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Border effects on the travel mode choice of resident and cross-border workers in Luxembourg

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We investigate the travel mode choice behaviour of both resident and cross-border workers in Luxembourg. Two categories of mode choice are considered: sustainable (public transport) and unsustainable (single occupancy car use), which both depend on a large set of spatial and socio-demographic variables. In particular, we determine whether and how the borders of the four countries involved (Luxembourg, Belgium, France, Germany) affect this choice. The results of a classical binary logistic regression model show that significant variables depend on the area of residence and that some border effects are relevant in the context of the studied cross-border areas. Moreover, the identification of these various border-effect variables does not require the use of big data processing techniques. Therefore the proposed method can be applied generally to other cross-border areas with an open border context to highlight the effects of border on functional integration. This study is helpful in terms of developing a better understanding of the determinants involved in the use of sustainable transport modes and in supporting decision-making to improve transport planning.

Keywords: *Cross-border workers; functional integration; logistic regression; mobility; mode choice; sustainable travel mode.*

1. Introduction

Luxembourg is heavily dependent on the use of cars: 80% of its residents use the car as their main form of transport while 86% of cross-border workers choose the same travel mode (Omrani et al., 2014). Moreover, between 1985 and 2011, the number of employees in Luxembourg doubled from 141,700 to 352,000 while cross-border workers increased from 16,100 to 153,800 (Schmitz et al., 2012). This has led to increased difficulties in transportation management (Beyer and Reitel, 2011, Dörry and Decoville, 2012; Durand and Nelles, 2014).

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The widespread use of cars in Luxembourg and its border areas has become an important sustainability issue for a variety of reasons including environmental protection, pollution reduction, urban sprawl and traffic congestion. Indeed, according to the Inrix Traffic Scorecard (see: http://scorecard.inrix.com/scorecard) for example, Luxembourg has been in the world top 10 for road congestion since 2010 and the intensity of congestion has continued to increase – by 29% from 2012 to 2014 – and Luxembourg now ranks sixth globally. Both resident and cross-border commuters contribute very heavily to the problems of traffic congestion in Luxembourg because they work in the most congested areas, namely, Luxembourg City and neighbouring cities.

Moreover, these home–work mobility practices appear to be at odds with the principles of sustainable mobility, especially regarding urban sprawl (Schmitz et al., 2012) and environmental protection (Schmitz, 2012). In this paper, because both resident and cross-border commuters contribute to the problem of extensive car use in Luxembourg, we combine the home–work travel mode characteristics of both groups in a unique dataset in an attempt to understand what drives the choice of travel mode.

In order to promote sustainable mobility, the government of Luxembourg is hoping to limit car use by residents and cross-border workers, aiming to reduce it to 75% of motorised travel by 2020. This is why the model in this study distinguishes between unsustainable (single occupancy car use) and sustainable (public transportation [PT]) travel modes, first to test the effect of various factors on the choice of travel mode, and second to highlight some potential discontinuities on both sides of the border, for all workers in Luxembourg: outcomes from the latter investigation should provide some indication of the level of functional integration in the studied cross-border area (Sohn et al., 2009). More precisely, at least two attributes of each border could have an impact on travel mode choice: the border as an interface and the border as a barrier or a discontinuity (Gerber and Carpentier, 2013).

At the aggregated level, some authors have already analysed the border as an interface by examining differences on either side of it, particularly in terms of wages and house prices, which leads many individuals to cross it daily to work (Lord and Gerber, 2012). Others have dealt with the border as a barrier (Grasland, 1997; Hamez, 2004), especially to travel flows (Dujardin, 2001). Some researchers have tried to combine border effects at both the aggregated and dissagregated levels (e.g., Gerber, 2012), but do not focus on modal choice. At the individual level, some previous studies have dealt with the daily mobility of workers, specifically the modal choice of cross-border workers (Schmitz et al., 2012) or resident workers (Omrani et al., 2013), but did not assess its effect. The current study extends these previous studies by considering both border effect and modal choice at the individual level for both groups of workers.

Our approach is innovative for two reasons. First, we aim to compare modal choice at the individual level for four countries of residence, which to our knowledge, has not previously been attempted. Second, by adding newly generated variables to the spatial analysis at local and regional levels, we develop a more comprehensive framework that can be applied generally to highlight functional integration in cross-border areas within an open border context (i.e within the Schengen agreement).

The rest of the paper is organised as follows. Section 2 provides a short overview of recent empirical results, cross-border issues, and travel mode choice. Section 3 includes a descriptive analysis of our cross-border case study. Section 4 deals with the building of specific datasets in the cross-border context as well as the methodological framework. Section 5 presents the empirical results, especially the border effects on travel modes. The two final sections concludes and discusses policy implications, limitations and future work.

2. Literature review and research question

2.1 Travel mode choice determinants

Discrete choice models still dominate this area of research, because it is generally more efficient to analyse different travel modes in scenarios using two or more travel mode choices, even though more advanced computer science approaches are available, such as machine learning methods (e.g., decision trees, neural networks; see Jovic, 2000; Xie et al., 2003; Omrani et al., 2014). Some studies have been conducted using logistic regression methods: Lerman and Ben-Akiva (1976) employed a multinomial logistic regression to analyse travel mode choice in Washington D.C. The same method was used to study the choice between six travel modes in the Netherlands: bicycle, moped, car, bus, train and walking (Ben-Akiva and Richards, 1976).

Besides the techniques applied at the individual level, we must also consider the variables that influence travel mode choice. Recent comprehensive literature reviews on mode choice behaviour affirm that four important determinants, related to socio-demographic, spatial, journey characteristics and socio-psychological factors, characterise individual mobility behaviour (De Witte et al., 2013; Van Acker et al., 2010). It was found that the main significant socio-demographic determinants are age, education, occupation, household composition, and car availability. The main spatial variables determining travel mode choice are density, diversity (mixed land-use), proximity to infrastructure and services, availability of parking, and frequency of PT. Thus limited accessibility by PT may result in car use (Schwanen and Lucas, 2011). Journey characteristics consist of trip purpose, travel distance, travel time, travel cost, departure time, trip chaining, weather conditions, and interchanges between different transport modes (i.e., the seamlessness of connection). Finally, past experience, familiarity with the public transport system, lifestyle choices related to education and occupation, habits, and perceptions and attitudes to transport mode are the main factors that characterise the socio-psychological aspect.

Previous research and travel mode choice in Luxembourg is limited. Omrani et al. (2013) were among the first to study this topic. They used machine learning methods and multinomial regression analysis to analyse the travel mode choice of 3,673 residents in Luxembourg. Age, the individual's wage and public transport cost were found in statistical terms to increase the probability of taking the car significantly. As regards the variables of accessibility, when the number of bus stations increases, more people choose to take public transport. Moreover, the analyses carried out at LISER (formerly CEPS/INSTEAD, Center for research on population, poverty and socio-economic policy / International Networks for Studies in Technology, Environment, Alternatives, Development) especially in the framework of the MOEBIUS and the CABAC projects (Schmitz et al., 2012; Gerber et al., 2013), have revealed a certain number of characteristics that are peculiar to daily and residential mobility in Luxembourg and its bordering regions (Carpentier and Gerber, 2009; Carpentier et al., 2013; Gerber et al., 2012). Another study used a logit model estimation which clearly indicated that the mode choice behaviour of the cross-border workers of Luxembourg is mainly determined by situational characteristics, specifically related to the ease of parking at the workplace, workplace location, and type of residence (Enaux and Gerber, 2014). This model also highlights the important influence of beliefs and attitudes on mode choice behaviour. For instance, energy beliefs is identified as encouraging the use of more eco-friendly modes of transport such as train or bus. However, one of the most striking factors is the cross-border nature of Luxembourg's labour market, which is sustained by the sizeable differences in wages and in land prices between Luxembourg and neighbouring countries. These differences generate extensive cross-border travel.

In light of the foregoing, this paper aims to extend previous studies on Luxembourg, which analysed either residents or cross-border workers, by employing binary logistic regression to focus on the contrast between sustainable and unsustainable travel modes for both groups. Moreover, one of the novel aspects of our work is that we investigate the influence of the border as a barrier effect on modal choice in Luxembourg (Schiebel et al., 2013). To the best of our knowledge, this kind of study is new and is well suited to Luxembourg's configuration as a country because we are examining travel mode choice in cross-border areas. In addition to the standard variables that could explain modal choice, we also introduce new ones that are specific to the cross-border context and which could explain any potential distinctions between the four countries (Luxembourg, France, Germany and Belgium) involved. The proposed model allows us to test the relationships between these independent variables and the travel mode choice of workers in Luxembourg, while always keeping in mind its possible application to other cross-border areas.

2.2 Border effects and functional integration

The different effects of national borders on mobility can be studied by considering the border either as an interface or as a barrier (Gerber and Carpentier, 2013); some authors refer to this as the bordering process (Newman, 2006; Paasi and Prokkola, 2008). This study aims to investigate both types of border effect.

First, with respect to the border as an interface, in our cross-border area – the 'Greater Region' – the creation of a new political dimension following the introduction of the European Grouping of Territorial Cooperation (EGTC) in 2010, may favour greater integration between the different countries. Moreover, some administrative changes such as the introduction of the single currency in 2002 and the creation of the legal entity of the 'cross-border worker' in 1971 (Article 1408/71/CEE) have made it much easier to find jobs on the other side of the border and this has consequently generated daily cross-border mobility. In addition, differentials related to wages, level of unemployment, taxes and fiscal advantages between two neighbouring countries may equally encourage many workers to cross the border every day to go to work. These conditions may thus favour a high level of asymmetry with countries across the border from Luxembourg: more than 160,000 workers cross the border to work in Luxembourg, whereas less than 800 workers from Luxembourg work in one of the four neighbouring countries (Statistiques Grande Région, 2011). Nevertheless, travel flow is not the key focus of our analysis; rather, we are interested in the link between mode choice and PT network efficiency.

In other words, this study aims to investigate the influence of the border as an interface on mode choice by analysing the behaviours of cross-border workers using the PT network of Luxembourg instead of the PT network of their place of residence. Indeed, we suppose that in a cross-border area, some workers cross the border to use the PT network of a neighbouring country when it is more efficient, since the connection between the different national PTs may be limited (De Boe et al., 1999).

Second, barrier effects such as the presence of cultural, legal, economic or functional differences (Plat and Raux, 2008) can limit integration. For example, house price disparities between Luxembourg and neighbouring countries encourage a large number of cross-border workers to reduce the spatial mismatch without actually moving into Luxembourg (Lord and Gerber, 2012, Omrani et al., 2010). Another example of the barrier effect can be perceived in the travel cost differences of PT in Luxembourg and its bordering areas (Schiebel et al., 2013) and other areas in Europe (ESPON, 2010).

Travel mode choice behaviours can result from the efficiency of the PT network; in this sense we assume that the efficiency of a PT network for commuting may be a revealing indicator of the level of integration in a cross-border area. Furthermore, when analysing travel mode choice, the border could have a structural impact on this choice because both travel flow characteristics and transport network supply (car and PT) are important for the mobility of individuals. In addition, in the context of our comparative study by country of residence, specific variables are required to highlight the effect of the border on travel mode.

In this study, the influence of the border as a barrier on daily mobility can be analysed by considering travel flows at the border (Nijkamp et al., 1990; Batten and Fischer, 1993). These flows can be adversely affected, for example, by extra costs at the border (Nijkamp et al., 1990) or lack of available informations to the traveller (Grasland, 1999). Thus the barrier effect on spatial interaction (De Boe et al, 1999) can be measured by using a gravity model (Brocker and Rohweder, 1990; Flowerdew, 1991). Again it should be emphasised that this study investigates the influence of the border as a barrier on individual modal choice, not on flow. First, we investigate whether the variables that determine travel mode choice differ depending on the country of residence. Second, we examine whether differences in modal choice depend on PT efficiency; we assume that even if the level of PT services is the same, that there will be a difference in modal choice between the different countries studied.

3. Context and descriptive analysis

3.1 Descriptive analysis of the demand

Due to its small size and good economic performance, Luxembourg faces the challenge of managing the journeys to work of more than 160,000 cross-border commuters. Despite a significant increase between 2007 and 2010 in the use of public transport by cross-border workers to commute to Luxembourg (Schmitz et al., 2012), the car remains the most used travel mode (Table 1). Germany has the highest share of car users with 90% while France has the smallest with 83%.

Table 1. Main travel mode by country of residence (2007–2010)

Country	Year	Car	Train	Bus	Soft modes
Luxembourg	2007	73.9%	3.6%	11.1%	11.4%
	2009	72.5%	14.5%		13%
Belgium	2007	89.5%	8%	2.5%	0%
	2010	88%	9%	3%	0%
Germany	2007	95%	1%	4%	0%
	2010	90%	2.5%	7.5%	0%
France	2007	89%	9.5%	1.5%	0%
	2010	83%	11.5%	5.5%	0%

Sources: PSELL survey-EU-SILC, 2007, MODU, 2009, cross-border survey 2010, LISER

While there has been a decrease in car use, this varies between the three bordering countries: France posted the biggest decrease of 6 points, then Germany with 5 points and finally Belgium with 1.5 points. This change in cross-border commuter behaviour can be linked to the efforts made by decision makers from the four countries to improve their respective public transport networks (Schmitz and Gerber, 2011).

Luxembourg has also made improvements in this respect that may have affected mode choice among resident workers. According to the Socio-economic Panel Survey Liewen zu Lëtzebuerg (PSELL) survey, 73.9% of resident workers in Luxembourg used their private car for commuting in 2007, which declined to 72.5% in 2009 (see Table 1).

Nevertheless, overall, the private car still remains the dominant transport mode, accounting for 86% of total in-country and cross-border commuting in 2010. Moreover, despite the decline in car use in terms of overall share, the number of cross-border car users increased from 2007 to 2010 by 10% because of the increase in the number of cross-border workers. Indeed, the increase in car use and stagnation in the practice of carpooling at 15% resulted in a net growth of border traffic over that period.

Finally, although 11.4% resident workers use soft modes of transport (i.e., cycling or walking) to go to work, the percentage of cross-border workers who do so is insignificant, perhaps unsurprisingly due to the distances involved (Schmitz et al., 2012).

There are various possible explanations for the slight shift away from the car and the differences in public transport use in the countries studied, which are outlined below.

3.2 *Supply of cross-border public transport*

The introduction of new train connections between bordering countries and Luxembourg, through bilateral strategy, as well as an improvement in the cross-border rail system, led to an increase of 3,200 daily commuters using the train between 2007 and 2010. The improvement in the railway network was accompanied by a major upgrade of cross-border bus networks as well as the building of park and ride facilities close to the borders and near the bus routes of Luxembourg. Nevertheless, previous analyses (Schiebel et al., 2013) highlight some discontinuities between Luxembourg and its bordering areas and between the bordering areas themselves in terms of direct access to workplaces by public transport (Figure 1). A large part of Luxembourg is very well connected in terms of public transport; however, in border areas a dichotomy can be observed between the spatial units that have the highest density of cross-border workers and have better accessibility and other areas that have a lower density of such workers and do not have an efficient public transport supply.

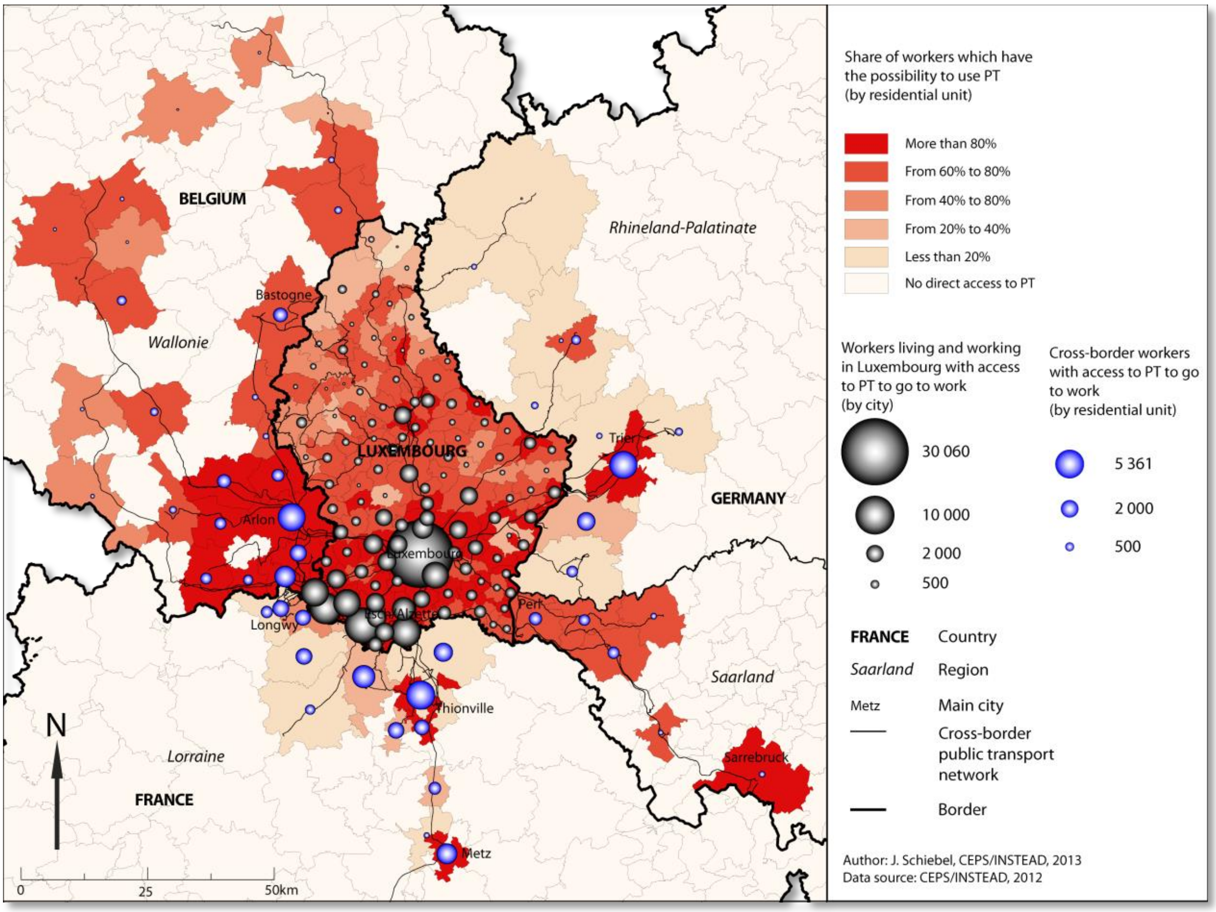

Figure 1. Direct access to the workplace by public transport: comparison between Luxembourg and its bordering areas

From Figure 1, this supply appears to match demand because urban areas such as Metz, Thionville, Arlon and Trier have the highest rates of public transport use with a percentage of

34%, 24%, 23% and 21%, respectively (Schmitz et al., 2012). Car use is more common in areas that are less dense and less accessible by train or bus.

There are other reasons, beyond the spatial distribution of the public transport network, that may explain its limited use. According to our cross-border survey, time is one of the most important factors that affects a shift in travel mode choice. A comparison of network efficiency (car and public transport) using a spatio-temporal approach (e.g. Hägerstrand, 1970; Neutens, 2010) allows us to state that the car is more efficient than public transport (Figure 2).

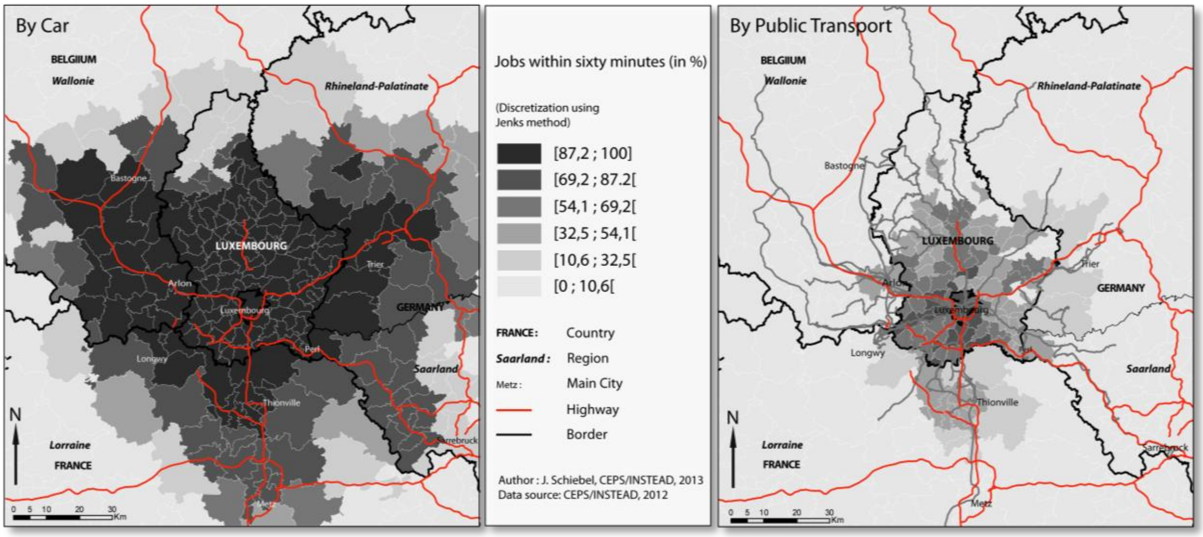

Figure 2. Access to the workplace in Luxembourg within 60 minutes during peak hours: comparison between car and public transport

Besides place of residence, transport mode choice also depends on the location of the workplace. For instance, 33% of commuters travelling to Luxembourg City use public transport compared to 2% travelling in the rest of the country. This substantial difference can be explained in part by the structure of the public transport network, especially the railway service which is centred on the capital. These aggregated indicators (spatial, temporal) should be taken into consideration when evaluating modal choice. However, as stated earlier, our aim is to analyse this choice, not at the aggregated level but at the level of the individual.

4. Data collection and methodology

This study aims to compare travel mode choice behaviour in relation to country of residence in a cross-border context and to measure border effects on modal choice. We use not only those variables identified from the literature review (see Section 4.1), but also include some new ones to measure border effects (see Section 4.2). The motivation for including and testing these new variables is to develop a model that can be easily applied to other cross-border areas and thereby contribute to sustainable transport planning. The proposed methodology is based on a standard logistic regression model (see Section 4.3).

4.1 Data sources and standard variables

The first set of independent variables are selected based on the literature on commuting in the border context. They are classified into five categories: social, economic, urban, spatial, and perception factors. It should be noted that the variables related to perception are only available for cross-border workers (Enaux and Gerber, 2014), and cannot therefore be used for residents.

The social and economic data used in this paper was obtained from two surveys. The first focused on the mobility of 7,235 cross-border workers living in France, Belgium or Germany and working in Luxembourg. It was conducted in 2010 by LISER in collaboration with the French institute CNRS in the framework of the CABAC research project (Schmitz et al., 2012). The second survey, conducted in 2007 (PSELL-EU-SILC, 2007), concerns 4,133 resident workers in Luxembourg on which several studies have drawn (e.g., Carpentier and Gerber, 2009). After data cleaning, only 5,250 cross-border workers and 3,099 resident workers could be used in our case study. In order to compare these two datasets, first we needed to harmonise some variables. For instance, the level of education is not built in the same way in the two surveys; the categories are different across the four European countries, so we obtained only three categories after harmonisation (at International Standard Classification of EDucation [ISCED] standard level).

Urban structure and spatial variables are estimated using GIS software. They are first built at the municipality level and then allocated to each worker. We assume that spatial variables are crucial in explaining travel mode choice in a cross-border context: the presence of direct PT services, frequency of services or the number of PT stations (accessibility to a PT network), as well as travel time or trip distance (accessibility within network) are all used at the beginning of the modelling process. In addition of using GIS software, the spatial variables are built with a car traffic model (Schmitz and Klein, 2011) and a public transport database (Schiebel et al., 2013). To ensure the consistency between the two surveys, spatial indicators are built using data from the same years, 2007 for resident and 2010 for cross-border workers. For example, the travel time by public transport for cross-border workers is measured using the timetables of 2010.

4.2 Addition of new border effect variables

As explained in the earlier sections, we assume that border constraints may have a strong impact on modal choice. To measure the spatial effects of this situational constraint, we use a synthetic border variable built using the cross-border trip distance and the part of that trip that lies within Luxembourg in terms of distance. This variable can be considered to represent the level of functional integration of the trip (Figure 3).

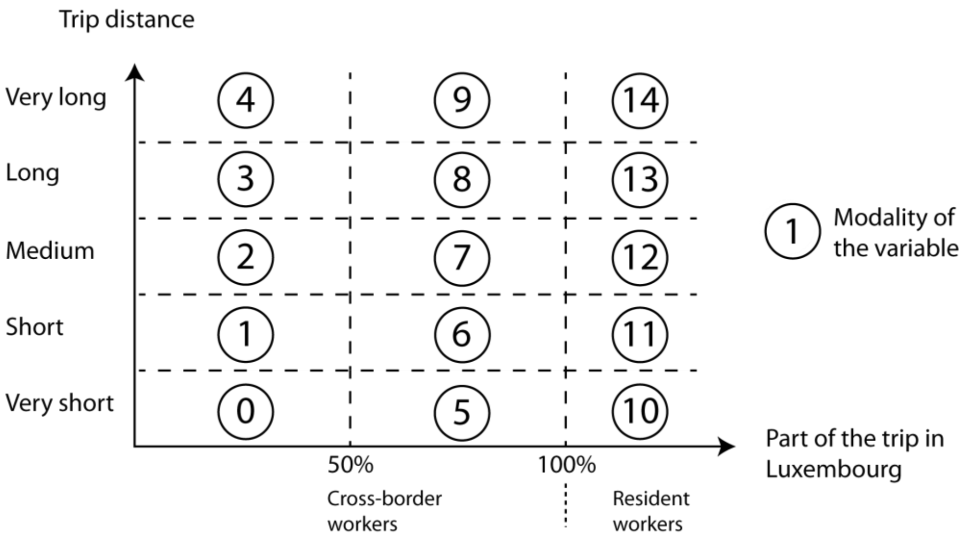

Figure 3. Synthetic border variable: cross-border trip distance and percentage of distance travalled within Luxembourg

This network variable allows us to better understand whether the travel mode choice of workers is similar on both sides of the border given equivalent travel distance. For instance, is the travel mode different for resident workers travelling a short distance entirely within the territory of Luxembourg compared to cross-border workers who make the same trip but mainly from outside Luxembourg? We also aim to compare the behavioural aspects of cross-border workers with the weakest functional integration (categories 0 to 4 shown in Figure 3) and those with the highest functional integration (categories 5 to 9) to resident workers (categories 10 to 14). The accessibility of PT for commuting significantly decreases further away from Luxembourg (Schiebel et al., 2013). We aim to test the following hypothesis: when cross-border workers can take advantage of the high level of public transport network services in Luxembourg, the modal share of PT is higher. In other words, we expect that when a greater proportion of the cross-border trip is within Luxembourg, a higher share of travel will be undertaken by PT. Conversely, when the part of the trip within Luxembourg is 50% or less, we expect that the lower level of PT network supply will encourage cross-border workers to take the car more often.

Another variable we consider here is the territorial border effect (Cattan and Grasland, 1994). Indeed, we assume that areas near the border are marginalised (ESPON, 2010; CTJ, 2011) because the national stakeholders invest less in the transportation infrastructure in such areas. Consequently, the PT network could be less developed than that further away from the border, in terms of spatial distribution, frequency or travel time. Therefore travel mode choice is affected by place of residence. This indicator assumes that the probability of commuting by car is greater in areas close to the border. Lastly, the varying travel mode behaviours on both sides of the border may result from differences in public transport supply between countries.

4.3 Methodology

A binary logistic regression model is used to predict the probability of mode choice for all Luxembourg workers. It allows us, after estimating the coefficients, to model the link between a set of explanatory variables and a dichotomous dependent variable. Suppose the dependent variable Y is binary, i.e., it can have only two possible outcomes, denoted as 1 and 0. Let $Y=X\beta+\varepsilon$, where the normalised error term ε follows a logistic distribution with mean 0 and variance σ^2. X is a vector of independent variables that we assume to be related to the outcome Y. The outcome probabilities can be defined as follows:

$$P(Y = 1|\, X\,) = \frac{\exp(X\beta)}{1+\exp(X\beta)} \tag{1}$$

The parameter vectors β are typically estimated by maximising the likelihood function, as shown in Eq. (2):

$$L = \prod_{i=1}^{n} \left(\frac{\exp^{X\beta}}{1+\exp^{X\beta}}\right)^{y_i} \left(1 - \frac{\exp^{X\beta}}{1+\exp^{X\beta}}\right)^{1-y_i} \tag{2}$$

where n represents the sample size.

As mentioned earlier, there are five categories of independent variable (socio-demographic, socio-economic, urban structure, spatial, and border). The dependent variable is the travel mode choice, i.e., a sustainable mode (PT: bus or train) or an unsustainable mode (car). For multimodal trips, we consider travel time to determine whether a trip is made by a car or PT. If more travel time is spent in the car (>50% of full travel time), we consider it as a car trip; if travel time by car is lower than 50%, we consider it as a PT trip (Table 3).

In this sample, 84.1% of cross-border workers use the car for home-to-work travel and 83.6% of residents use the car for the same purpose if we do not take into account walking and biking modes (as few cross-border workers use these). Concerning the modalities of some urban structure and spatial indicators, the method of classifying variables depends on the statistical distribution of the data series: for some variables we use the quantile method, whereas for others, we use Jenks algorithm (which reduces inter-class variance and maximises extra-class variance) or graphical classification based on observed values.

Table 2. Description of the variables

Variable	Modalities	Kind of worker (N= 8,249)	
		Resident (N= 3,099) %	Cross-border (N=5,250) %
Dependent variable			
Travel mode	0 = Car	83.6	84.1
	1 = Public Transport	16.4	15.9
Socio-demographic indicators			
Gender	0 = Male	57.1	59.9
	1 = Female	42.9	40.1
Age	0 = 30 years and under	26.6	16.9
	1 = 31-36 years	22.2	20.1
	2 = 37-41 years	16.8	20.4
	3 = 42-47 years	13.9	23.1
	4 = 48 years and more	20.5	19.5
Level of education	0 = Elementary or less	31.3	2
	1 = Secondary	31.6	45.1
	2 = High School	37.1	52.8
Number of children	0 = Without children	47.4	37.8
	1 = One child	23.1	22.9
	2 = Two children or more	29.5	39.3
Housing	0 = Individual house	56.0	77.4
	1 = Apartment and others	44.0	22.6
Household type	0 = Single	11.6	18.3
	1 = More than one individual	88.4	81.7
Socio-economic indicators			
Socio-professional category	0 = Senior executives	26.6	22.4
	1 = Employee, Technicians	42.4	48.8
	2 = Artisan, Retail Trader	11.8	20.2
	3 = Others	19.2	8.6
Employment	0 = Full time	83.3	82.9
	1 = Part time	16.7	17.1
Income of household (in € per year)	0 = Low (<= 36000)	31.7	5.7
	1 = Medium [36000;72000[	58	76.2
	2 = High (>= 72000)	10.4	18.2
Cars in the household	0 = No	4.0	0.6
	1 = Yes	96.0	99.4
Driving licence	0 = No	6.4	0.7
	1 = Yes	93.6	99.3
Urban structure indicators			
Density of population at municipality of residence	0 = Very low [1.94;507[	45.8	58.7
	1 = Low [507;1464[	12.4	22.5
	2 = High [1464;2075[	15.5	8.8
	3 = Very High [2075;3501]	26.4	10.0
Density of employment at workplace	0 = Very low [55;873[	13.7	10.6
	1 = Low [873;1800[	16.4	17.8
	2 = Medium [1800;2626[	15.4	17.2
	3 = High [2626;4981[	11.6	13.9
	4 = Very high [4981;7890]	43.0	40.5
Type of municipality of residence	0 = Big city	26.4	12.8
	1 = Others	73.6	87.2
Working in Luxembourg-city	0 = No	58.2	60.7
	1 = Yes	41.8	39.3

Number of amenities in the municipality of residence	0 = Very low [1;30]	14.6	15.6
	1 = Low]30;105]	29.9	33.7
	2 = Medium]105;206]	7.9	5.7
	3 = High]206;425]	5.8	5.8
	4 = Very high (=1913)	41.8	39.3
Availibility of parking at workplace	0 = Without problem	97.7	80.9
	1 = Some problems	2.3	16.1
	2 = Impossible	0.0	2.9
Spatial indicators: accessibility to PT network			
Direct bus line between municipality of residence and workplace	0 = No	30.2	80.7
	1 = Yes	69.8	19.3
Direct train line between municipality of residence and workplace	0 = No	50.0	86.2
	1 = Yes	50.0	13.8
PT station (bus or train) in the municipality of residence with direct access to Luxembourg-city	0 = None	5.0	46.3
	1 = Very low (=1)	3.8	11.7
	2 = Low [2;6[	7.7	19.0
	3 = Medium [6;11[	18.4	12.8
	4 = High [11;39]	46.1	10.3
	5 = Very high (=321)	19.0	0.0
Frequency of public transport (by day)	0 = None	21.0	50.6
	1 = Very low (=1)	0.1	10.9
	2 = Low [2;11[	6.8	19.1
	3 = Medium [11;20[	3.5	19.4
	4 = High [20;1043]	56.2	0.0
	5 = Very high (=7380)	12.4	0.0
Generalised travel cost by public transport	0 = Very low (20% cheapest trips)	46.4	3.9
	1 = Low	33.7	11.9
	2 = Medium	13.6	23.2
	3 = High	5.7	29.2
	4 = Very high (20% more expensive trips)	0.5	31.7
Generalised travel cost by car	0 = Very low (20% cheapest trips)	44.2	5.4
	1 = Low	26.9	15.9
	2 = Medium	15.9	22.4
	3 = High	9.5	26.2
	4 = Very high (20% more expensive trips)	3.5	30.1
Spatial indicator: accessibility in PT network			
Travel time by public transport between municipality of residence and workplace	0 = Very low (20% fastest trips)	10.0	26.0
	1 = Low	17.8	21.3
	2 = Medium	17.3	21.6
	3 = High	28.8	14.7
	4 = Very high (20 slowest trips)	26.0	16.4
Spatial indicators: accessibility in Car network			
Travel time by car between municipality of residence and workplace	0 = Very low (20% fastest trips)	50.5	1.5
	1 = Low	30.7	13.7
	2 = Medium	12.3	24.6
	3 = High	4.6	29.3
	4 = Very high (20% slowest trips)	1.8	30.9
Trip distance by car between municipality of residence and workplace	0 = Very low (25% smallest trips)	37.4	1.8
	1 = Low	34.5	6.9
	2 = High	18.3	22.8
	3 = Very high (25% longest trips)	9.9	68.5

Border effect indicators			
Network variable: trip and part of the trip distance	0 to 14	See figure 3	See figure 3
Territorial variable: residence location	0 = near the border 1 = far away from the border	See section 4.2	See section 4.2

Table 3 gives a descriptive statistical overview of the differences concerning accessibility and urban structure indicators that may influence modal choice. Resident workers have better values than cross-border workers as regards accessibility indicators. Despite these results, the modal share of PT for residents is not more important than for cross-border workers.

We use a two-step methodology to estimate the significance of the variables depending on mode choice. Model 1 takes into account all the variables except border effect indicators, whereas Models 2a and 2b focus mainly on these border effect indicators with significant variables of Model 1. First, in Model 1, we analyse all four categories of variable for resident workers and cross-border workers in the neighbouring three countries, to determine whether there are any cultural differences in terms of modal choice behaviour. In other words, is the effect similar regardless of country of residence? The selected variables may explain modal choice, which refer to multidimensional behaviours. Nevertheless, we have to remove some variables according to the results of the multicollinearity variance inflation factor (VIF) test, namely, those which are too closely correlated to our accessibility indicators: density of employment at the workplace, the number of amenities at the workplace, and whether or not the workplace is in Luxembourg City. We know that characteristics such as the density of the destination may influence mode choice (Ben-Akiva and Lerman, 1985 in Schwanen and Lucas, 2011; Ewing and Cervero, 2010). However, we retain interaction among the spatial variables because they are related both to residence and workplace, which can help us to identify discontinuities between countries. Moreover, we delete some variables such as travel distance or generalised cost because these variables are correlated with travel time. The latter is retained because cross-border workers are more sensitive to travel time than travel cost or travel distance. Second, in Model 2, we added to these variables (Model 1) border effect variables to measure the impact of border on modal choice.

5. Results

In Section 5.1, we present the results derived from Model 1, first according to situational constraints and second according to accessibility. In Section 5.2, we focus on border effect indicators (Models 2a and 2b).

5.1 The importance of place of residence

The estimated results based on the logistic regression model for all variables are shown in Appendix 1. The global model significance is different between countries of residence (pseudo R^2 between 0.31 and 0.44). Only the significant variables (p-value less than 5% or 1%) are commented on here.

Results related to situational constraints and demand characteristics

In general, the results are consistent with those seen in previous studies. Regarding urban structure, in line with the findings of e.g Cervero (2002), a low level of population density at a place of residence increases the probability of taking the car. A parking facility at the workplace, which may be correlated with population density, increases the probability of taking the car, which is also in line with the literature (Kaufmann and Guidez, 1996). Concerning the socio-demographic and socio-economic variables, men are likely to use a private car if they are residents in Luxembourg or cross-border workers from France. Regardless of these countries of residence, an increase in the number of children in the household increases the probability of taking the car (Limtanakool, 2006). Moreover, if an individual lives in a house, then the probability of taking the car is higher for workers in Luxembourg and from Belgium.

In contrast, low-income workers in Luxembourg and from France or the lack of driving licence increase the probability of taking PT. With respect to age, the probability of using PT is inversely related to age; our results for cross-border workers from Belgium show that the younger the worker, the greater the probability of taking the car.

The results for the socio-professional category are also ambiguous. As regards cross-border workers living in Belgium, the probability of taking the car is higher for executives than for manual workers and labourers, which is an expected result based on earlier studies. In contrast, in the case of France-based cross-border workers, the higher the socio-professional category, the greater the probability of taking PT. This could be explained by the fact that many workers with executive jobs who live in big cities such as Metz or Thionville take PT to go to Luxembourg City, where there are many skilled jobs.

These results highlight that numerous situational constraint variables are at play in travel mode choice. Moreoever, the country of residence appears to have high explanatory potential. We also analyse the accessibility indicators to determine whether they confirm these initial findings.

Results related to accessibility

Good access to PT (a direct train line to the workplace) logically increases the probability of using PT. The odds ratios are very strong for Luxembourg and France and strong for Belgium. Moreover, the existence of a direct bus line is also significant, especially for Germany, and to a lesser extent for Belgium. The frequency of PT is significant for Belgium, where a high frequency of services increases the probability of using PT. This result confirms that transport policies which promote the use of PT can have a positive effect on uptake. In this respect, the Luxembourg government, in its Stratégie pour une Mobilité Durable (MODU, 2012), aims to promote a modal shift from car to public transport, particularly by creating new bus and train lines. The same is true of Luxembourg and France who have implemented a collaborative Schéma de Mobilité Transfrontalière (SMOT) strategy (2009).

The number of bus or train stations with direct access to Luxembourg City is significant in the case of Luxembourg, France and Germany (odds ratio very strong for Luxembourg and Germany, lower for France). The higher this number of bus or train stations, the greater the probability of using PT. A short travel time on PT may lead to its greater use. It therefore seems to be important for transport policy to aim at reducing travel time in order to promote a modal shift toward PT. Furthermore, car users are very conscious of travel time. The shorter the travel time by car, the more people tend to use this mode (odds ratio very strong, especially for very short distances). So if PT is more accessible and efficient this may reduce congestion levels.

All these results highlight that good accessibility of PT is not on its own sufficient to increase its use. There are some situational constraints which influence mode choice. The types of variable and their relative significance depends on where workers live. For instance, in Germany, the important variables are mainly linked to supply network, whereas in the other countries, some other variables related to transport demand can explain modal choice as well. This makes the development of a global cross-border mobility strategy (in this case involving four countries) much more complex and may encourage stakeholders to collaborate in implementing a bilateral strategy. The issue is further complicated by the border effects, which we consider in the next section.

5.2 Border effect variables

To confirm our assumption about territorial border effect, we need to compare modal choice first according to places of residence near the border as opposed to far from the border (Model 2a) and second according to the country of residence (Model 2b). We use the distance from residence to the border and the PT network efficiency as proxies for the border effect.

For the first comparison, we proceed in two steps as follows. First, we consider workers living in an area within a distance of 8 km from the border of Luxembourg compared to the others4. The results are not significant. The travel mode choice of workers living far away from the border does not differ significantly from those living close to the border. Second, we consider only workers living in municipalities adjacent to the border (compared to the other workers). The results show that they are more likely to use the car than others (p-value < 1%, odds ratio = 1.3), whatever their country of residence (Table 5).

Table 3. Model 2a. Living in a bordering municipality: results for unsustainable travel mode (car)

	Bordering municipalities (resident and cross-border workers)	
	Coefficient	Odds ratio
	0.277(2.680)**	1.319
Other Municipalities far away from the border	Ref	-

* 5% significant level ; ** 1% significant level
Note: This summary is a result from the logit model with accessibility indicator and other significant variables from table 3.

More precisely, cross-border workers could be employing a strategy of living close to the border of Luxembourg so that their trip distance and travel time is reduced and, for some of them, their route may avoid areas of congestion. In the case of resident workers, their strategy appears to be different. They increase their trip distance and travel time by living close to the border where house prices are cheaper than those near Luxembourg City but where PT is less efficient. Hence we observe two different strategies; however, both lead to the same modal choice – the more frequent use of the car. This means that this territorial border effect is really only apparent close to the border. Far from the border area, this effect becomes uncertain. Thus only areas close to the border seem to be marginalised in terms of the PT network.

Nevertheless, some differences between the four countries may exist. By analysing this territorial border effect, more precisely only for workers who live close to the border, we can compare workers' travel behaviours according to their country of residence (Table 6).

[4] This threshold is determined by experience.

Table 4. Model 2a: Three barrier effects close to the border: results for unsustainable travel mode (car)

	Luxembourg residents	
	Coefficient	Odds ratio
	-1.135(-3.470)**	0.321
Cross-border from France	Ref	-
	Luxembourg residents	
	Coefficient	Odds ratio
	-0.405(-0.995)	0.667
Cross-border from Belgium	Ref	-
	Luxembourg residents	
	Coefficient	Odds ratio
	0.733(1.923)*	2.082
Cross-border from Germany	Ref	-

* 5% significant level ; ** 1% significant level

Note: This summary is a result from the logit model with accessibility indicator and other significant variables from table 3.

These results highlight some between-country distinctions. The odds ratio is 0.3 for Luxembourg residents versus cross-border workers from France. This means that these cross-border workers use the car more often than resident workers. This part of the border separates urban space on the one hand (Luxembourg) from space that is less dense on the other hand (France). From the model, the most significant spatial variables are 'travel time by PT', 'direct train line' and 'direct bus line'. The cross-border workers from France living near the Luxembourg border have a PT network that is less efficient than that accessible to resident workers. Here there is no border effect as a barrier on mode choice because the more quality PT services that exist, the more individuals use PT, regardless of whether they live in France or Luxembourg. However, there is a border effect in terms of a discountinuity related to various PT qualities (price, frequency, etc.), which strongly decreases at the border outside Luxembourg.

The border effect is the opposite for cross-border workers from Germany living near the border of Luxembourg: they take PT more often than resident workers, even if PT services qualities decreases at the border between Luxembourg and Germany. Moreover, while PT use for cross-border workers from Germany is low (Table 1), those close to the border use significantly more PT than those living far from it (17% versus 10%). Here the border can be seen as an interface because cross-border workers from Germany cross the border to reach the PT network in Luxembourg, which is more efficient in terms of price, frequency or spatial servicing.

For Belgian cross-border workers the results are not significant. They do not use the car more or less than resident workers. Some previous studies highlight that discontinuities of PT qualities are lower at this border than between Luxembourg and France or Luxembourg and Germany. This result also confirms that when discontinuites of PT qualities at the border are weaker, the border effect on modal choice is also weaker. Moreover, this may be a modifiable area unit problem (MAUP; Openshaw, 1984) in our cross-border context. While in France and Germany we take into consideration a group of municipalities no further than 8 km from the border (municipalities adjacent to the Luxembourg border), in Belgium the large size of the adjacent municipalities makes the buffer larger (the boundary needed is a distance of up to 20 km from the Luxembourg border). Consequently, the results are not comparable: the border effect applies really apparent close to the border but is not significant at 20 km.

To take the analysis further, the last border effect indicator we investigate is related to network efficiency (Model 2b). In this part of the analysis, we want to use a different way to see if PT supply is directly linked with travel mode choice. This indicator may also confirm (or not) our results on the interface effect of the border. In other words, it should help us to determine whether our assumption that a decrease of PT availability, especially near the border, influences modal choice is correct. To do so, and using all the workers, we first compare the probability of using the car or PT depending on the part of the trip lying within Luxembourg (comparison of categories 0 and 5 to 10, then 1 and 6 to 11, and so on, in Figure 4). We assume that the more this part is important the more workers may use PT because they can use the better PT network within Luxembourg.

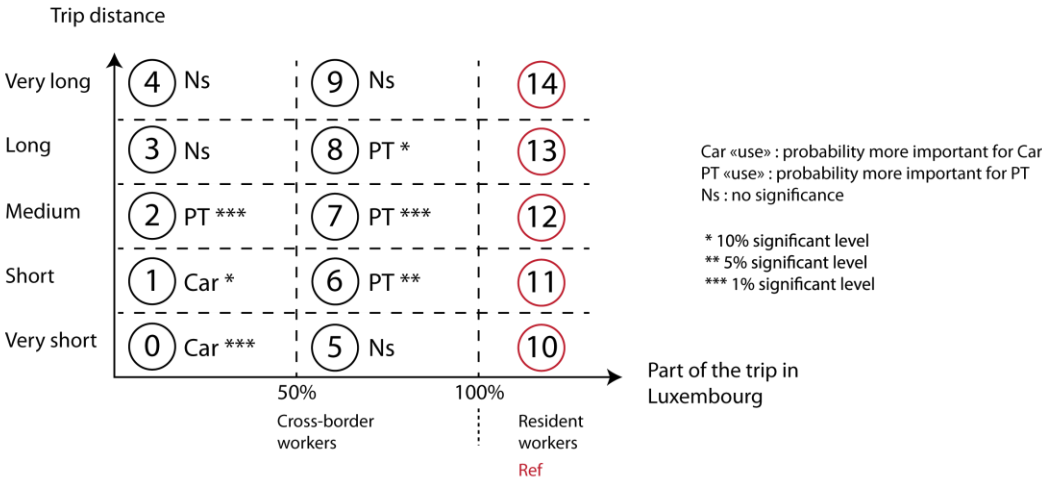

Figure 4. Model 2b: Network efficiency of the border effect indicator

The results reveal two distinct strategies according to the trip distance: resident workers use PT more often for short distances (categories 0 and 1) and cross-border workers use it more frequently for medium and long distances (categories 2, 7 and 8). This may be due to the decrease of PT supply at the border. For cross-border workers, the PT network seems to become attractive compared to the car for longer distances. For residents, it becomes attractive for short distances. In any case, despite better PT services for residents, they do not use PT more often than cross-border workers, all other things being equal.

Finally, a second border effect exists according to the part of the trip made within Luxembourg. The greater this part is, the higher the probability of using PT. For cross-border workers, the PT network seems to become attractive when the part of the trip lying within Luxembourg is greater. The strategy of some cross-border workers is to live near the border outside Luxembourg, even if the PT network there is less efficient, then use the better service in Luxembourg where necessary, especially to avoid congestion (category 6). This confirms that the border can be considered as an interface. This type of cross-border worker can access the good PT qualities of services provided in Luxembourg that are not available in their place of residence. In contrast, the accessibility of PT is better in dense municipalities in the bordering countries (categories 2 and 7), so cross-border workers who live in these dense areas can take advantage of PT directly from their place of residence. The part of the trip within Luxembourg does not therefore have an effect on mode choice for these categories.

6. Conclusion

Luxembourg and its borders still rely heavily on the car. Hence, the promotion of sustainable travel modes will bring many benefits to the government of Luxembourg both in terms of protection of the environment as well as in pollution reduction. Two new findings presented in this paper may aid decision-makers in formulating transport policy. First, depending on the country of residence, the proposed model highlights that significant variables are not similar for modal choice. This could go in the direction of more bilateral governance systems (as in the SMOT between France and Luxembourg, and upcoming between Germany and Luxembourg and between Luxembourg and Belgium). Second, there are certain border effects, territorial as well as functional, which may affect the travel mode choice. We highlight that, depending on the place of residence of cross-border workers (regardless of whether they are close to the border or not), the probability of using the car (or PT) differs. Moreover, depending on the proportion of the trip lying within Luxembourg, there are some differences between areas in the same country. Those with good PT accessibility make better use of PT, whatever the proportion of the distance of the trip lies within Luxembourg. So here functional integration is high. At the other end of the spectrum, less dense areas with a lower level of PT accessibility make less use of PT, except when workers can also use the PT of Luxembourg. Here the border effect is seen as an interface.

In addition, situational constraints also affect modal choice, especially in a cross-border area. The results indicate the complexity of cross-border representation with respect to social characteristics, accessibility and urban structure. Border effects do not always go in the same direction, and this entails further complexity. While we might expect the superior efficiency of the PT network in Luxembourg to encourage resident workers to use it, at the border between Germany and Luxembourg cross-border workers use PT more often than residents. Moreover, at equivalent distances, the probability of using PT is higher for cross-border workers than for residents, especially when the greater part of the trip is made within Luxembourg. Thus, it would appear that rather than there being a clearly defined barrier effect between Luxembourg and the other bordering countries (as a territorial effet; see Cattan and Grasland, 1994), it seems to be a question of the barrier effect varying between catchment areas, whatever the country of residence (Enaux and Gerber, 2008). Our results show that some spatial and urban structure variables are significant in the decisions on travel mode choice. Particularly, all groups of workers use PT more often when they have a direct PT line/route to reach their workplace. This gives a good insight into how to increase the use of sustainable modes of transport.

Finally, not only the results, but also the methodological framework presented in this paper, may be useful to decision-makers. On one hand, we aimed to use a methodological framework that was as simple as possible so that it could easily be used in other cross-border areas. The variables used do not require big data processing (even if the traffic model and GIS software are recommended for spatial analysis) and the model is based on a standard logit model. In addition, a large part of these variables are significant in terms of explaining travel mode choice and can be used in transport scenario assessments. For example, decision-makers could measure the impact on modal choice of new bus/train lines or new stations.

7. Perspectives

Some limitations to the developed model should be mentioned. First, we had to focus mainly on the socio-economic and spatial variables when comparing residents and cross-border workers because there was a lack of data available for both residents and cross-border workers in relation to some other variables, particularly those reflecting environmental concerns (e.g., mixed land-use) and those for perception such as habits and experience, trip chains, and the like. In addition, some variables such as travel time, travel distance and parking availability need to be more precise. For instance, concerning parking availability, we had to build this variable because this information was not available in the resident survey. It was difficult to obtain a related variable to estimate parking availability as the number of parking places in each city, so we used a probit model based on the data of the cross-border survey to estimate the parking at the workplaces of the residents (as either easy, difficult, or impossible) depending on the city of workplace and the socio-professional category. When assigning the category with the higher probability to each resident worker, none fell in the 'impossible' category, which may explain the insignificance of this variable for Luxembourg. Also, as regards 'place of residence', sometimes this was the city and somtimes it was the exact address, so again we lost a degree of precision because we had to reaggregate some data to maintain confidentiality. Lastly, all workers living in a given municipality and working in another were given the same spatial and urban structure values (density, direct lines, frequencies, etc.), whatever their precise location in that municipality. We know that in some larger municipalities this can make a big difference in terms of travel time or travel distance according to the area of residence or workplace.

Secondly, as briefly mentioned above, the spatial structure of our cross-border context may well be an example of a MAUP in that, for Belgium, the larger size of the municipalities in the border area under consideration could explain the absence of any significant variables. For example, concerning the border effect variables, in France and Germany we take into consideration a group of municipalities no further than 8 km from the Luxembourg border. In Belgium the large size of the municipalities makes it impossible to use the same method: the buffer is much larger (the boundary needed was a distance of up to 20 km from the Luxembourg border) and, consequently, the results are not comparable. The border effect applies really apparent close to the border but may be not significant at 20 km.

Lastly, in terms of enhancing the model used in this study, we could adapt it to test the effects of different groups of variables, which can be too correlated. To do so, we could build cross-variables or use other type of techniques such as structural modelling equations (e.g. Simma and Axhausen, 2001; Ory and Mokhtarian, 2009). Nevertheless, we would still prefer to develop a comprehensive model that can show the effects of a wide variety of separate variables that is as simple as possible and that can be easily applied to other cross-border areas. Moreover, to improve the model further, it would be interesting to integrate multimodal travel choice modelling to investigate how workers could combine multiple travel modes to perform a single trip.

Currently, the developed model provides a good degree of information about the level of functional integration and is therefore a useful decision-making tool, even if it needs further refinement by, for example, including other barrier effect variables such as labour market differentials to measure other integration levels.

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Appendix 1. Results for unsustainable mode choice (car) with socio-demographic, urban structure and spatial variables (model 1)

	Luxembourg		**France**		**Belgium**		**Germany**	
	Coefficient	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**	**Coefficient**	**Odds ratio**
Socio-Demographic Indicators								
Gender: Male	0.312(2.280)*	1.367	0.527(3.975)**	1.694	Ns		Ns	
Gender: Female	Ref	-	Ref	-	Ref	-	Ref	-
Age: 30 years and under	Ns		Ns		0.735(2.125)*	2.085	Ns	
Age: 31-36 years	Ns		Ns		1.075(3.286)**	2.929	Ns	
Age: 37-41 years	Ns		Ns		Ns	1.414	Ns	
Age: 42-47 years	Ns		Ns		Ns	1.169	Ns	
Age: 48 years and more	Ref	-	Ref	-	Ref	-	Ref	-
Level of education = secondary and under	Ns		0.277(1.859)*	1.319	Ns		Ns	
Level of education = high school	Ref	-	Ref	-	Ref		Ref	-
Number of children = 0	-0.633(-3.955)**	0.531	-0.555(-3.769)**	0.574	Ns		Ns	
Number of children = 1	-0.448(-2.626)**	0.639	Ns	0.810	Ns		Ns	
Number of children = 2 and more	Ref	-	Ref	-	Ref	-	Ref	-
Housing = Individual house	0.483(3.607)**	1.622	Ns		1.196(4.171)**	3.308	Ns	
Housing = Apartment and other	Ref	-	Ref	-	Ref	-	Ref	-
Household type = single	0.408(2.034)*	1.504	Ns		Ns		Ns	
Household type = 2 people and more	Ref	-	Ref	-	Ref	-	Ref	-
Socio-Economic Indicators								
Socio-Prof cat = senior executives	Ns	1.376	-1.124(-3.372)**	0.325	0.944(2.019)*	2.571	Ns	
Socio-Prof cat =employee, technicians	Ns	1.092	-0.905(-3.031)**	0.405	Ns	1.670	Ns	
Socio-Prof cat =artisan, retail trader	0.579(2.454)*	1.784	Ns	0.787	0.954(2.116)*	2.596	Ns	
Socio-Prof cat =workers, labourer	Ref	-	Ref	-	Ref	-	Ref	-

Employment = Part-time	0.359(2.154)*	1.432	Ns		Ns		Ns	
Employment = Full-time	Ref	-	Ref	-	Ref	-	Ref	-
Income of household = Low	-1.005(-3.646)**	0.366			Ns		-1.866(-3.467)**	0.155
Income of household = Medium	-0.486(-2.000)*	0.615	Ns		Ns		-0.810(-2.951)**	0.445
Income of household = High	Ref	-	Ref	-	Ref	-	Ref	-
Cars in the household = no	-2.343(-8.226)**	0.096	Ns		Ns		Ns	
Cars in the household = yes	Ref	-	Ref	-	Ref	-	Ref	-
Driving licence = no	-2.692 (-12.338)**	0.068	-2.456(-4.404)**	0.086	Ns		Ns	
Driving licence = yes	Ref	-	Ref	-	Ref	-	Ref	-
Urban structure indicators								
Density of pop at residence = Very Weak	Ns		0.641(2.260)*	1.889	Ns		Ns	
Density of pop at residence = Weak	Ns		0.828(2.935)**	2.288	Ns		Ns	
Density of pop at residence = High	Ns		Ns	1.515	Ns		Ns	
Density of pop at residence = Very High	Ref	-	Ref	-	Ref	-	Ref	-
Municipality of residence = City	Ns		Ns		Ns		Ns	
Municipality of residence =Other	Ref	-	Ref	-	Ref	-	Ref	-
Avail. of parking at workplace = easy	Ns		2.849(11.230)**	17.267	3.019(8.144)**	20.472	1.810(2.469)*	6.109
Avail. of parking at workplace = some problems	Ns		0.593(2.309)*	1.810	Ns		Ns	
Avail. of parking at workplace = impossible	Ref	-	Ref	-	Ref	-	Ref	-
Spatial indicators: accessibility to transport network								
Direct bus line to workplace = no	Ns		Ns		0.591(2.301)*	1.807	1.493(4.781)**	2.413
Direct bus line to workplace = yes	Ref		Ref		Ref		Ref	
Direct train line to workplace = no	0.969(6.690)**	2.636	0.878(4.179)**	2.407	0.585(2.185)*	1.796	Ns	
Direct train line to workplace = yes	Ref	-	Ref	-	Ref	-	Ref	-
PT station at residence with direct access to Luxembourg-city = None	1.397(3.000)**	4.044	Ns		Ns		Ns	

PT station at residence with direct access to Luxembourg-city = Very Weak	1.247(2.873)**	3.481	Ns		Ns		1.098(2.255)*	2.998
PT station at residence with direct access to Luxembourg-city = Weak	0.881(2.828)**	2.413	-0.871(-1.829)*	0.419	Ns		1.443(3.315)**	4.232
PT station at residence with direct access to Luxembourg-city = Medium	Ns		-1.723(-2.641)**	0.179	Ns		1.466(3.243)**	4.332
PT station at residence with direct access to Luxembourg-city = High	Ns		Ref		Ns		Ref	
PT station atresidence with direct access to Luxembourg-city = Very High	Ref	-	Ref	-	Ref	-	Ref	-
Frequency of PT per day = None	Ns		Ns		1.213(2.271)*	3.288	Ns	
Frequency of PT per day = Very Weak	Ns		Ns		0.963(2.082)*	2.532	Ns	
Frequency of PT per day = Weak	Ns		Ns		Ns		Ns	
Frequency of PT per day = Medium	Ns		Ns		Ref	-	Ns	-
Frequency of PT per day = High	Ns		Ns				Ns	
Frequency of PT per day = Very High	Ref	-	Ref	-			Ref	-
Spatial indicators: accessibility in transport network								
Travel time by car = Very Short	1.487(2.753)*	4.422	2.564(3.265)**	12.232	Ns		Ns	
Travel time by car = Short	Ns		1.567(4.722)**	4.717	1.536(3.101)**	4.446	Ns	
Travel time by car = Medium	Ns		0.505(2.107)*	1.612	1.295(3.567)**	3.649	Ns	
Travel time by car = Long	Ns		Ns		0.842(2.619)**	2.320	Ns	
Travel time by car = Very Long	Ref	-	Ref	-	Ref	-	Ref	-
Travel time by PT = Very Short	Ns		-0.919(-2.742)**	0.399	Ns		Ns	
Travel time by PT = short	-0.756(-2.870)**	0.484	-0.666(-2.098)*	0.514	-1.783(-4.448)**	0.168	-1.059(-2.793)**	0.347
Travel time by PT = medium	-0.810(3.228)**	0.468	Ns		-0.930(.2.372)*	0.395	-0.686(-1.979)*	0.504
Travel time by PT = long	-0.380(-2.069)*	0.694	Ns		Ns		Ns	
Travel time by PT = Very Long	Ref	-	Ref	-	Ref	-	Ref	-
N	3,099		2,470		1,395		1,285	
R^2 (Nagelkerke)	0.366		0.422		0.438		0.310	

* 5% significant level
** 1% significant level

Appendix 2: Results of network efficiency of the border effect indicator (model 2b)

Category	Coefficient	Odds ratio
0	1.549(3.430)***	4.697
5	-0.312(-0.846)	0.732
10	Ref	-

Category	Coefficient	Odds ratio
1	0.418(1.763)*	1.519
6	-0.519(-2.237)**	0.595
11	Ref	-

Category	Coefficient	Odds ratio
2	-1.243(-3.678)***	0.288
7	-1.541(-4.698)***	0.214
12	Ref	-

Category	Coefficient	Odds ratio
3	Ns	
8	-0.404(-1.896)*	0.667
13	Ref	-

Category	Coefficient	Odds ratio
4	Ns	
9	Ns	
14	Ref	-

* 10% significant level
** 5% significant level
** 1% significant level

* Note: This summary is a result from a logit model with network efficiency indicator and significant variables from table1.