct perspectives that offer a basis for policy design in the case study later on. Section 'Policy mix to reduce GHG emissions due to commuting' discusses general elements of a policy package for reducing GHG emissions of commuting. Section 'Application to the Barcelona Metropolitan Region (BMR)' presents the case study of the BMR. Section 'Conclusions' concludes.

Commuting distance and transport mode: three perspectives

In subsequent subsections we identify the major factors underlying commuting based on a review of the literature. These factors include built environment (BE), transportation factors (TF), market factors (MF), socioeconomic factors (SE) and behavioural factors (BF). They are summarised in Table 1, while their relationship with the core factors of GHG emissions from commuting are depicted in Fig. 1. It should be noted that these factors are not independent but some of their components may affect or correlate with those in others. In addition, a sixth factor ''policy and regulation'' can influence all of the factors. Together, the factors provide a framework to design a policy package to reduce GHG emissions from commuting (Section 'Policy mix to reduce GHG emissions due to commuting').

Table 1 combines the many suggestions found in the broad literature on commuting, which is reviewed in subsequent sub-sections. The table can thus be seen to provide a close to complete picture of all the factors that determine commuting. In view of the broadness and completeness of the framework, it is impossible to offer a fully quantified analysis approach as many factors defy quantification. As a result, we are forced to use a qualitative approach of analysis.

Commuting distance versus time

Commuting distance and time are related through speed. Improvements in private vehicles and public transport have allowed commuters to travel longer distances at higher speeds within the same time (Metz, 2004). Information about commuting distance is especially relevant from a planning perspective, while commuting time and time perception are more relevant to the individual and thus to understand their choices regarding commuting distances and transport modes. Average commuting times for many metropolitan areas have been rather constant over time, known as the ''commuting time paradox'' (van Ommeren and Rietveld, 2005). This has led to the idea that an upper bound to commuting time may exist, that is, a time threshold below which workers are indifferent to commuting distances (Rouwendal, 2004). This threshold is suggested to be about one hour for total daily travel. The results of Rouwendal and Meijer, (2001) indicate that commuters may change their residence when commuting time exceeds one hour. An explanation for this one-hour budget time is competition between various uses of time during the day (Metz, 2004; Mokhtarian and Salomon, 2001). To compare, the

Table 1
Factors underlying commuting patterns.

Built environment (BE)	Transportation factors (TF)	Market factors (MF)	Socioeconomic factors (SE)	Behavioural factors (BF)
• Urban density (i.e., employment and residential densities) • Diversity of land uses (balance of jobs and houses) • Design of street and transport networks • Design attributes of the neighbourhood • Destination accessibility • Regional accessibility • Urban form • Distance or access to public transport (including infrastructure)	• Average travel time, reliability and punctuality (travel time variability), • Uncertainty about occurrence of unpredictable events (e.g., vehicle breakdown, accidents) • Level of service of public transport • Parking opportunities • Congestion (peak and off-peak periods)	• Labour market imperfections (search and moving costs, imperfect information about job offers and uncompensated commuting costs) • Housing market imperfections (search and transaction costs, regional/local price differentials) • Transport market imperfections (transport price and the cost of commuting affect both distance and mode)	• Age • Gender • Income • Level of education • Professional category • Occupational status • Household structure (dual-career, children)	• Self-selection bias • Activity patterns and lifestyle • Past behaviour and habits • Norms • Status seeking behaviour • Emotions

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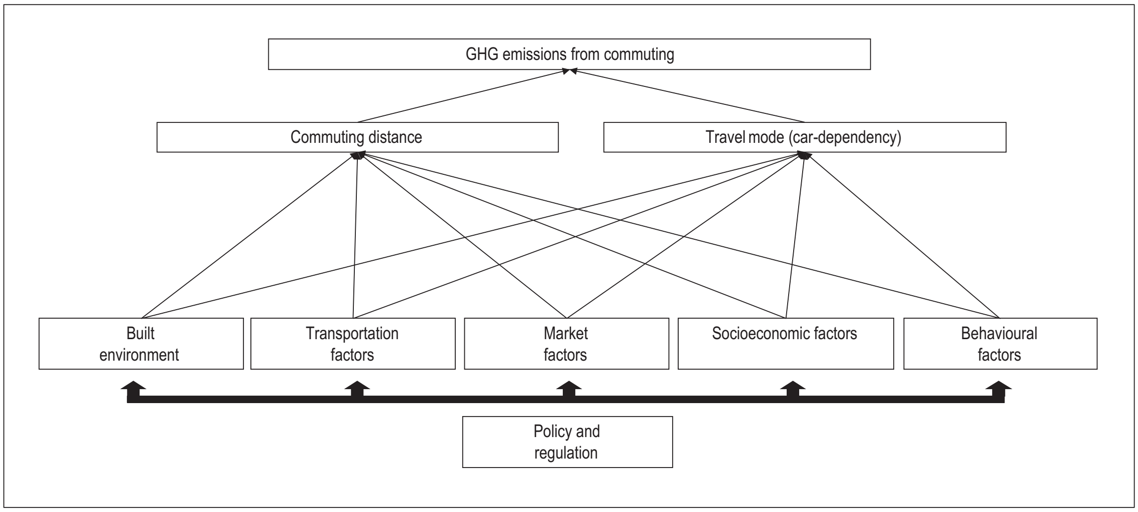

Fig. 1. Multi-level relationship between core factors, commuting dimensions and GHG emissions.

average daily commuting time for EU15 and Spain is 37.5 min, while it is 48.8 min for the US, that means they all are below one hour (Stutzer and Frey, 2008). The threshold may not just depend on the cost of commuting, but on other variables too, notably socioeconomic characteristics (e.g., income, employment status, and car ownership) and the spatial distribution of job offers around an individual's residential location (Mokhtarian and Chen, 2004; Rouwendal, 2004).

Three perspectives for policy: the planner, the economists and the behaviourist

Here we offer three perspectives on commuting that help us to organize the literature on factors of commuting. Moreover, these provide a clear basis for developing later, in the BMR case study, three distinct policy packages.

The planner

Planning studies focus on the provision of a supportive built environment. The aim is to indirectly influence commuters' travel behaviour through the alteration of the three dimensions of the built environment: land-use patterns, the transport system, and design features that are both functional and aesthetic (Handy, 2004). Variations in commuting distance and travel mode choice are commonly related to changes in the built environment. In particular, increases in commuting distance are regarded to be due to dispersion and urban sprawl, which in turn intensifies commuters' car usage (Anderson et al., 1996). Sprawl is generally considered undesirable as it raises commuters' transport costs as well as the costs of transport supply (including infrastructure). Actual elements of the built environment affecting commuting distances and transport mode used for commuting have been extensively researched. Surveys are offered by Cervero and Kockelman's (1997), Ewing and Cervero (2001), Handy et al. (2002), Handy (2004), TRB (2005), and Ewing and Cervero (2010).[1] Seven "D factors" are brought about (Table 2).

Urban form the spatial arrangement of jobs, homes, and the transport network that connects them (infrastructure)—determines commuting distance. A distinction is made between: traditional monocentric forms, where jobs concentrate in the CBD, and commuting distances are theoretically minimal; and polycentric forms, where journeys are shorter for better regional and destination accessibility, higher density (especially at destination), and more intermixing of land uses. At a local scale, diversity of land uses (jobs-housing balance) has the greatest impact on commuting distance (Horner, 2007). Transport mode choice depends on destination (job) accessibility, which has the strongest influence on car choice. Long distances act in favour of car usage and the opposite holds for "active commuting" (i.e., walking and cycling). Density and diversity variables have a substantially lower influence on car use. The second most important factor of modal choice is design features. The reason is that they favour more diversity of routes; mainly intersection density (grid pattern of street network) and street connectivity characteristics (i.e., directness of routes through the network and availability of route alternatives). For walking, other design characteristics like neighbourhood aesthetics, scenery and traffic turn out to be somewhat relevant, but less so than for "leisure walking". Public transport modalities like bus and rail depend very much on public transport accessibility.

A relevant issue in identifying the effects of the built environment on commuting decisions is the so-called self-selection bias. This denotes that commuters may anticipate their travel mode decisions –whether walking, cycling, public transport or driving a car – and choose a house location that matches them (Handy et al., 2005a,b; Handy and Mokhtarian, 2005; Cao et al., 2002). The possibility of self-selection casts doubts on a firm causal relationship between the built environment and commuting behaviour, something that should have implications for transport and spatial planning (e.g., Giuliano, 1991; Giuliano and Small, 1993; Handy, 2005; Handy et al., 2005a; Sohn, 2005).

It is remarkable that similar urban forms show sharp differences in commuting patterns. Evidence for this is provided by empirical studies, especially those on "excess commuting". These highlight the crucial role of location choice, and the criteria that commuters employ to arrive at their decisions (Section 'Three perspectives for policy: the planner, the economists and the behaviourist', economic perspective). Næss (2009), however, argues that the existence of self-selection just stresses the importance of the built environment. In a study for Copenhagen, he provides empirical evidence that re-locating to live far from (or close to) the city centre has a positive (negative) impact on the use of motor modes after controlling for self-selection. This is

[1] Ewing and Cervero (2001) included 14 studies, Handy et al. (2002) reported over 70 studies published during the 1990s, Handy (2004) reviewed 22 studies, TRB (2005) overlaps with Handy (2004) and other studies, and Ewing and Cervero (2010) revised over 200 studies from which, finally, 62 were used to undertake a formal meta-analysis.

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attributable to differences in neighbourhood spatial features (typology), as well as journey-related choices, like engagement in activities, activity locations, route and travel mode choices. In addition, such location choices influence household commitments and attitudes towards the car. Findings like these still offer support for planning policies to create neighbourhood attributes that discourage undesirable transport choices.

The economist

The *economist* regards commuting as a costly activity without any value or utility in itself (Banister, 2008). Workers should therefore be directed at minimising their commuting costs. In line with this, economic studies focus on an efficient spatial location of workers and economic activities. Initial research was limited to explaining transport and its relation with job and residence locations as a function of transport costs and housing prices, with decisions being constrained by income (or budget in the case of economic activities) (Alonso-Muth-Mills type of urban bid rent models). Households seek "the best value for money" (i.e., they are assumed to be rational – maximising their utility) which translates into the largest, best located, and cheapest houses (Wong, 2002). Three trade-offs are expected: location *vs.* price, size *vs.* price and size *vs.* location.

This approach has its flaws. Individuals possess imperfect information about housing options which makes them rather choose "satisficing" options. A more extreme form of bounded rationality is that people show strong preferences for certain locations and dwelling types, regardless of how costly they are in terms of travel and commuting, notably in the case of detached houses near the countryside (Rouwendal and Meijer, 2001). Strong differences exist in this respect between households with and without children. Individuals may evaluate elements other than commuting or job-residence location (e.g., aspects related to quality of life, such as environmental or neighbourhood amenities) (Feng, 2008). Further, prices of transport do not reflect their external costs, and workers do not seem to be generally and fully compensated for increased commuting disutility in labour and housing markets (Stutzer and Frey, 2008).

Subsequent studies acknowledge these limitations and explore constraints other than prices and income that prevent individuals from choosing optimally, such as coordination of choices in dual-career households and imperfect information (van Ommeren et al., 1998; van Ommeren, 2000). Commuters express bounded rationality in their location choices, while information is costly and changing job or residence generates both pecuniary and non-pecuniary costs (Larsen et al., 2008). Van Ommeren and van der Straaten (2008) found that about 40% to 60% of daily commuting time (46 min; van Ommeren and Fosgerau, 2009) is due to job search frictions, including imperfect information about job offers. Workers of high professional categories are most affected since job offers matching their qualifications are relatively scarce.

Generally household members change jobs more often than they change residences. Indeed, travellers are often reluctant to change housing location after a job relocation within the same metro region (Coulombel, 2011). The reason is that relocating is costly and gains in job-residence distance are perceived to be small. House owners seem to be more reluctant to change their residential location than renters. This is partly due to considerably high taxes associated with buying a house, resulting in house owners facing higher moving costs than renters. Van Ommeren and van Leuvensteijn (2005) note that taxes on house purchasing, very common in OECD countries, reduced residential mobility of house-owners in The Netherlands by 50%; this is usually interpreted as the effect of transaction costs (i.e., moving costs from re-location) on the length of commute, which is generally found to be larger for owners than for renters (Larsen et al., 2008).

Models of transport mode choice assume that commuters choose the most convenient option based on the specific attributes of each mode (Handy, 2004). Examples of such attributes are monetary and time costs (e.g., average travel time including in-vehicle time, waiting and time lost in transfers or parking), punctuality and reliability (travel time variability), uncertainty about unpredictable delays caused by, for instance, accidents and vehicle breakdowns, and comfort. However, in the particular case of the car, Gardner and Abraham (2007) find a systematic underestimation of car-related monetary costs, as well as a misconception of actual journey times for car and public transport. Modal choice is further studied as a function of people's socioeconomic profiles. Such studies often fail to capture all variability in travel mode choices (Anable, 2005). Gender differences in modal choice, notably regarding car usage, are well recognised (e.g., Law, 1999; Polk, 2004); on average women use the car less than men. This difference, however, seems to be getting smaller; women, notably working mothers, are moving towards a level of car usage equal to that of men in countries like the USA and Australia (Brown et al., 2003; Dowling, 2000). Behaviour with respect to age, which is largely connected to life-cycle variation in commuting behaviour (Ryley, 2006), seems to differ between territorial spaces. For instance, elderly people from USA or north-European countries, like UK or The Netherlands, tend to make much use of the car, whereas in Spain they often walk or use public transport (bus) (see De Witte et al., 2013). Results for income and professional category seem to yield rather consistent results; high income and high professional categories are correlated with frequent car use (Lucas, 2012).

The behaviourist

Transport studies on socio-psychological determinants of commuting behaviour focus mainly on travel mode choice. A notable share of driving does not respond to convenience, and for some drivers perceived barriers to modal change cannot be objectively measured, such as in terms of access or time and money costs (Goodwin, 1995). As highlighted by Handy et al. (2005b), the distinction between driving by choice or necessity is not always clear, yet it is important for policy. For necessary car journeys, planners can explore ways of reducing journey distances and facilitate public transport usage. For driving by (voluntary) choice, policy design is more complicated since psychological bounds to the car are not easily broken and behavioural changes are not easily achieved in this case. Burnett and Hanson (1982) distinguish between three alternative types of travel behaviour: namely, habits that are not easy to change because individuals do not consider alternative options; "avoidance behaviour" —individuals preferring to deviate from more economically desirable (cheaper) and more feasible options; and constrained choices— institutional constraints prevent choosing individually desirable options.

A large number of behavioural theories and models have been put forward for transport studies, which encompass these insights and explore a wide range of modal choice determinants (e.g., Bamberg et al., 2007; Bamberg and Schmidt, 2003; Carrus et al., 2008; Hunecke et al., 2001; Klöckner and Matthies, 2004). Relevant factors analysed are habits (e.g., Triandis' theory of interpersonal behaviour), attitude, perceived social pressure (e.g., social (dis) approval of certain behaviour), perceived constraints (Ajzen's theory of planned behaviour), feelings and emotions (attached to driving, like of freedom, shame, guilt or pride) (e.g., Perugini and Bagozzi's model of goal-directed behaviour), and personal norms or moral obligations to behave in a certain (sustainable/pro-social) way (e.g., Schwartz's norm activation model).

Particularly for commuting mode choice, habitual driving appears to be a key issue (Aarts et al., 1998; Gardner, 2009). Commuting trips are repetitive and create routines that are difficult to break (i.e., habitual choices are taken unconsciously and information about alternatives is ignored), and that can be generalised across other travel contexts. For example, the habit of driving to work every morning can be generalised into making all morning journeys by car (Verplanken and Aarts, 1999). In addition, Schwanen et al. (2012) argue that social pressure favouring car use may help reinforce or contribute to the formation of driving habits. Social influence and perceived constraints can also hamper conscious intentions to quit driving. Abrahamse et al. (2009) observe that leaving the car is a form of altruistic behaviour which may develop when personal norms (e.g., environmental concern) are strong enough and changing to alternatives to the car is perceived as easy and feasible. The formation of personal norms for public transport usage is influenced by negative feelings of guilt and social pressure (Bamberg et al., 2007; Carrus et al., 2008). Popuri et al. (2011) adds to these findings by noting that positive perceptions about public transport of friends and family contribute to preferences for public transport use. Indeed, studies by Steg (2003, 2005) suggest that car use for commuting is better explained by social and affective motives than by instrumental or functional motives (e.g., speed, flexibility, comfort, reliability, etc.). Males and young people give relatively more importance to symbolic and affective factors, for them the car expresses status and freedom and independence. Anable and Gatersleben (2005), however, show that instrumental attributes are more important in commuting while for leisure trips both instrumental and affective factors are equally valued.

Policy mix to reduce GHG emissions due to commuting

Based on the insights of Section 'Commuting distance and transport mode: three perspectives', in what follows we suggest policies to reduce GHG emissions from commuting. We do not discuss here political feasibility, although we are well aware that policy does not have all degrees of freedom as it is deeply politicised. Policy measures are proposed in Table 3, derived from the framework. The design of the policy mix was inspired by Banister et al. (2000). Policy measures affect the two core transport mechanisms (i.e., targets in third set of columns): reduced commuting distances and promotion of a modal shift to sustainable modes. Most measures affect several factors simultaneously (fourth set of columns), even though they are designed in order to address (a) particular factor(s) specified in the first column. The fifth set of columns assesses various policy features including policy strategy, type of policy instrument, effect and time horizon.

Policies affecting the built environment through changes in urban spatial structure can be used to concentrate population and economic activities in places already served (in terms of public transport, too) and with high intermixing of land uses (Nijkamp, 1994). These measures mainly target commuting distance, but also stimulate modal shift. At the same time, limits are needed on the proliferation of low-density building projects. Two ways to avoid this are direct prohibition or increasing the costs to promoters for their construction.

The main policy measure aimed at correcting both spatial structure and transportation factors is the design or adaptation of the public transport network to spatial developments (while of course spatial developments might also adapt to, or be limited by, public transport networks). In this line, existing low-density residential and employment centres should be provided with alternatives to the private car (e.g., public transport and if not cost-effective, private collective transport that could be motivated by neighbours or firms themselves). These types of sites are big emitters and receivers of commuters, respectively. The purpose is, then, to facilitate modal shifts especially in those places and for those journeys that are car-oriented.

Main policy measures targeting transportation factors seek to increase the energy efficiency of vehicles, so as to reduce emissions per kilometre and local air pollution (e.g., by means of speed limits). Measures further intend to make driving undesirable and, thus, are mainly oriented to promote modal shift.

Other market measures target housing and labour market imperfections, namely searching and moving costs. They affect individual locational decisions and influence both commuting distance and modal split. A complementary measure is to provide affordable housing in strategic sites (i.e., CBD, sub-centres and network nodes). This is directed at low and middle income groups and young households, the groups having affordability problems with housing.

Behavioural factors are more difficult to tackle, mainly due to a lack of understanding of complex commuting behaviour. We propose measures aimed at raising awareness about transport externalities and promoting pro-environmental practices, as well as informing about the benefits of optimally choosing a location

Table 2
Features of the built environment influencing commuting behaviour.

Feature	Definition	Measurable indicators	Commuting distance and travel mode affected
Regional accessibility	Distribution of activities and transportation facilities across the region	Proximity to the CBD, rate of decline in density with distance from the CBD	Commuting distance, walking, car use
Urban density	Amount of activity concentrated in a given area	Population, dwelling units, employment, building floor area per unit of area	Commuting distance
Diversity of land uses	Number of different land uses and the degree to which they intermix	Entropy measures of diversity, index of dissimilarity, jobs-to-housing ratios	Commuting distance, walking, public transport use
Design of street and transport networks	Availability of alternative routes through the network	Density of intersections, street connectivity, sidewalk coverage, and continuity, etc.	Commuting distance, walking, public transport use, car use
Design attributes of the neighbourhood	Attractiveness and appeal, and other physical variables that differentiate pedestrian-oriented environments from car-oriented ones	Average street widths, number of trees on streets, presence of amenities, traffic intensity, safeness	Walking
Destination accessibility	Proximity of destinations (i.e., job accessibility)	Distance to journey destination, facilities reachable within a given distance or time	Commuting distance, walking, car use
Distance or access to public transport	Proximity to public transport stops/stations	Shortest street routes from homes/jobs to the nearest stop/station, density of routes of public transport, distance between stops, density of stations	Public transport use

Based on Handy et al. (2002), and making use of insights from Cervero and Kockelman (1997), Ewing and Cervero (2001, 2010), Handy et al. (2002), Handy (2004) and TRB (2005).
Notes: CBD = central business district (where jobs are concentrated).

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Table 3
Suggested policies derived from the factors underlying commuting.

Main factor(s)	Policy measure	Targets		Factors[a]					Policy features	
		Journey distance	Travel mode	BE	TF	MF	SE	BF	Policy strategy[b]	Policy instrument[c]
BE	Internalisation of *full* transport costs in low-density building projects	*	*	**	*				PPM	P
	Prohibition of low-density building projects	*	*	**	*				PPM	C
	Changing the function of existing buildings at strategic sites with high accessibility – e.g., city centre and network nodes	*	*	**	*				PPM	C
BE/TF	Adaptation of the design of the public transport network to spatial developments and vice versa		*	**	**			*	SOP, PPM	I
	Provision of existing low-density residence/employment spaces with public transport		*	**	**			*	SOP, PPM	I
	Provision of park-and-ride facilities in stations close to low density residential areas		*	**	**			*	PPM, SOP	I
	Designation of environmental zones with limits on high-pollutant vehicles (e.g., city centres)		*	**	**			*	DOP, PPM	C
TF	Give public space to sustainable modes and promote street connectivity		*	*	**			*	SOP, PPM	I
	Speed limits in congested areas to lower pollution and make them less attractive, automatic speed control	*	*		**			*	PPM, DOP	C
TF/MF	Variabilisation through increase of fuel tax + remove fixed road tax	*	*		**	**	*	*	DOP	P
	Congestion charges for rush hours or certain transport zones		*		**	**		*	DOP	P
	Parking charges and controls (e.g., in zones were driving is intense and that are well served by public transport, like city centres and certain business districts)		*		**	**		*	DOP	P,C
	Feebates on new cars dependent on emissions/fuel consumption		*		**	**		*	DOP	P
	Concessionary fares for public transport based on social purposes (young, elders, and more generally low income groups) and economic incentives for public transport use to break-down car habits		*		**	**	*	**	DOP	P
MF	(Economic or social) incentives for those living close to their jobs	*	*	*		**	*	*	PPM	P
MF/TF/SE	Substitute taxes on owned housing by road taxes	*	*	*	**	**	**	*	PPM, DOP	P
MF/SE	Incentives to rent	*		*		**	**	*	PPM, DOP	P
MF/BF	Centralised (public) web-site to diffuse information about job offers	*	*	*	*	**		**	TEC, DOP	K
BE/SE	Build social housing at strategic sites with high accessibility — CBD, employment subcentres (if possible), and network nodes	*	*	**		*	**	*	PPM	C, I
BF	(Injunctive) normative messages on transport externalities and sustainable modes	*	*					**	DOP	K
	Normative messages (descriptive or injunctive, depending on the case) about environmentally sustainable settlements	*	*					**	DOP	K
	Campaigns offering re-location solutions for dwellers	*						**	DOP	K
	Temporary road closures and withdrawal of parking spaces to break-down driving habits (e.g., in roads/zones where driving is intense and public transport alternatives exist)		*		*			**	DOP	I
	Temporary incentives for public transport (e.g., a free-period ticket) to create new habits of using public transport		*				*	**	DOP	P
	Innovative transport measures[d]		*		*			**	DOP, SOP	C, I, K
	Application of IT-systems to public transport systems to decrease uncertainty about reliability and waiting/transfer times		*		**			**	TEC	K
TF	Real time information on road congestion to divert traffic from congested roads		*		**	*		*	TEC	K
All	factors affected	Public (and								stimulating private)
	investments in R&D								TEC	K
	Computerized emission control via electronic sensors (monitoring)								TEC	K

Inspired by Banister et al. (2000).
Notes: The stars (*) mark means there is an impact of a given policy (second set of columns) on the two core aspects of commuting considered (targets in third set of columns) and the factors (fourth set of columns). A distinction is made between main factors (**) and other factors (*) being affected.
[a] 'BE' (built environment), 'TF' (transportation factors), 'MF' (market factors), 'SE' ([individual] socioeconomic factors), 'BF' (behavioural factors), 'CF' (contextual factors) column titles relate to the specific factor affecting the three outlined targets.
[b] 'DOP' (demand-oriented policies), 'SOP' (supply-oriented policies), 'TEC' (technology policies), 'PPM' (physical planning measures) column titles relate to the policy strategy.
[c] 'P' (price-based instruments), 'C' (command-and-control measures), 'K' (knowledge, information, and moral suasion) and 'I' (infrastructure) indicate the type of policy instrument.
[d] Individualised marketing, "deliberation intervention", car-sharing, car-clubs, car-pooling, PAYD, public transport traveller information systems, fuel-efficient driving, etc.

for living and working. Regarding the provision of information, Cialdini (2003, 2007) proposes to raise the effectiveness of the informative message by capturing people's normative concerns. This is using injunctive norms (perceptions about socially approved behaviours) when the intention is to change environmentally undesirable but socially extended behaviour, and descriptive norms (perceptions about behaviours socially extended) when pro-environmental behaviour is sufficiently extended.

For habitual car users, however, the provision of information may not be enough since drivers with strong habits are less responsive to new alternatives and new information. Proposed measures to alter habitual driving are changes in the structure of the physical environment, like temporary road closures or withdrawal of parking spaces (Brown et al., 2003; Fuji et al., 2001), so-called "deliberation intervention", which makes travellers more aware of their decision-making process, indicating clearly decision alternatives (Carrus et al. 2008), and monetary incentives to use alternatives to the car (Fujii and Kitamura, 2003). These types of interventions promote the conscious re-thinking of travel mode options available. The effects of monetary incentives, however, should be monitored since crowding-out effects might occur (Gneezy and Rustichini, 2000). In addition, so-called innovative transport measures can be considered, like individualised marketing, car-sharing, car-pooling and the formation of car clubs, as well as fuel-efficient driving and public transport traveller information (Banister et al., 2000).

Verhoef and van Wee (2000), propose to address the issue of car and status through feebates on new cars dependent on emissions/fuel consumption. In this case, feebate application is to vehicles for achieving increased fuel efficiency. The amount of the feebate applied to the purchase price of a vehicle is determined by the relative fuel efficiency of a vehicle; if the vehicle has higher fuel efficiency than average, it receives a rebate; if the fuel efficiency is lower, a fee is assessed (Davis et al., 1995). The feebate may vary in direct proportion to fuel consumption or emissions, the most straightforward design. Feebates can further be made fiscal-neutral (Verhoef and van Wee, 2000).

Some of the measures included in the list deserve more attention and may need a deeper explanation. For instance, variabilisation through an increase of fuel taxes while removing fixed road taxes is proposed for several reasons. First, a fuel tax, when set sufficiently high, is one of the most effective measures to reduce emissions (see Sterner, 2007). Second, pricing mechanisms increasing the variable costs of driving (i.e., fuel taxation, kilometre tax, road pricing, congestion charging, parking charges, insurance tax) have proven to be more effective than those raising fixed costs for owning a car (Dargay, 2008). Third, factors like vehicle price, fuel consumption, size, reliability, and comfort affect car purchasing (i.e., vehicle type, fuel-efficient or less polluting vehicles) more than incentives like emission charges per kilometre (Dargay, 2008). Such factors tend to be more important than environmental considerations.

Regulatory measures, such as emission standards, are not useful in reducing car use and emissions from actions like speeding, rapidly accelerating and cold starts (Banister et al., 2000; Proost and van Dender, 2001). Standards may here achieve reductions in urban air pollution from motor vehicles (e.g., regulating fuel components and emissions from exhaust pipe engines, and ultimately from combustion engines), but limiting car usage is not their purpose and so only part of the actual emissions is affected by them.

Some reductions in fuel consumption will also be achieved by increased fuel efficiency. However, energy efficiency alone will not make a substantial difference in the short or medium term. Available technology has limitations and technological innovations will only be effective in the period after 2020 if a strong policy driving them is implemented now (Hickman and Banister, 2007).

To correct housing market imperfections one can substitute house-moving taxes (also known as "transfer taxes") by road taxes as suggested by Larsen et al. (2008). They argued that empirical findings show that road pricing affects the location choice of households and firms by increasing travel expenditures. On the other hand, taxes on owned housing exert the opposite effect; they increase transaction costs and discourage households to relocate close to their jobs. Their suggested tax correction only holds for commuters who own their house as other road users do not face such a barrier in changing house location. Removing housing taxes, however, may have side-effects, such as mobilisation of capital investments into housing, and tax evasion by owners of multiple properties (including second residences). The removal of the tax should apply only to first residences and involve all members of the household registered within it. In this way, owners of multiple properties could not register their relatives as living in their second residences to skip paying housing taxes.

A well-known problem with taxes, and this applies to all economic incentives proposed here, is that they need to be set high enough to be effective. This may cause equity problems among different socioeconomic groups with the possible outcome of poor people being disproportionately affected (e.g., in the case of regressive taxes). Proost et al. (2002) suggest that the best way to deal with equity issues is via specific income supplements (e.g., bringing down distortionary taxes, such as labour taxes), rather than via reduced transport prices. This means using the net revenue from the transport sector to correct for spatial and social inequities. Another issue in implementing pricing mechanisms is that they are often subject to public rejection. However, acceptability can be raised by publicly explaining how revenues would be used (recycling to tax payers or investing).

Although we have proposed concessionary fares for public transport based on social purposes, these incentives should be independent from receiving net revenues from optimal pricing in the transport sector (Proost et al., 2002). Our support for incentives for public transport use is based on studies suggesting that changing the relative cost of the two modes (i.e., public and private) will influence personal transport choices (e.g., OECD, 2008b).

Application to the Barcelona Metropolitan Region (BMR)

This section applies the set of factors identified in Section 'Commuting distance and transport mode: three perspectives' and general policy insights of Section 'Policy mix to reduce GHG emissions due to commuting' to the case of the Barcelona Metropolitan Region (BMR) (see Fig. 2). We have based our study of the BMR on the insights from empirical studies and official reports, which used primary data sources of general mobility surveys.[2] In some cases, data from the population census track were consulted as well (IDESCAT for several years).

An overview of the two aspects of commuting considered shows that in 2006 commuting made up 15.8% of the total number of journeys made within the BMR (the latter was equal to 2,528,365 one-way journeys to job destinations). Of these journeys 19.3% were made walking, 24.7% were made by public transport and 56.0% by private vehicle. Average commuting time (one-way journey) was 24.15 min.[3] Commuting distances are indirectly calculated (journey lengths were measured in min); in 2006 the proportion of population living and working in the same municipality was of 47.4% (Oliver-Frauca, 2010).[4]

Built environment

The BMR has a large, diverse and compact centre (the municipality of Barcelona); an extremely dense first metropolitan ring formed of housing estates and industrial parks physically connected to Barcelona, with discontinuities in the form of agricultural

[2] Two main series of general surveys are available for the BMR, which include aspects of commuting behaviour, namely the *Survey of living conditions and habits of the population of Catalonia* (ECVHP, acronym in Catalan) and the *Survey of Daily Mobility of Catalonia* (EMQ, acronym in Catalan). While the latter is specific for daily travel behaviour, the former includes also other general aspects of travellers' lifestyles.

[3] Calculated from data in*Survey of Daily Mobility of Catalonia 2006* (EMQ 2006).

[4] Estimating commuting distance from journey lengths has limitations, since the speed of commuting may be different depending on the travel mode chosen and traffic situation. However, general surveys do include information on the origin and destination of journeys, thereby facilitating accurate estimates of distance.

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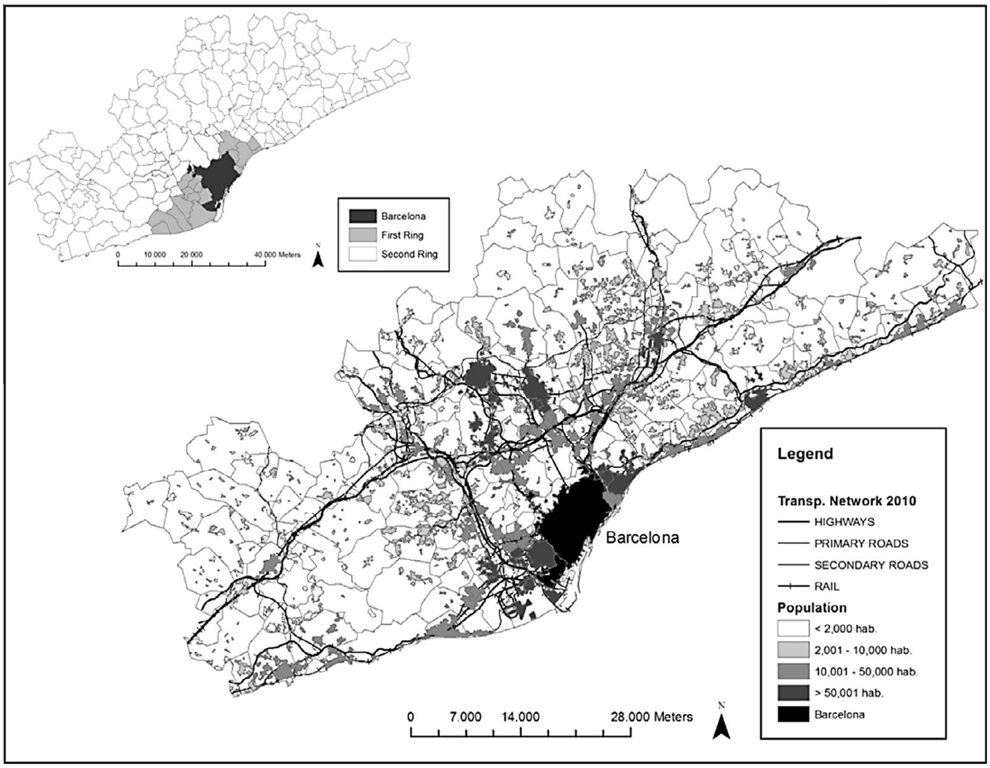

Fig. 2. The Barcelona Metropolitan Region (BMR) with main features of the transport network, urbanised areas and populations of the municipalities; the small overview map shows the division of the BMR territory into Barcelona city and the two metropolitan rings (figure on top).

land and peri-urban natural parks; and a second metropolitan ring comprising seven traditional satellite cities or sub-centres and their corridor areas, as well as an extensive area that combines both rural and low-density residential uses (Muñiz et al., 2003). The satellite cities were traditionally independent in terms of labour and services and have until recently been big attractors of population and employment. The region as a whole has a polycentric form in spite of dispersion trends (Trullén and Boix, 2000; García-López and Muñiz-Olivera, 2007; Garcia-Lopez, 2010).Trends that promote commuting are the spatial segregation of economic sectors (i.e., zoning of tertiary, industrial and construction sectors), and a sharp decrease in the number of people that work in the municipality where they reside. Noteworthy is the proliferation of so-called "exclusionary spaces", suburban low density residential areas and industrial parks, mainly car-oriented (Cebollada and Miralles-Guasch, 2010). Studies confirm that persons without access to a private vehicle, while living and working in these exclusionary spaces, can see their personal mobility compromised, with the result of being disadvantaged in the labour market (Cebollada and Miralles-Guasch, 2008; Cebollada, 2009; Miralles-Guasch, 2010).

Transportation factors

Motorised modes, and especially private vehicles, dominate commuting trips within the BMR; the proportion of commuting trips made by motorised modes in 2006 was on average of 84.3% (52.7% private vehicles, 25.9% collective public transport, and 1.2% multimodal trips). In addition, data shows a decrease in non-motorised modes in favour of the private vehicle in the past two decades (the use of public transport remains almost unchanged) (Nel·lo, 2010). When distance precludes walking or cycling to work, the choice between public and private transportation in the BMR is very much conditioned by territorial differences in accessibility to public transport services; (lack of) access to public transport. Accessibility decreases with distance to Barcelona city, the (public) transport network of the BMR is radial and has not yet accommodated the most recent dispersion trends taking place mainly in the Second metropolitan ring, which explains a spatial mismatch between its demand and supply. In addition, Matas (1991) and Asensio (2002) identify quality and reliability of public transport services as further relevant factors. Private vehicle usage further increases with car access, namely with the number of vehicles in the household, and with access to a parking Oliver-Frauca (2010). About 77% of households have access to a car and 17% to a motorcycle in the BMR. The Second ring has a larger proportion of households with more than one car, related to houses here being larger and commonly including a garage. In Barcelona city the proportion of households without vehicle however is rising (from 29.3% in 2000 to 33.3% in 2006). Commuters with parking access at destination (job location) drive more (60% use the car) than those without parking (43.5% use the car). Only 9.7% of commuters with parking access use public transport versus 34.0% of commuters without parking using public transport.

Labour market factors

The incidence of temporary jobs is in the range 85.85–88.84% for the period 1998–2011 (IDESCAT, 2012). Temporary workers are continuously engaged in the search for another job (Dolado et al., 2002), thus incurring higher job-searching costs (Kahn, 2012). Moreover, workers with fixed-term contracts have lower salaries (Dolado et al., 2002), so they cannot afford housing in certain locations and may not be able to afford residential moving costs either. There is a low residential mobility for work purposes. With regard to workers' location adjustments, between the motives for residential movement declared among the population of the BMR in the *Survey of living conditions and habits of the population of Catalonia (2006)* (Alberich, 2010), labour motives

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occupied the third position (9.0%), after motives such as housing/environment (44.0%) and family motives (38.5%). Ahn et al. (1999) and Antolín and Bover (1997) also report a very inelastic demand for mobility for working purposes when this implies a change of residence.

Housing market factors[5]

Housing prices increased 130% in the last two decades, mostly in the central city and First ring.[6] Variations in dwelling price and household income, throughout the region, influence the spatial distribution of the population. 82% of householders are owners, but renting is still considered an option within the BMR; renters display a greater number of housing re-location which may favour reduced commuting distances. In the case of Catalonia, however, Artís et al. (2000) found that both house-owners and renters within the controlled rental market (i.e., having almost lifelong renting terms and thus paying very low rents) faced longer commuting lengths (measured in commuting time). In the case of owners, they note that for many households residential moving was not an option to relocate closer to their jobs since they face fixed moving costs that would more than offset the savings in commuting costs. Renters within the controlled rental market, in turn, would see an increase in their rental costs to an amount that would not be offset by savings in commuting costs.

Households' outlay on buying a house (i.e., average annual household expenditure allocated to pay the mortgage on the total income) increased by 26.7% in 2006, with respect to 2000, and varies territorially. Average outlay by households on mortgages[7] has mostly increased in the First ring, where housing prices are approaching those in Barcelona. Outlay in the First ring is now even higher than that of the Second ring, which traditionally encloses large residential areas with more expensive and larger dwellings, but also wealthier people. Traditionally, housing was the cheapest in the First ring and people living there had a low average income level. Barcelona, however, is still where the highest loans are paid, a direct consequence of increased housing prices due to the concentration of population. Housing affordability, measured by taking into account average income and housing prices by area, makes a family from Barcelona allocate 26.5% of its income to locate in this same municipality, 25.6% in the First ring, and just 23.7% in the Second ring. Therefore, housing affordability increases with distance to the region's core for both owners and renters. As a direct consequence, population growth has mainly taken place in small towns and new suburban settlements within the Second ring; between 1996 and 2010 population increased by 7.3% in Barcelona, 11.5% in the First Ring, and 39.6% in the Second Ring (ATM, 2011). The social groups moving to small cities and towns from the Second ring are, generally, low income households with children, women, and young people.

Transport market factors[8]

From 1990 to 2006, the average commuting time (one-way) in the BMR has changed from 22.5 to 24.6 min, an increase of 9.3%. This is despite improvements on the road network implemented between 1990 and 1995 (construction of the "Rondas" in Barcelona and other infrastructure), which temporarily reduced commuting time to 21.4 min in 1995 (Nel·lo, 2010). Transport costs in time and money vary among the mode used and location of residence; both increase with distance to the CBD for those who use motorised modes. The former is connected to distance travelled and access (non-access) to public transport. In this respect, Trullén and Boix (2000) note that inequalities in the provision of transport infrastructures within the region make distinct areas show substantial commuting time differences for same number of kilometres travelled. A majority of commuting journeys made by private vehicles have a length of 15-30 min (48%), while those made by public transport exceed the 30 min (48%). On the other hand, average monthly expenditure in public transport is of €26, while for private vehicles it is about €100, of which 70% corresponds to expenses on fuel and the remaining 30% is split between parking and road toll expenses. Using the car is therefore on average quicker, but more expensive than using public transport. Asensio (2002) notes that rail modes, in particular the metro, are the closest substitute for the car since they incur similar monetary and in-vehicle time costs. Costs allocated to commuting vary with gender, age, professional level and income. Congestion further involves time losses for commuters in the BMR of 69% of the total commuting cost, reflecting a value of time of €7.57 per hour (Domínguez-Varela, 2007). The time-distribution of mobility for commuting purposes shows three daily peak times: 7–9 am, 1–3 pm, and 5–6 pm; peaks of return journeys are less significant since journeys are more time-scattered (Miralles-Guasch and Oliver-Frauca, 2008). During these peak times, traffic is presumably dense, while congestion is presumably at its highest. In 2008, in the BMR, the cost of congestion in terms of productivity loss was estimated at €311 million.

Socioeconomic factors

Travel behaviour differs by age, gender, occupation status, and professional category, with consequences for mobility purposes, commuting distances, and mode choice. General trends in the travel patterns of people, according to their socioeconomic individual attributes, in the BMR coincide with the findings of the literature on the issue (see Table 4). People within studying and working ages display a greater occupational mobility. Men also have greater occupational mobility and make a larger number of commuting journeys, whereas women tend to show a higher mobility for personal motives, and the same holds for those engaged in housework, the unemployed and retired segments of population. Gender differences have usually been attributed to variations in male and female roles. Commuting distance and time differ by gender. Workers belonging to high socio-professional categories drive more, while workers from low socio-professional strata are the ones that walk more to work. Workers belonging to higher socio-professional categories are still the social groups working closer to residence. Workers from lower socio-professional categories commute longer, on average; they form the social group showing greater tendency to work outside their municipality of residence.

Behavioural factors

These are probably the least studied of the factors for the BMR. Studies have mainly focused on individuals' preferences for location of residences and jobs, and commuting mode choice. 60.2% of households prefer to live in a single-family dwelling (Donat, 2010). This is consistent with findings from Artís et al. (2000), dwelling characteristics being a significant factor of commuting in the BMR. Data are available on the motives for mode choice and the levels of satisfaction with the different transport modes. Nevertheless, the results do not allow for the extraction

[5] When not indicated otherwise, information regarding the housing market has been taken from Donat's (2010).

[6] The evolution in housing prices by regime of tenure for Barcelona and other municipalities of the BMR is offered by the Catalan Department of Territorial Policy and Public Works (DPTOP in Catalan).

[7] In the BMR, household spending on a mortgage is, on average, 26.6% of income. This amount increases to more than a third, if the entry and taxation costs are included (Donat, 2010).

[8] When not indicated otherwise, information regarding the transport market has been taken from Oliver-Frauca's (2010).

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Table 4
Commuting patterns for different individual socioeconomic attributes.

Commuting indicator	Age			Gender[a]		Professional category		
	18–24	25–44	45–64	Male	Female	Low	Medium	High
Commuting distance	there is no clear trend			+	-	++	+	-
Commuting time	++	+	–	-	+	++	+	-
Private vehicle use	–	++	+	++	-	-	+	++
Public transport use	++	+	-	-	++	++	+	-
Walking/cycling	+	-	++	-	++	++	-	+

Source: Based on Oliver-Frauca (2010). Data from *Survey of living conditions and habits of the population of Catalonia 2006* (ECVHP 2006, acronym in Catalan).
Notes: Signs ++, +, - and – denote the relative magnitude of the indicator in the respective row for the group in the respective column.
[a] Double sign reflects a gender difference larger than 15%.

of categorical conclusions. Habitual car users seem to be more critical about public transport services and for them more satisfying transport modes are those reinforcing individuality (i.e., motorcycle, walking and cycling). The tram and *ferrocarril* train, which have fewer delays and are less crowded than other collective transport modes, are also among the most preferred modes. Regarding the awareness of environmental and transport externalities, 73.4% recognised co-existence with traffic problems (45.3% perceive them as severe or serious), while just 33.7% perceive severe air pollution and noise (Oliver-Frauca, 2010).

Summary and policy lessons for the BMR

The analysis of factors undertaken reveals interdependencies that are of relevance to understand the particularities of the commuting behaviours and patterns in the BMR. A clear interaction exists between the built environment, market and socioeconomic factors (demographic movements). One interpretation is that population dispersion into small towns and newly constructed low-density residential areas —lacking adequate (public) transport infrastructure and services to accommodate such population growth— is featured by social groups with low incomes (i.e., young couples, women, etc.), which found affordable housing within these municipalities (Nel·lo, 1995). However, in many cases their jobs are located in either the centre or the main employment sub-centres of the BMR, which stimulate car use. With this in mind, one might think that investment in public transport (infrastructure supply) could help correct for excess driving. However, behavioural factors, although comparatively less researched, seem to show a reinforcing pattern; habitual driving may be relevant in affecting perceptions about alternatives other than private vehicles, which in turn may compromise the effectiveness of investment efforts. In this vein, the possibility of self-selection bias (residential location-habitual transport mode) needs to be explored as well. Many more interactions can be linked in this way and policy suggestions can be derived in line with notions stressed in the literature on transport policy: integrated policy development and context-specific policies packaged to target all aspects of travel behaviour (e.g., Hickman et al., 2010).

Table 5 provides an example of how the measures can be combined and packaged to address the interaction between the factors described before. Policy packages (PP) in Table 5 are consistent with the three perspectives presented in Section 'Commuting distance and transport mode: three perspectives', namely planning (PP1), economic (PP2) and behavioural (PP3). As a result, the packages differ in the type of instruments used. PP1 ("Planning") mainly includes planning/infrastructure and command-and-control instruments, PP2 ("Economic") includes price-based instruments, and PP3 ("Behavioural") includes a mixture of informative and price-based instruments.

Policy measures have been selected that address the main factors which stood out in the analysis of the BMR. In choosing a package of measures, attention was paid to avoid potential overlap and assure complementarities between policy measures. Policies reducing car use, for instance, require acceptable alternative transport modes and a favourable built environment. Synergies are expected among the different measures. Hickman et al. (2009) show that positive synergetic effects on emissions are to be expected between pricing measures raising the cost of driving considerably, and planning measures improving the coverage of the public transport network and facilitating relocation decisions. Only qualitative statements about impacts are feasible, as precise quantitative reductions of emissions due to a specific policy package are of course impossible to determine since the complex framework used for the analysis of the BMR cannot be completely quantified. Instead we propose something that might be called "adaptive policy": adjustments of specific measures (e.g., fuel tax) can be made through trial and error until an acceptable outcome that can be monitored is reached (like the level of GHG emissions). Two complementary measures are included, namely investment in R&D and monitoring of emissions, so as to allow for actual policy adaptation and assessment of synergies.

Policy measures are further assessed according to three ("e") criteria: effectiveness, efficiency and equity. Effectiveness was already assessed on the basis of the literature review in Section 'Policy mix to reduce GHG emissions due to commuting'. Regarding economic efficiency (or cost-effectiveness), taxes or other price incentives are judged as positive (+), a subsidy as negative (−), and other measures as relatively neutral or ambiguous (0). A measure is considered inequitable (−) if poor people are disproportionately affected, it is considered equitable otherwise, and when no change in equity is expected, it is considered neutral or ambiguous (0). Implementation costs of measures are also considered. Planning measures like infrastructure supply and subsidies are considered to incur high implementation costs (+++), organisational or administrative instruments (e.g., designation of low-emission environmental-zones, centralised public web-site to diffuse job offers, or awareness campaigns) are assumed to incur medium costs (++), and command-and-control measures and taxes (e.g., increasing existing fuel taxes or feebates systems) are considered to incur relatively low implementation costs (+). These allow for a fair comparison between different measures. All measures in Table 3 were assessed in these terms and whenever overlapping or negative synergies existed between two measures, the final decision (i.e., which one to include) was taken based on how policies scored on these criteria. For instance, prohibition of low-density building projects and internalisation of full transport costs in low-density building projects overlap (same policy objective with same or similar effect, namely discouraging of low-density building projects). However, internalising the transport costs of low-density projects scored positively on economic efficiency, while prohibiting scored neutrally (0) (performance on the other criteria was similar). This latter option was hence discarded. Finally, we reviewed the current transport-policy agenda

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Table 5
An example of a policy package for the BMR.

Policy package	Policy measure	Effectiveness[a,b]	Efficiency[a]	Equity[c]	Implementation costs[d]	Level of planning[f]
PP1: Planning (focus on BE, TF and SE)	Changing the function of existing buildings in strategic sites with high accessibility (e.g., city centre and network nodes)	+	0	0	++	M
	Build social housing in strategic sites with high accessibility – city centres, employment subcentres (if possible), and network nodes	+	0	+	+++	
	Adaptation of the radial design of the public transport network	+	0	+	+++	M
	Provision of existing low-density residential/employment spaces, so-called "exclusionary spaces", with public transport or travel plans	+/0	0	0	+++	R
	Provision of park-and-ride facilities in stations close to low density residential areas	+/0	0	+	++	R
	Give public space to sustainable modes and promote street connectivity (if possible) within cities	+/0	0	+/−	++	P
	Designation of environmental zones with limits on high-pollutant vehicles (e.g., city centres)	+	0	0	++	P
	Speed limits in congested areas to lower pollution and make driving less attractive (e.g., Barcelona Metropolitan Area) – automatic speed control	+	0	+	++	R
PP2: Economic (focus on BE, TF and SE)	Internalisation of *full* transport costs in low-density building projects	+	+	0	+	
	Variabilisation through increase of fuel tax + remove fixed road tax	+	+	−/0	+	
	Substitute moving taxes by geographically differentiated road taxes	+	+	0	+	
	(Economic or social) incentives for people to live closer to their jobs	−	−	0	+++	
	Centralised (public) web-site to diffuse *all* information about job offers (e.g., through the web-site of the Employment Service of Catalonia, SOC in Catalan)	+	+	0	++	
	Congestion charges during rush hours and within the central metropolitan area (Barcelona and First Ring)	+	+	−/0	++	
	Parking charges and controls (e.g., Barcelona city and other cities or city zones where driving is intense and which are well served by public transport, like city centres and business districts)	+/0	+	-	++	M
	Concessionary fares for public transport based on social purposes (young, elders, and more generally low income groups)	+	−	+	++	M
PP3: Behavioural (focus on BF)	Campaigns offering re-location solutions for dwellers within empty flats in dense areas with mixed land uses	+/0	0	0	++	
	Application of IT-systems to public transport systems to decrease uncertainty about reliability and waiting and transfer times	+	0	0	++	R
	Temporary road closures and withdrawal of parking spaces to break down driving habits (e.g., in roads/zones where driving is intense and there are public transport alternatives for such routes/zones – Rondes in Barcelona and Nus de la Trinitat)	+	0	−/0	++	
	Monetary incentives for public transport (free-period ticket) to form habits of use of public transport	−	−	0	+++	
	(Injunctive) normative messages on transport externalities and sustainable transport modes	+	0	0	++	
	Descriptive normative messages about living in flats in dense areas with mixed land uses	+	0	0	++	
	Feebates on new cars dependent on emissions/fuel consumption	+	+	−/0	+	
	Innovative transport measures[e]	+/0	0	0	++	
Complementary measures	Public investments and stimulating private investments in R&D	+	0	0	+++	M
	Computerized emission control via electronic sensors (monitoring)	+	0	0	++	R

Inspired by Banister et al. (2000).
Notes: A and *B* are mutually exclusive, and either one or the other are complemented with *C* policy measures.
[a] + positive, − negative, 0 neutral or ambiguous.
[b] Effectiveness is considered as reduction in GHG emissions and minimal rebound.
[c] + is more equitable, − more inequitable (poor people disproportionately affected), 0 no change in equity.
[d] + denotes small, ++ moderate, +++ large.
[e] 'R' (realised), 'M' (implemented but in need of modification) and 'P' (planned) refer to policies included in planning for the BMR.
[f] Individualised marketing, "deliberation intervention", car-sharing, car-clubs, car-pooling, PAYD, public transport traveller information systems, fuel-efficient driving, etc.

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of the BMR, and compared it with our proposal (last column of Table 5 "Level of planning").

Conclusions

The relationship between commuting and GHG emissions is complex. There are many factors involved, which interact with one another. This poses a major challenge for effective policy targeting commuting-related emissions in urban areas. Both commuting distance and travel mode, especially car use, affect emissions. These aspects of commuting are relevant to climate policy, transportation policy and spatial planning. Empirical studies find an almost universal increasing trend in commuting lengths (mostly in distance), as well as a dominance of the private vehicle for commuting journeys. Commuting distance and travel mode choice are related to the built environment through urban form elements. However, when commuters choose location (i.e., residence and job locations) and mode of transport, they take into account a wider range of factors, as well as facing several constraints. Differences in behaviour exist between socioeconomic groups. In addition, studies note marked individual attitudes and preferences (including habits) for certain locations and modes, which deviate from rational behaviour and do not facilitate the effectiveness of policies.

We have identified five main factors of commuting, namely built environment characteristics, transportation factors, market factors, socioeconomic factors and behavioural factors, and within each of these a range of sub-factors. These factors have been examined for the case of Barcelona Metropolitan Region (BMR). We identified the influence of all five factors in explaining variations in commuting patterns and emissions from transport. We found that commuters face constraints when choosing locations, notably due to market imperfections in the labour and housing markets and related to, among others, high job-searching costs and high house moving costs. We identified variations in commuting behaviour for different socioeconomic groups, which correspond with those described in the literature. In addition, we observed contradictory commuting behaviours when analysing demographic trends; immigrants locate in central places with high accessibility to public transport, while locals move into less accessible small towns, thus increasing their commuting distances and car use. We further noticed that there is insufficient knowledge about the role that behavioural factors play in shaping commuting patterns through individuals' lifestyles, preferences, attitudes and habits in the BMR.

Specific public policies can be connected to all these factors. We analysed effective policies on the basis of the factors identified. This takes into account rebound effects in a proactive manner (i.e., anticipating undesirable effects and interactions). Essential for the case of the BMR are limiting spatial dispersion trends and providing adequately designed public transport services. The latter is already included within the political agenda of the BMR and is currently being implemented. As for the former, it seems that there is little willingness to restrain low-density building projects (both residential and business/industrial centres). A similar conclusion is reached by Hickman et al. (2013) for London and Oxfordshire metropolitan regions. A reduction in CO_2 emissions from transport to a level compatible with reasonable aspirations can be achieved through heavy investment (i.e., radical projects) in urban and transport planning. The political feasibility and affordability of such stringent investments are questionable, however, especially within a time horizon that is needed for rapidly controlling emissions. We did not examine political feasibility here, but it could well form part of a future step in research on the BMR. In addition, the effects of market imperfections on labour and housing markets need more attention as they complicate policy analysis; so far the role of these factors seems to have been completely overlooked in policy studies, design and implementation for the BMR. Possibly, corrections of these imperfections can further contribute to reducing GHG emissions from transport. Policy packages, of whatever type would have to include measures discouraging car usage. Measures increasing the costs of driving are effective and have low implementation costs. However, alternative strategies based on behavioural research can also be competitive in this sense. Generally, a reduction in journey distances seems feasible, while the use of private vehicles can be reduced through effective policy intervention. Of course, one has to expect policy limits to exist with regard to social groups with strong preferences for low-density sites and pro-car attitudes.

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