

# Trends in regional jobs-housing proximity based on the minimum commute: the case of Belgium

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## Abstract

This paper investigates recent trends in the efficiency of the Belgian territorial structure in terms of commuting, at both the urban and regional scales. The minimum commute distance (MCD) and excess rate (ER) are used to compare observed home-to-work trip lengths with an "optimal" alternative commuter pattern in which the sum of the distance traveled by the working population is minimized. The MCD is a proximity indicator that measures the spatial match between the labor market and the housing stock, which can also be regarded as an interesting indicator of potential border effects on travel behavior, especially in the inter-regional context of Belgium. An MCD calculation requires an origin-destination (OD) matrix and a distance matrix. In our Belgian case study, we employ a recent OD matrix (2010) originating from Social Security (ONSS) data. We compare this matrix with data from the 2001 and 1991 census surveys. In addition to identifying trends in jobs-housing proximity, the article assesses methodological implications regarding geographical scale arising from the use of the two data sources mentioned. Based on the available data, it was found that average actual commuting distance increased over both periods studied, while in general, growth rates of MCD are considerably lower than growth rates of the actual commuting distance. This indicates that the spatial proximity between the labour market and the housing stock in Belgium has declined over all periods studied, although this loss of spatial proximity only explains a small part of the increase of the actual commuting distance. Furthermore, we found that the comparison of excess commuting metrics between regions and time periods sets high standards on data requirements, in which uniformity in data collection and spatial level of aggregation is of great importance. Finally, as the main contribution of this study, the results demonstrate, through a statistical approach, that municipalities that are experiencing a higher-than-average increase in MCD and ER in one of the considered time frames are more likely to continue to exhibit a higher-than-average increase in the subsequent period. Therefore, the observed trends appear to be consistent over time.

**Keywords:** Excess commuting, jobs-housing balance, border effects, Belgium

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## 32 **1. Introduction**

33 In the 1970s, most industrial countries experienced a general energy crisis, involving petroleum short-  
34 ages and high oil prices. In response to this crisis, governments all over the world recognized the necessity  
35 of developing a strong policy with the aim of greater independence from oil and increased energy efficiency.  
36 Consequently, in the early 1990s, further increases in energy prices and more pronounced concerns about  
37 livability, sustainability and climate protection forced authorities to take energy issues at both local and  
38 global scales into serious consideration (Blanco et al., 2009). In this context, Hamilton highlighted the  
39 necessity of understanding urban commuting efficiency by introducing the concept of excess or wasteful  
40 commuting (Hamilton and Röell, 1982). This excess was defined as the difference between the actual mean  
41 commute and the theoretical minimized mean commute based on the spatial structure of the considered city  
42 (Hamilton and Röell, 1982). This measure is an interesting indicator of how urban spatial structure may  
43 influence travel distances for commuting and the associated levels of fuel consumption.

44 As outlined by Boussauw et al. (2011), several reports related to transportation policy and mobility  
45 management have emphasized the importance of spatial planning as a key area of policy, which has the  
46 potential to improve the sustainability and efficiency of mobility patterns. Indeed, the territorial structure of  
47 a region, which constrains the interactions between morphological elements and activities, is regarded as an  
48 important factor in explaining travel patterns (e.g., patterns resulting from commuting behavior) (Dujardin  
49 et al., 2012; Giuliano and Small, 1993; Van Acker et al., 2007). Various studies have revealed that commut-  
50 ing distances have been continuously increasing, especially in European and North American metropolitan  
51 areas, mainly driven by households' aspirations to combine the challenge of dual careers with a pleas-  
52 ant residential environment (Aguilera, 2005; Banister et al., 1997; Sandow and Westin, 2010; Sharma and  
53 Chandrasekhar, 2014). In contrast to these increasing travel distances, travel times have remained relatively  
54 constant because of the urge to employ ever faster means of transport (Ma and Banister, 2006a). Boussauw  
55 et al. (2011) argued the importance of distinguishing between the main reasons for expanding commute  
56 patterns, such as land-use policies and general growth in prosperity, and other factors such as congestion  
57 levels, the quality of the transportation network, and the market price of fuel. In this regard, the concept of  
58 excess commuting might help to better understand mechanisms underlying trends in commuting distance.

59 Originally, excess commuting analyses were applied to monocentric urban models (Hamilton and Röell,  
60 1982), after which concerns were raised about the implications with respect to actual metropolitan urban  
61 structures and about the applicability of the traditional urban economics model to modern metropolitan areas  
62 (Ma and Banister, 2006a). In this context, White (1988) re-examined the principle of cost minimization

63 by considering the minimized excess commute from a "transportation problem" perspective. Following  
64 White's work, no equivalent to the "transportation problem"-based approach arose until recent years. Over  
65 the past two decades, the main issues addressed have been related to explaining the underlying reasons for  
66 excess commuting (Aguilera, 2005; Banister et al., 1997; Rouwendal, 1999; Sandow and Westin, 2010;  
67 Sharma and Chandrasekhar, 2014), estimations of regional variations in jobs-housing proximity and the  
68 associated excess commuting (Boussauw et al., 2011; Frost et al., 1998; Lee, 2012; Rodriguez, 2004), and  
69 detailed assessments of jobs-housing imbalances (Jiangping et al., 2014; Loo and Chow, 2011; Suzuki and  
70 Lee, 2012; Wang and Chai, 2009; Zhao et al., 2011; Zhou et al., 2012).

71 From a methodological perspective, Boussauw et al. (2011) proposed an extension to the work of  
72 Niedzielski (2006) and Yang and Ferreira (2008). Two indicators were proposed to characterize spatially  
73 homogeneous non-monocentric entities, i.e., the minimum commuting distance and excess commuting.  
74 Boussauw et al. (2011) used these indicators as metrics for spatial proximity, considering physical distance  
75 instead of time distance because of their focus on environmental concerns and fuel dependency. Further-  
76 more, they assumed the existence of important regional variations in minimum commuting distances and  
77 excess commuting, for which connections with spatial characteristics (e.g., density, functional mix or prox-  
78 imity to major transportation infrastructures) can be established.

79 In the current study, we assess the indicators of the minimum commute distance (MCD) and the excess  
80 rate (ER) in order to study the efficiency of the Belgian territorial structure in terms of commuting, at both  
81 urban and regional scales. This approach allows a comparison of observed trip lengths with the lengths  
82 of trips in an "optimal" alternative overall travel pattern in which the sum of the distances traveled by the  
83 working population is minimized. The trip length after minimization is represented by the MCD, whereas  
84 the ER is the ratio between the MCD and the observed trip length of the actual commute.

85 This paper contributes to the state of the art in this field of research in several respects. First, it extends  
86 the geographical scope of previous research efforts such as that of Boussauw et al. (2011) to cover all re-  
87 gions of Belgium, enabling an intraregional comparison. Second, this study verifies whether conclusions  
88 with respect to commuting behavior are consistent across different types of data sources. In particular, ESE  
89 1991 and 2001 data and ONSS 2010 data are used in this study, whereas previous research such as that of  
90 Boussauw et al. (2011) has focused on regional travel surveys. Third, this paper assesses the temporal con-  
91 tinuity of the evolution of the minimum commute across different regions of Belgium (Flanders, Brussels,  
92 and Wallonia) by investigating the trends of the MCD and ER indicators. Fourth, the paper contributes to  
93 the existing literature by critically assessing spatial-scale effects on the level of accuracy with which the

94 MCD and ER can be measured. Furthermore, we argue that despite differences in regional policies and  
95 economies, the national scale of Belgium should be considered paramount in the context of home-to-work  
96 distances, given the large interdependency between the three regions with regard to the distributions of jobs  
97 and housing (Dujardin et al., 2012). Interestingly, the MCD appears useful as an indicator of potential  
98 border effects on travel behavior, especially between Luxembourg and Belgium.

99 Although excess commuting was presented earlier as a standardized way of describing urban structures,  
100 we yet want to present our research explicitly as a regional case study, about which we do not necessarily  
101 argue that the results are generalizable. The reasons therefore are partly of geographical nature (two-thirds  
102 of Belgium consist of a particular polycentric urban network, the functioning of which is strongly affected  
103 by language border effects) (van Meeteren et al., 2016), and otherwise of methodological nature (available  
104 data is usually aggregated within administrative boundaries, which makes comparison with other cases  
105 difficult). Following Flyvbjerg (2006), we argue that despite the possibly non-generalizable results of our  
106 research, this case study certainly contributes to a better understanding of the functioning of polycentric,  
107 networked, urban systems.

108 Our research hypotheses are formulated as follows:

- 109 1. The average actual commuting distance in Belgium is growing continuously, while the rate of growth  
110 is slowing down over the last study period, as compared to the previous periods. At the one hand, this  
111 hypothesis is fuelled by the known general trend of growth of personal mobility, while at the other  
112 hand the "peak car" phenomenon that was found in several western countries is at stake (Goodwin,  
113 2012).
- 114 2. The growth of the actual commuting distance is partly attributable to a decrease of spatial proximity  
115 between the housing market and the labour market, measured by means of the calculated minimum  
116 commuting distance (MCD), and by non-spatial developments such as an increasing degree of spe-  
117 cialization of the labour market and a general increase in wealth, which has an impact on the housing  
118 preferences of consumers. Regional trends in spatial proximity loss (or gain) and commuting effi-  
119 ciency are consistent over time.
- 120 3. Collection of data that is consistent over time and therefore mutually comparable is of great impor-  
121 tance to be able to quantify phenomena such as those described in hypothesis no.2.
- 122 4. Due to methodological problems, such as the modifiable areal unit problem (MAUP), and assump-  
123 tions with respect to intra-zonal trips, both the actual and the minimum commuting distance do not  
124 necessarily have an absolute meaning, and may even be inappropriate to compare areas. By contrast,

125 these metrics do prove meaningful for analyzing trends over time.

126 In order to address the research hypotheses as defined above, the paper is structured as follows. First, a  
127 concise literature review on excess commuting and jobs-housing balance is presented in Section 2. Section 3  
128 describes the Social Security data (ONSS: Office National de Sécurité Sociale) and the 2001 Census data  
129 used in this study and is followed by a discussion of the methodology in Section 4. Subsequently, the main  
130 research results are reported in Section 5 and are discussed in Section 6. Finally, Section 7 summarizes the  
131 main conclusions of this study.

132 In the remainder of this paper, we distinguish between the MCD at the origin (i.e., zones viewed as  
133 residential areas) and at the destination (i.e., zones viewed as working areas). We make a similar distinction  
134 with respect to the ER. Therefore, the corresponding MCD and ER measures are respectively abbreviated  
135 as MCDo and MCDd, and as ERO and ERd.

## 136 **2. Literature review**

137 In many places in the world, actual commuting distances have been growing continuously, although  
138 the rate of growth might have slowed down in recent years. Such growth may be partly attributable to a  
139 decrease of spatial proximity between the housing market and the labor market. For example, Horner and  
140 Murray (2003) proposed a multi-objective approach to assess policy measures geared towards improving  
141 jobs-housing balance at the regional scale. That study revealed that policies specifically dedicated to the  
142 geographical relocation of workers have a higher impact than those that act directly on job locations to  
143 mitigate the average minimum commute. Based on these findings, the authors considered several planning  
144 scenarios in which specific levels of residential and job growth in particular areas were favored to decrease  
145 commuting. Furthermore, they emphasized that minor reallocations of workers could contribute to a sig-  
146 nificant decrease in the average minimum commute. However, the framework presented by Horner and  
147 Murray (2003) does not account for the differences between job types, as the authors assumed complete  
148 interchangeability of workers. Moreover, the control of spatial correlations and the jobs-housing balance  
149 could also mitigate commuting distances (Suzuki and Lee, 2012).

150 In the context of a bi-level analysis at both micro- and macroscales, Buliung and Kanaroglou (2002)  
151 have indicated that at the microscale, gender and household composition affect commuting distances. In  
152 view of this effect, the distributions of job locations and workers are not necessarily sufficient to explain the  
153 observed commuting patterns (Buliung and Kanaroglou, 2002). As outlined by Buliung and Kanaroglou  
154 (2002), the formulation of the excess commute lacks sufficient consideration of behavioral factors and relies

155 on certain assumptions. Aspects related to wealth may also contribute to growing commuting distances.  
156 Indeed, for lower-income and lower-skilled individuals, jobs-housing proximity matters as they tend to be  
157 constrained by the daily commuting costs (McLafferty, 1997). Their job search area is smaller as they  
158 generally face spatial barriers to employment. In contrast, higher-income and higher-skilled individuals can  
159 afford to travel larger distances as other factors, such as individual preferences in terms of employment and  
160 housing, get more important (Kneebone and Holmes, 2015).

161 Besides, older female workers and female workers with young children are more reluctant to accept  
162 jobs that are remote from their residential locations (Rouwendal, 1999). In addition, mothers with young  
163 children generally prefer to work part-time so that they can use more time for private purposes. Additionally,  
164 the location choices of employers within a given area are also important to ensure that their job openings are  
165 filled in an acceptable period of time (Rouwendal, 1999). In this context, the spatial aspects of the locations  
166 of jobs with respect to workers appear to play an important role.

167 Furthermore, multiple factors can be involved in the decision-making process regarding occupational  
168 and residential locations, e.g., the gender of the decision-maker and the household income (Niedzielski,  
169 2006). With respect to the level of income, Niedzielski (2006) has previously indicated the crucial role of  
170 this factor in commuting efficiency. For example, in a richer area, people tend to travel longer distances  
171 compared with workers coming from poorer areas. Such observations confirm that people are willing to  
172 accept longer commuting distances as long as their jobs are worth it, trading trip length for job satisfaction.  
173 This is consistent with Van Ommeren et al. (1997). Besides, Niedzielski (2006) also outlined similar trends  
174 when he analyzed the spatial variations in commuting efficiency in four Polish cities.

175 From a methodological perspective, Murphy and Killen (2010) used the concept of random commuting  
176 to propose two new indicators: commuting economy and normalized commuting economy. They con-  
177 cluded that choosing a random commute leads to specific behavior in which the cost is not considered in the  
178 decision-making process. Furthermore, the proposed framework assesses to what extent individuals econ-  
179 omize their commuting costs from a collective perspective. It has been shown that the observed average  
180 commute has shifted away from the average random commute, meaning that improved commuting effi-  
181 ciency has been achieved. Indeed, this can be explained as a result of the heterogenic merging of residential  
182 and employment patterns (Murphy and Killen, 2010). Based on a disaggregate analysis of the choice of  
183 transport modes, Murphy (2009) investigated the excess commute for two time periods (1991 and 2001).  
184 His findings revealed that the excess commute for users of private transport is higher than that for users of  
185 other modes.

186 Additionally, Buliung and Kanaroglou (2002) outlined the importance of paying attention to potential  
187 transferability. Indeed, it is difficult to confirm that the findings for one area are also true for other geograph-  
188 ical areas. Suzuki and Lee (2012) confirmed the previous statements. One must take care when comparing  
189 the efficiency of urban structures for different cities. In this regard, excess commute and capacity utilization  
190 should be considered simultaneously to assess the efficiency of the urban structure of an area.

191 The measurement of commute metrics can be associated with potential uncertainties. In this regard,  
192 Hu and Wang (2015) applied a Monte-Carlo-based approach to show that the reported commuting times of  
193 respondents and the scale of analysis can contribute to miscalculation of the excess commute. In another  
194 study, Horner and Murray (2002) measured the impact of the MAUP on the excess commute in urban  
195 regions, showing that spatial effects and the definition of the areal unit problem in particular may have an  
196 important impact on excess commute patterns.

197 The metrics used to study commuting efficiency and the jobs-housing balance can be affected, some-  
198 times significantly, by the partitioning of zones and the zone sizes corresponding to various levels of ag-  
199 gregation. In this regard, Niedzielski et al. (2013) investigated the effects of scale on jobs-housing and  
200 commute efficiency metrics to assess the magnitude of scale effects. Surprisingly, they observed that the  
201 metrics proposed after 2002 are completely unaffected by changes in scale. By contrast, those introduced  
202 in the pre-2002 period are subject to relative variations, although these variations can be predicted. As an  
203 extension of the work of Horner and Murray (2002), MAUP effects on three different metrics, namely, the  
204 theoretical minimum commute, the theoretical random commute and the theoretical maximum commute,  
205 have been measured (Niedzielski et al., 2013). That study confirmed the insensitivity of these metrics to  
206 changes in scale. However, these findings are valid only for the specific case study considered in Niedziel-  
207 ski et al. (2013) and cannot be guaranteed for other regions, particularly urban agglomerations exhibiting a  
208 polycentric structure. Therefore, the effects of the MAUP on the commute metrics used in this study will  
209 be briefly investigated in this paper.

210 To distinguish between job characteristics and worker characteristics, O'Kelly and Lee (2005) proposed  
211 a method of disaggregating the total commuting flows within the excess commute framework. They re-  
212 vealed that the disaggregation procedure has certain implications regarding the excess commute and the  
213 jobs-housing balance. Furthermore, investigations of excess commute patterns and jobs-housing proxim-  
214 ity may be subject to measurement uncertainties. From that perspective, based on a set of computational  
215 experiments, Horner (2010) highlighted the existence of variability in estimated commuting patterns due  
216 to uncertainties in travel time. One can refer to the work of Kanaroglou et al. (2015) for an overview of

217 the major commuting benchmarks and excess commuting indices. In this review paper, the advantages  
218 and limitations of the various concepts are identified from a comparative perspective. Their performances  
219 within the commuting efficiency framework are also investigated. Furthermore, the excess commute frame-  
220 work has also been applied in the context of non-work trips (Boussauw et al., 2012; Horner and O’Kelly,  
221 2007). For example, by considering the spatial structure of Flanders and non-professional trips in that re-  
222 gion, Boussauw et al. (2012) demonstrated that travel distances are more important in rural areas than in  
223 urbanized areas, as opposed to excess rate patterns.

224 As an extension of the excess commute framework, Ma and Banister (2006b) proposed a technique for  
225 quantitatively and qualitatively characterizing the jobs-housing imbalance in Seoul. Their findings revealed  
226 that between 1990 and 2000, commuters attempted to mitigate the imbalance from the time perspective  
227 rather than the distance perspective. In a generalized framework, Horner (2002) established connections  
228 between excess commuting, urban sprawl and urban sustainability. He proposed an alternative understand-  
229 ing of the excess commute issue. Specifically, he first determined the commuting capacity of a city and  
230 then estimated the extent to which the "available" commute capacity was consumed by the observed one.  
231 The results of that study suggest some differences between the excess commute and the consumed potential  
232 commute (Horner, 2002).

233 The concepts of the minimum and maximum commute have been criticized for a lack of real spatial  
234 behavior. In this context, Charron (2007) argued that  $C_{min}$  and  $C_{max}$  are simply extreme values of a richer  
235 distribution. To capture new trends in terms of commuting patterns, the authors generated the distribution of  
236 urban forms associated with each city and compared the different distributions. This approach is particularly  
237 well suited for comparing commuting patterns in terms of means and standard deviations.

238 Besides, the manner in which data are collected for determining excess commute metrics is of great  
239 concern. Zhou et al. (2014) have shown that using smart-card data in addition to household travel surveys  
240 is a particularly interesting method of determining excess commute metrics. They compared the minimum  
241 commute and the excess commute for two different transport modes in Beijing, namely, car and bus. Their  
242 findings revealed that bus use was associated with a better jobs-housing balance compared to car use.  
243 Indeed, car users lived farther away from the city center. In this regard, the results of Zhou et al. (2014)  
244 confirmed the findings of Murphy (2009). Consistency of longitudinal data collection and comparison is  
245 of great importance in order to quantify phenomena such as those described above. In the current paper, a  
246 particular attention will be paid to such data consistency issues.

247 In summary, we could consider MCD as a metric that quantifies spatial proximity between the job

248 market and the housing stock. ER should be considered a metric that quantifies commuting efficiency  
249 in relation to the underlying spatial structure. Both metrics prove useful in developing regional planning  
250 policy, as they identify regions with oversupply of housing, undersupply of jobs, and overconsumption of  
251 transport. In practice, however, comparison of regions in terms of excess commuting metrics often not that  
252 straightforward due to a lack of standardization in terms of data collection and spatial aggregation of data.

### 253 **3. Data**

254 In order to investigate the evolution of the MCD and ER, data was obtained from two different types  
255 of sources . The first type corresponds to population censuses, in which, in addition to basic socio-  
256 demographic information, information about professional activities and corresponding trips is collected.  
257 The value of using such data sources is highlighted by Cools et al. (2010) in the context of OD matrix  
258 estimation. It is important to note that the census collects information about the entire Belgian population  
259 (over 10 million persons). In this study, information from the 1991 and 2001 censuses is used. Unfor-  
260 tunately, since 2011, the traditional decennial census has been discontinued. Therefore, various existing  
261 databases are used to synthesize a 2010 commuting OD matrix. This commuting matrix is provided by  
262 the ONSS (Social Security) service. It should be noted that information obtained from the latter source  
263 is partially biased by the fact that it does not record independent workers or those working abroad, since  
264 such employees depend on other social security services. Therefore, in addition to assessing trends, the  
265 current research briefly addresses the effects of variety in scales, institutional borders (especially the bor-  
266 der with Luxembourg), and data sources on the MCD and ER metrics obtained. Furthermore, it should be  
267 emphasized that at present, Social Security data in Belgium are only available at the municipal scale level.  
268 Besides, the practice of allocating each job to just one municipality should be treated with some caution  
269 because for some limited number of enterprises, information about employment may not be available at the  
270 fine-grain level of enterprise sites but may rather be aggregated at the scale of the entire company. In such  
271 cases, the connection between jobs and destinations is based on estimates. However, the overall effect of  
272 this replacement procedure is negligible.

### 273 **4. Methodology**

274 From a methodological point of view, our calculations of the MCD and ER are based on an iterative  
275 algorithm that was developed by Boussauw et al. (2011) for Flanders and Brussels. This algorithm is  
276 elaborated through a global optimization process performed in several local optimization cycles. Although

277 the resulting values are 11 to 15% larger than the solutions generated by classical programs (e.g., lpsolve),  
278 this method performs better in terms of local optimization (Boussauw et al., 2011).

279 In this study, the data are aggregated into municipalities, which serve as traffic analysis zones (TAZ).  
280 Within each zone, the model matches as many departures as possible with arrivals observed in the same  
281 municipality (the intrazonal level). Then, the remaining deficit or surplus is matched with the nearest zone  
282 (the interzonal level). The distances covered in all modeled trips are progressively recorded. This process  
283 is repeated until all departures are matched with all arrivals. Although, in principle, the methodology works  
284 regardless of the chosen scale, the geographical units into which the data are aggregated (municipalities)  
285 have some limited impact on the results.

286 In our analysis, the physical distance  $d_{ij}$  between two zones is defined as the distance between their  
287 respective centroids. Thus, the shortest paths between all pairs of centroids in the network are computed  
288 using as-the-crow-flies distances. Hence, an OD distance matrix  $c_{ij}$  is obtained, in which both the rows  $i$   
289 and columns  $j$  correspond to zones. The cells represent the shortest distances between zone  $i$  and zone  $j$ .  
290 Generally, intrazonal trip lengths have not been considered in previous models (O’Kelly and Lee, 2005).  
291 In our study, intrazonal trips are represented by taking half of the distance between the centroid of a given  
292 zone and the closest centroid of an adjacent zone. By combining the OD matrix with the distance (cost)  
293 matrix, the total distance traveled can be calculated for each zone. This aggregated calculation is performed  
294 twice: once for the trips departing from the zone during a given time frame (e.g., the morning rush) and  
295 once for the trips arriving in the considered zone. A more detailed description of the algorithm is available  
296 in Boussauw et al. (2011).

297 In addition to a static analysis, this paper also presents an assessment of the spatio-temporal dependency  
298 of changes in the MCD. To this end, we investigate whether zones in which the jobs-housing proximity was  
299 declining more rapidly than average in the 1991-2001 period showed the same trend in the period of 2001-  
300 2010. In particular, the relative increase in the MCD per time period is calculated for each municipality.  
301 For each time period, a dummy variable indicates whether the relative increase in the MCD is above (1)  
302 or below or equal to (0) the mean or the median. Fisher’s exact test is adopted to check the dependency  
303 between the two dummy variables. If the null hypothesis (independence) is rejected, then this implies that  
304 zones in which the value of the considered metrics increased (decreased) over the first period (1991-2001)  
305 showed a continuous growth (decline) during the subsequent period (2001-2010). Note that we have chosen  
306 a non-parametric test because the assumptions of the parametric alternative (the Pearson chi-square test) are  
307 not met.

308 **5. Results**

309 *5.1. General trend between 1991 and 2010*

310 To obtain preliminary insight into the evolution of the jobs-housing proximity patterns in Belgium and  
 311 its three regions, Table 1 presents the mean MCD and ER values for three moments in time (1991, 2001,  
 312 and 2010), weighted by the working population in each municipality. From this table, one can observe that  
 313 the lowest values of the MCD at the origin correspond to the capital area of Brussels, whereas the MCD  
 314 at the destination (see Figures 2a, 2c and 2e) is high in Brussels. This meets original expectations because  
 315 the capital accommodates an important concentration of service industries and government activities while  
 316 also serving as a main center of employment for the entire country. A similar observation can be made for  
 317 the Antwerp conurbation, where the international port serves as a main source of employment.

318 When comparing Flanders and Wallonia, although the at-destination MCDs are quite similar, the at-  
 319 origin MCDs appear larger for Wallonia. This means that globally, Walloon inhabitants must take longer  
 320 trips to reach their places of work, which are generally situated at the periphery of major Walloon cities or  
 321 in industrial zones along highways. This difference is also related to the dependency of jobs on the wider  
 322 Brussels catchment area and the relative lack of jobs in the southern area of Belgium.

	Belgium (N = 589)			Wallonia (N = 262)			Flanders (N = 308)			Brussels (N = 19)		
Year	1991	2001	2010	1991	2001	2010	1991	2001	2010	1991	2001	2010
Actual commute (observed from OD)	12.7	14.3	20.5	14.4	16.9	24.4	12.7	14.1	20.0	6.8	7.4	10.9
MCD at origin	9.8	10.1	10.9	11.3	12	13.2	9.9	10.1	10.8	3.9	3.9	3.9
MCD at destination	6.9	7.1	7.6	6.4	6.5	6.5	6.4	6.6	6.9	12.1	13.8	16.6
ER at origin	1.7	1.9	2.7	1.7	2	2.8	1.7	1.9	2.7	1.8	2	2.9

Table 1: Comparison between the mean actual commute, MCD and ERo values in 1991, 2001 and 2010 for the three Belgian regions and Belgium as a whole

323 Interestingly, the actual commutes appear to have increased much more rapidly than the MCD metrics,  
 324 which is also reflected in the growing ERo values. This suggests that people are traveling ever longer  
 325 distances for their jobs, although the jobs-housing proximity has decreased only slightly (see also Figure 1).

326 Table 1 shows that from 2001 tot 2010, the actual commute increased significantly. However, this trend  
 327 is not in line with the results of recent surveys (Cornelis et al., 2012), which seem to indicate that even in  
 328 Belgium we can to a certain extent talk about "peak car", which in the actual commute is reflected as a ten-  
 329 dency towards stabilization. The inconsistency between our findings and the aforementioned survey results  
 330 may be partly due to data issues, which will be discussed further. The MCDo increased by 3.0% between  
 331 1991 and 2001 and by 7.6% between 2001 and 2010 in Belgium. This change was more pronounced in  
 332 Wallonia (5.7% and 9.9%, respectively). ERo increased by 13.3% between 1991 and 2001 and by 43.5%

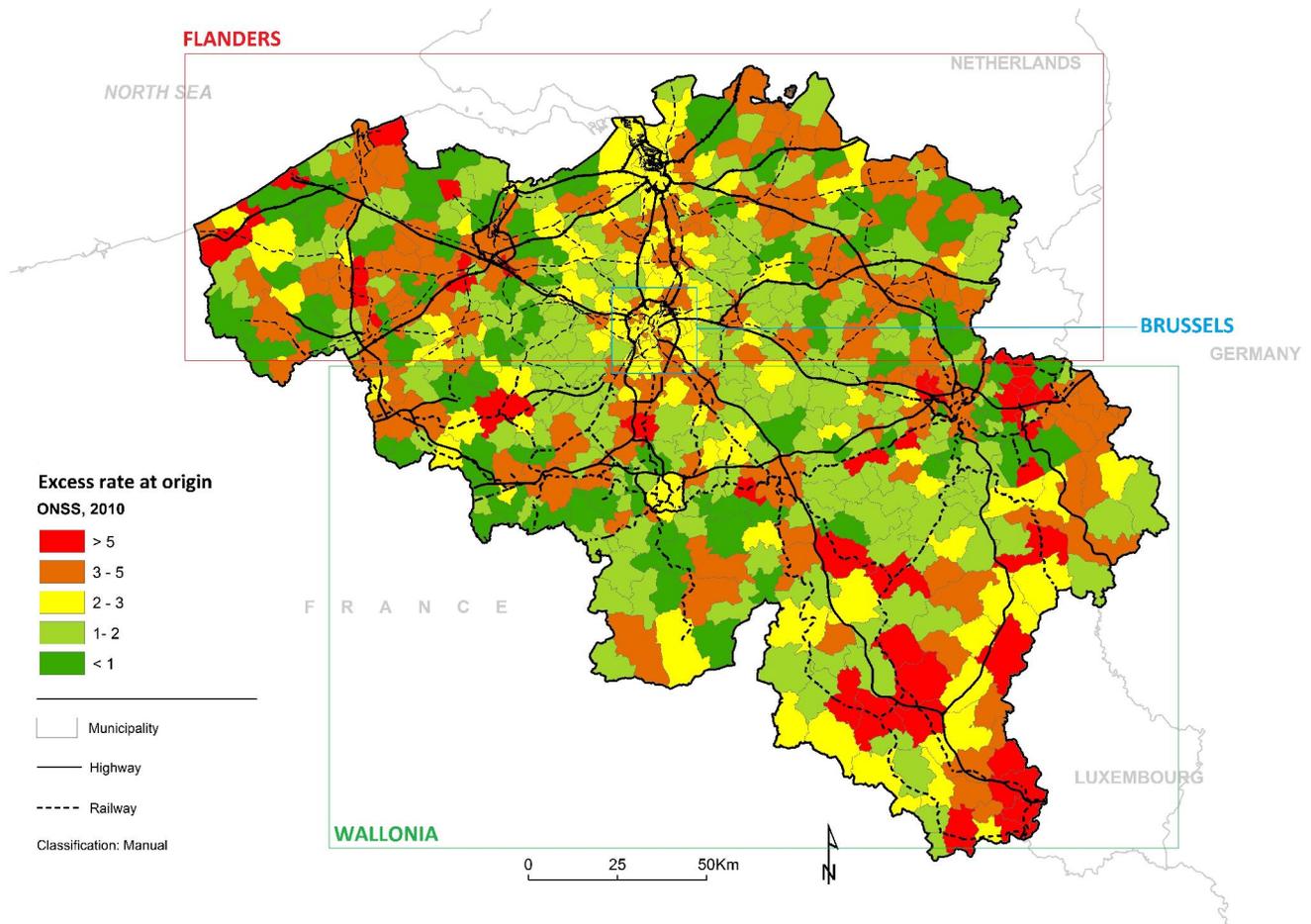


Figure 1: Excess rate at the origin determined from 2010 ONSS data

333 between 2001 and 2010. The spatial pattern of MCD<sub>o</sub> is quite stable over time. The ER<sub>o</sub> and ER<sub>d</sub> values  
 334 are less stable; nevertheless, more than half of the municipalities are found to be in the same relative classes  
 335 in 2010 as in 1991.

### 336 5.2. Transition patterns between the three time periods

337 To assess the stability of MCD and ER, the differences between the two time frames are tabulated.  
 338 In particular, Table 2 presents the numbers of municipalities in which discontinuous trends over time are  
 339 observed. A more detailed overview of transition probabilities is provided in Appendix Appendix A. First,  
 340 the MCD<sub>o</sub> remained quite stable over the analyzed years, although a considerable number of municipalities  
 341 showed a decrease (-32.09% in the period of 1991-2010). The MCD<sub>d</sub> also exhibited a strong change toward  
 342 lower values during the period of 2001-2010, at a significant rate of 41.6%.

343 We tested the application of the Jenks natural breaks optimization algorithm to categorize the munic-  
 344 ipalities in terms of MCD and ER performance and to determine the boundaries between the different

-	-	2001-1991		2010-2001		2010-1991	
Variable	Class change	N	%	N	%	N	%
MCDo	No change	435	73.85	378	64.18	341	57.89
	Upward change	59	10.02	49	8.32	59	10.02
	Downward change	95	16.13	162	27.5	189	32.09
MCDd	No change	540	91.68	339	57.56	362	61.46
	Upward change	43	7.3	5	0.85	11	1.87
	Downward change	6	1.02	245	41.6	216	36.67
ERo	No change	406	68.93	389	66.04	327	55.52
	Upward change	81	13.75	93	15.79	117	19.86
	Downward change	102	17.32	107	18.17	145	24.62

Table 2: Changes in performance class between time frames (N = number of municipalities)

345 categories. The application of this algorithm to the different datasets (years) resulted in different class  
346 boundaries for each dataset. Therefore, to allow a time-based comparison of the maps, manual classifica-  
347 tion was applied instead of an automatic one.

348 Figure 2 and Table 3 show that the average MCDo and MCDd values are increasing. These results  
349 are consistent with previous studies (Banister et al., 1997; Sandow and Westin, 2010; Sharma and Chan-  
350 drasekhar, 2014), which also indicate that an increase in the mean minimum commute distance is occurring  
351 in developed countries (especially in Northern European countries and in major metropolitan regions of  
352 America). Moreover, the results indicate a significant association between municipalities whose indicators  
353 showed an above-average increase between 1991 and 2001 and between 2001 and 2010 (the p-values of  
354 Fisher’s exact test are below the 0.05 level of significance).

355 The same holds true when the increase in indicators is evaluated with respect to the median instead of  
356 the average (relative) change. In other words, municipalities that exhibited a relatively rapid decrease in  
357 MCDd, MCDo or ERo during the period of 1991-2001 were likely to continue to exhibit this trend in the  
358 period of 2001-2010. These trends are also confirmed by Figure 3, which depicts the spatial distribution  
359 of the zones. From this figure, one can observe that for the majority of municipalities, changes in MCDo,  
360 MCDd and ERo between 1991 and 2001, are continued in the consecutive time period. This temporal  
361 continuity is especially exhibited by the strong increase in ERo (see Figures 3e and 3f).

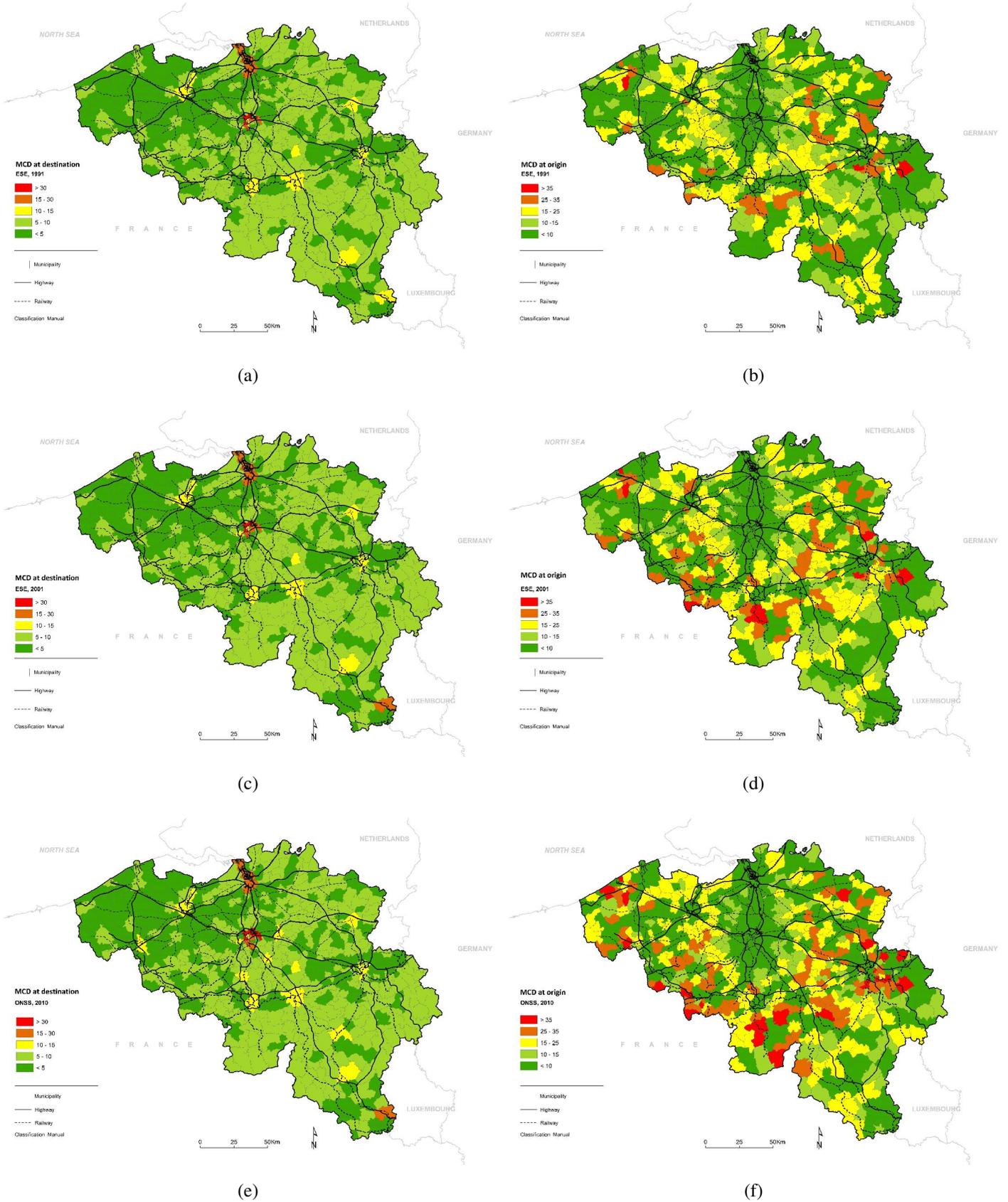


Figure 2: Temporal evolution (1991-2001-2010) of the minimum commute distance

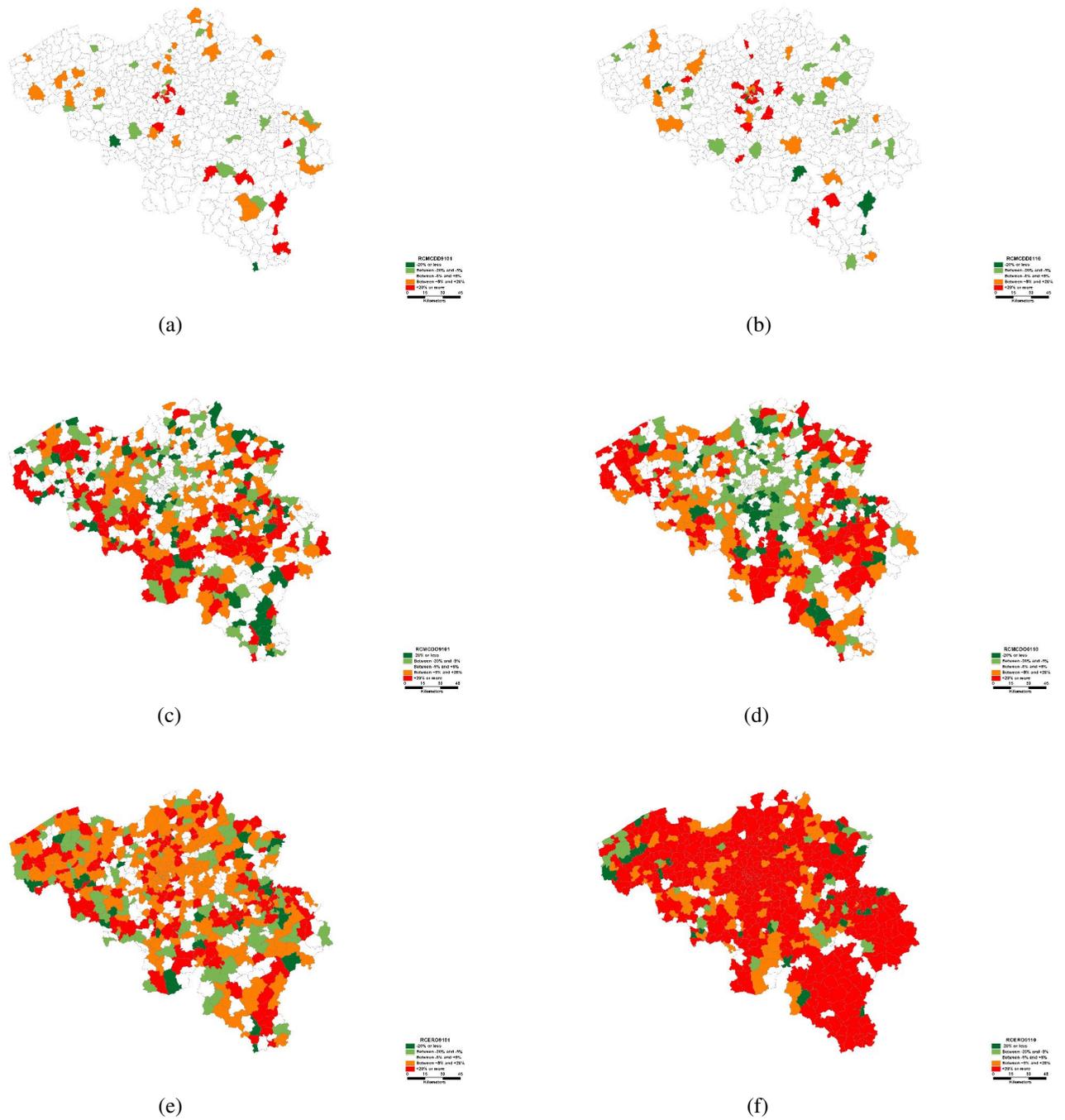


Figure 3: Relative changes (in %) of the MCDo, MCDd, and ERo for the time periods of 1991-2001 and 2001-2010

362 From Table 2, one can observe that between 1991 and 2010, 57.9% of the municipalities remained in the  
 363 same performance class in terms of the MCDo, whereas 32.1% of the other municipalities shifted to lower  
 364 classes. Despite a shift toward higher classes of only 10.0% of the municipalities, positive relative changes  
 365 in MCDo are observed between 1991 and 2001 and between 2001 and 2010 (6.3% and 11.8%, respectively,  
 366 according to Table 3). Although these two findings appear to be contradictory, this can be explained by the  
 367 fact that although the absolute value of the MCDo is increasing, the class transition patterns are based on  
 368 an automatic classification that accounts for this general increasing trend.

Variable	Mean			Median		
	91-01	01-10	p-value	91-01	01-10	p-value
Relative change in MCD at origin	6.3%	11.8%	<0.001	0.4%	0.8%	<0.001
Relative change in MCD at destination	1.8%	2.3%	<0.001	0.0%	0.0%	<0.001
Relative change in ER at origin	13.8%	40.5%	<0.001	9.0%	33.3%	0.004

Table 3: Relative changes in the MCDo, MCDd and ERo between 1991 and 2001 and between 2001 and 2010

### 369 5.3. Border effects

370 The results do not reveal the presence of any major border or language border effects within the country  
 371 except at the border with Luxembourg. Indeed, at the border between Luxembourg and Belgium, cars are  
 372 still the most commonly used mode of transport. The number of inhabitants on the Belgian side of the border  
 373 that travel significant commute distances to work in Luxembourg, is known to be on the rise. Schiebel  
 374 et al. (2015) highlighted that territorial and functional border effects may affect the choice of travel mode.  
 375 The attractiveness of public transport plays a role in shifting preferences toward greater sustainability in  
 376 transport. In this regard, Schiebel et al. (2015) revealed that workers living near the border are more willing  
 377 to use public transport when direct routes to their workplaces are available. The analysis of Schiebel et al.  
 378 (2015) can explain the importance of the ERo near the border with Luxembourg. Economic activity in this  
 379 area is quite low; therefore, a significant percentage of the workers living in this region use their cars to  
 380 commute to Luxembourg.

### 381 5.4. MAUP and scale effects

382 In order to assess the effects of scale on MCD and ER, data derived from the 2001 census could be  
 383 aggregated at a more detailed scale level. Figure 4 presents comparisons of three indicators (MCDo, MCDd  
 384 and ERo) calculated at two different scales (current municipalities on the left, and former municipalities,  
 385 dating from before the municipal merger of 1977, on the right). Aspects inherent to MAUP and its under-  
 386 lying scale effects were discussed in Section 2. Studies have shown that the impact of MAUP on excess

387 commute metrics is rather limited (Niedzielski et al., 2013; Horner and Murray, 2002). In order to en-  
 388 sure that the metrics' sensitivity to MAUP is sufficiently low, we propose a comparative assessment of  
 389 the results for two different scale patterns in the year 2001 based on the census data. In this regard, from  
 390 Figures 4a and 4b, one can observe that the main MCDo pattern remains rather stable with respect to the  
 391 disaggregation procedure. The MCDo is low in the Brussels and Antwerp areas, with some comparatively  
 392 higher values in the Liège area and to the south of Charleroi and Namur. Furthermore, Figures 4c and 4d  
 393 present the main MCDd patterns corresponding to the commuting distances of people coming from outside  
 394 to work in the main employment hubs of Belgium (participating in the work activities of Brussels and the  
 395 port of Antwerp). The disaggregation reveals more heterogeneity near the interregional border. Also, ERO  
 396 patterns show more important heterogeneity, perhaps reflecting local particularities of the spatial structure.  
 397 A finer scale allows better localization of the zones where ERO is high; however, the main conclusions are  
 398 not impacted. It can be observed from Table 4 that the MCDo and MCDd are estimated to be 8.6% and  
 399 24.6% higher, respectively, when calculated at the level of the current municipalities in comparison to the  
 400 calculation at the level of the former municipalities. By contrast, the ERO decreases by 9.5% when a more  
 401 highly aggregated scale is adopted.

402 Besides, the effects of MAUP on the calculated actual distances, MCDo and ERO are considerable.  
 403 Indeed, a difference of about 25% is observed when comparing results based on current municipalities with  
 404 results based on the former municipality aggregation. By merging municipalities, the detail of the analysis  
 405 is reduced. In this way, data does not exist anymore at the level of former communes. The relative lack of  
 406 consistency of data across the different levels of aggregation can explain the deviations found in Table 4.

407 Also, it is important to face that calculated intra-zonal trip lengths may be affected by MAUP. However,  
 408 the impact on the research hypotheses and conclusions is small because the current research is entirely  
 409 based on current municipalities which are studied over time. This approach eliminates MAUP issues to a  
 410 considerable extent.

	Current municipalities (a)	Former municipalities (b)	Deviation with respect to (b)
Actual commute distance <sup>1</sup>	14.3	12.9	10.9%
MCD at origin	10.1	9.3	8.6%
MCD at destination	7.1	5.7	24.6%
ER at origin	1.9	2.1	-9.5%

<sup>1</sup> Calculated from observed origin-destination matrix

Table 4: Comparisons of the MCD and ER values calculated with respect to the current and former municipalities

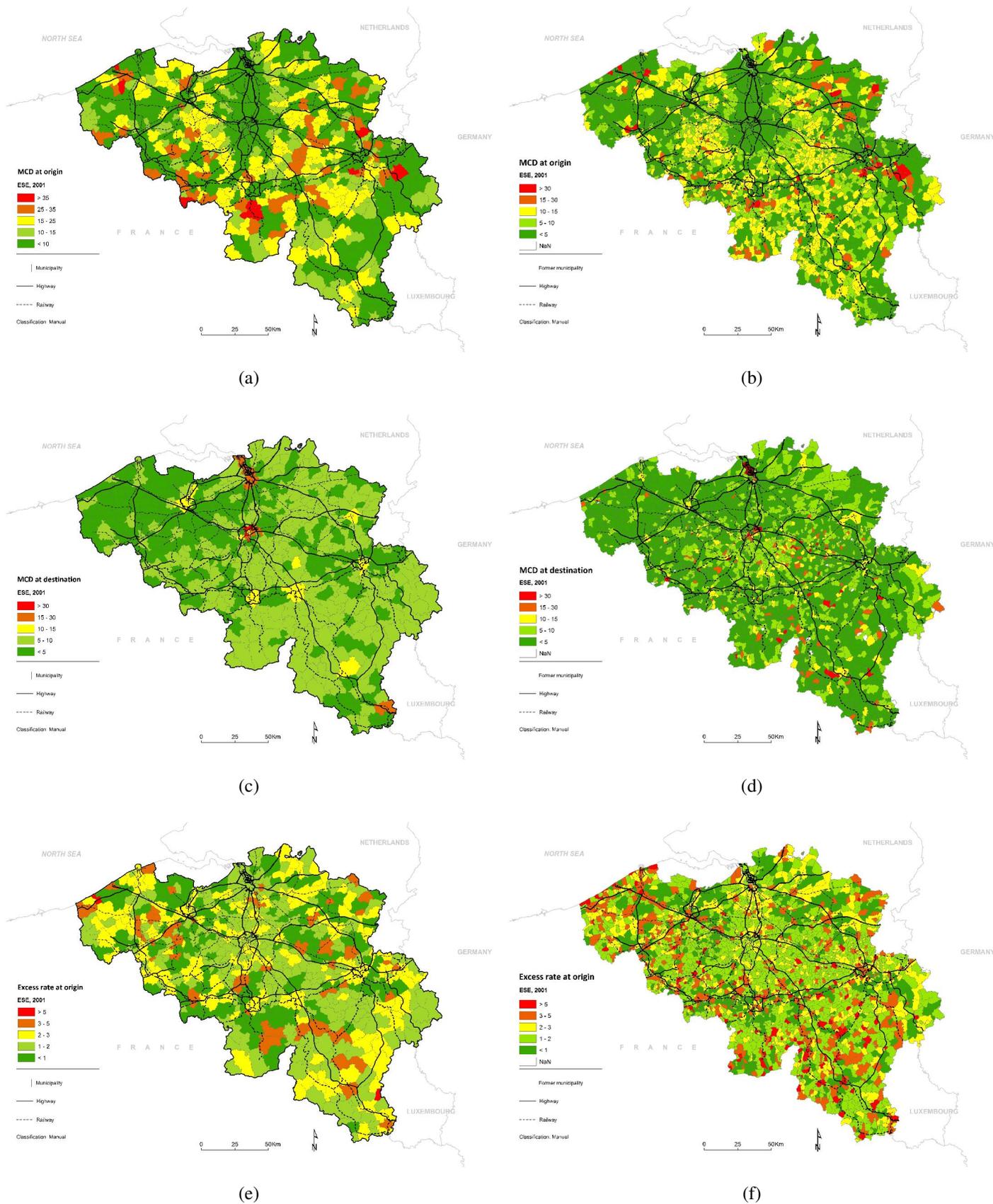


Figure 4: Comparison of excess commute metrics calculated at two different scales

## 411 6. Discussion

412 The presented analysis confirms some of the results of Boussauw et al. (2011) for Flanders. The MCDO  
413 is significantly lower in Brussels and other important cities (Antwerp, Gent and Liege) than it is in suburban  
414 and, especially, rural areas. By contrast, the area located between 20 and 40 km from the center of Brussels  
415 forms a ring showing particularly large MCDO values. In general, MCDO tends to increase between 2001  
416 and 2010. The polarizing nature of Brussels largely transcends its regional borders. The effect of the lin-  
417 guistic border is relatively minor when we consider the ERO map, especially in municipalities located close  
418 to important urban areas located on the other side of the regional border. This finding further emphasizes the  
419 role of urban areas and municipalities located near important infrastructures (motorways and train stations)  
420 as major "exporters" in the daily commute. This is especially true when one compares the results for 2001  
421 and 2010.

422 Based on our analysis, we can respond to the stated research hypotheses as follows:

- 423 ● In each of the three regions of Belgium, the average actual commuting distance increases over both  
424 periods studied. Contrary to expectations, observed growth is faster in the second period. Also, com-  
425 muting distances grew much faster in Wallonia, which is less affected by congestion than Flanders  
426 and Brussels. Although the data do not show that growth is levelling off, there are good reasons to  
427 believe that congestion levels may affect commuting distance growth rates.
- 428 ● In Flanders and Wallonia, minimum commuting distance (MCD) too was growing during almost  
429 all of the periods studied. In Brussels, this is also the case with regards to the incoming commute  
430 (MCDd), but not with regards to the outgoing commute (MCDO). In general, the growth rates of  
431 MCD are considerably lower than growth rates of the actual commuting distance. This indicates that  
432 the spatial proximity between the labour market and the housing stock in Belgium has declined over  
433 all periods studied, although this loss of spatial proximity obviously only explains a small part of the  
434 increase of the actual commuting distance. Growth of the actual commuting distance is largely due to  
435 non-spatial causes, such as the increasing specialization of the labour market, and changing location  
436 preferences. Also, regional trends in spatial proximity loss (or gain) and commuting efficiency appear  
437 to be rather consistent over time. The relatively rapid growth of MCDd in Brussels then points again  
438 to an ever increasing concentration of jobs in the capital region.
- 439 ● While origin-destination matrices are meant to map home-work relations in a standardized way, the  
440 dramatic increase of the actual commuting distance in the period 2001-2010 is not in line with the

441 results of recent surveys (Cornelis et al., 2012) which seem to indicate that even in Belgium we can  
442 to a certain extent talk about "peak car", which in the actual commute is reflected as a tendency  
443 towards stabilization. The inconsistency between our findings and the aforementioned survey results  
444 may be partly due to differences in the composition of the various origin-destination matrices from  
445 1991, 2001 and 2010. The matrix from 2010 is synthetic, while the older matrices are based on  
446 censuses. Previous findings underline the importance of data sets being consistent over time, and of  
447 the necessary cautions to take into account when drawing conclusions from such analyses.

- 448 • The analyses made are susceptible to technical constraints, such as the size of the areas within  
449 which data is aggregated (MAUP), and the method used to simulate intra-zonal trips. Since origin-  
450 destination matrices are typically based on data that are aggregated at an administrative level (e.g. a  
451 municipality), caution should be exercised when interpreting absolute figures that were calculated on  
452 the basis of such matrices. In principle, interpretations of relative figures, such as in a longitudinal  
453 analysis, will be more sound than those based on absolute figures.

454 An important trend in the ERo is observed along the border with Luxembourg. Related to this ob-  
455 servation, it may occur that jobs and/or housing characteristics do not compensate for the costs related to  
456 commuting from the perspective of the commuter. Paradoxically, however, commuters are ready to accept  
457 such a situation because they expect it to be temporary and subject to change in the future. Some workers,  
458 after beginning to earn better incomes, decide to relocate toward Luxembourg or into the suburbs. In this  
459 regard, one should keep in mind that, generally speaking, jobs and residential patterns tend to be spatially  
460 shifting and cannot be regarded as fixed (Van Ommeren et al., 1997). Workers do not specifically attempt  
461 to find the most optimal combination of job and residence to minimize their commuting distances. Instead,  
462 they seek the most appropriate job and residence separately (Van Ommeren et al., 1997).

463 Notably, the results obtained at the scale of the former municipalities exhibit a much higher diversity  
464 of patterns, especially in rural areas, where high-performing locations with low excess rates are directly  
465 adjacent to low-performing ones. However, the model still exhibits some limitations. For example, some  
466 more policy-sensitive issues are not considered (e.g., job qualifications). This means that a worker may  
467 be assigned a position that does not correspond to his/her educational background. Moreover, several  
468 fundamental phenomena are neglected, such as the difference in terms of traveled distances between men  
469 and women.

470 Finally, it can be argued that the MCDd is characterized by two divergent patterns: one of extreme  
471 stability between 1991 and 2001 and one of strong differences between 2001 and 2010. This may be related

472 to a bias in the ONSS data sources (differences between information collected at the enterprise versus plant  
473 levels and an absence of information concerning self-employment).

## 474 **7. Conclusion**

475 In this paper, we studied recent trends in commuting efficiency and jobs-housing proximity. In this  
476 context, we considered two different metrics: the minimum commute distance and the excess rate.

477 The study revealed that the MCD and ER values are clearly related to regional and national patterns  
478 of employment and residence. Indeed, with regard to the MCDo specifically, urban areas are much more  
479 efficient in terms of jobs-housing proximity than are rural and suburban ones. The Brussels-Antwerp axis  
480 is a clear example of this phenomenon.

481 With regard to ERO, high values appear along the border with Luxembourg because of the number  
482 of daily commuters traveling to that country. With respect to MCDd, important metropolitan enterprise  
483 districts in and around the Brussels and Antwerp areas are revealed.

484 One of the major findings reported in this paper concerns the spatio-temporal dependency of municipal-  
485 ities. The results indicate a significant association between municipalities whose indicators increased at an  
486 above average rate between 1991 and 2001 and those whose indicators exhibited a similar trend between  
487 2001 and 2010.

488 An assessment of MAUP revealed that the effects are considerable especially in the case of MCDd.  
489 However, these differences do not affect the hypotheses and the conclusions of the study.

490 In addition, the internal limitations of the Social Security OD matrix should be acknowledged. Most  
491 importantly, there is significant uncertainty regarding the work locations of employees working for multi-  
492 site companies. This issue will gradually be addressed through stricter requirements and penalties for  
493 companies that do not provide accurate figures at the site level. It may then be possible to monitor home-  
494 to-work trips on a shorter time scale than that of the usual decennial census period.

495 In terms of policy recommendations, knowledge of the commuting patterns across Belgium clearly re-  
496 veals which areas should be considered for the implementation of efforts to mitigate commute distances as  
497 much as possible. One solution could be to propose an improved allocation of workers and jobs (Niedziel-  
498 ski, 2006).

499 Further research should focus on an empirical assessment of the causal relationships between factors  
500 such as age, income and accessibility on the evolution of excess commute metrics.

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636 **Appendix A. Transition patterns between the three time periods**

637 The following tables provide an overview of the class transitions (expressed in %), where the classes  
 638 were automatically defined by Jenks natural breaks.

Table A.5: Transition probabilities for MCD<sub>o</sub>

		MCD <sub>o</sub> 2001				
		I (0-7.72)	II (7.73-13.22)	III (13.23-19.91)	IV (19.92-27.04)	V (>27.04)
MCD <sub>o</sub> 1991	I (0-7.27)	95.65	3.86	0.48	0.00	0.00
	II (7.28-12.09)	20.29	61.59	18.12	0.00	0.00
	III (12.10-17.72)	4.17	19.17	64.17	10.83	1.67
	IV (17.32-24.34)	2.33	4.65	22.09	59.30	11.63
	V (>24.34)	2.63	0.00	5.26	28.95	63.16

		MCD <sub>o</sub> 2010				
		I (0-9.46)	II (9.47-16.89)	III (16.90-24.65)	IV (24.66-34.67)	V (>34.67)
MCD <sub>o</sub> 2001	I (0-7.72)	91.88	5.56	2.14	0.43	0.00
	II (7.73-13.22)	40.00	48.33	10.83	0.00	0.83
	III (13.23-19.91)	2.42	40.32	45.97	8.87	2.42
	IV (19.92-27.04)	2.67	0.00	52.00	42.67	2.67
	V (>27.04)	0.00	0.00	5.56	50.00	44.44

		MCD <sub>o</sub> 2010				
		I (0-9.46)	II (9.47-16.89)	III (16.90-24.65)	IV (24.66-34.67)	V (>34.67)
MCD <sub>o</sub> 1991	I (0-7.27)	91.30	5.80	2.42	0.48	0.00
	II (7.28-12.09)	42.75	43.48	10.14	2.90	0.72
	III (12.10-17.72)	10.83	32.50	44.17	10.00	2.50
	IV (17.32-24.34)	5.81	10.47	43.02	32.56	8.14
	V (>24.34)	5.26	2.63	18.42	44.74	28.95

Table A.6: Transition probabilities for MCDd

		MCDd 2001				
		I (0-4.36)	II (4.37-5.76)	III (5.77-9.34)	IV (9.35-17.88)	V (>17.88)
MCDd 1991	I (0-4.40)	92.67	7.33	0.00	0.00	0.00
	II (4.41-5.84)	0.76	92.05	7.20	0.00	0.00
	III (5.85-9.39)	0.00	3.45	89.66	5.17	1.72
	IV (9.40-18.72)	0.00	0.00	0.00	86.67	13.33
	V (>18.72)	0.00	0.00	0.00	0.00	100.00

		MCDd 2010				
		I (0-4.93)	II (4.94-8.09)	III (8.10-14.04)	IV (14.05-28.27)	V (>28.27)
MCDd 2001	I (0-4.36)	99.44	0.56	0.00	0.00	0.00
	II (4.37-5.76)	44.44	54.02	0.77	0.77	0.00
	III (5.77-9.34)	0.00	91.06	8.94	0.00	0.00
	IV (9.35-17.88)	5.26	5.26	63.16	26.32	0.00
	V (>17.88)	0.00	0.00	0.00	42.86	57.14

		MCDd 2010				
		I (0-4.93)	II (4.94-8.09)	III (8.10-14.04)	IV (14.05-28.27)	V (>28.27)
MCDd 1991	I (0-4.40)	97.38	1.05	0.52	1.05	0.00
	II (4.41-5.84)	40.53	58.33	1.14	0.00	0.00
	III (5.85-9.39)	0.86	85.34	12.07	0.86	0.86
	IV (9.40-18.72)	6.67	0.00	46.67	40.00	6.67
	V (>18.72)	0.00	0.00	0.00	33.33	66.67

Table A.7: Transition probabilities for ERo

		ERo 2001				
		I (0-1.06)	II (1.07-1.68)	III (1.69-2.38)	IV (2.39-3.20)	V (>3.20)
ERo 1991	I (0-0.95)	83.66	13.07	2.61	0.65	0.00
	II (0.96-1.47)	21.56	61.08	12.57	4.19	0.00
	III (1.48-2.10)	1.67	25.83	57.50	14.17	0.83
	IV (2.11-2.95)	0.00	2.52	21.01	68.91	7.56
	V (>2.95)	0.00	3.33	0.00	13.33	83.33

		ERo 2010				
		I (0-1.37)	II (1.38-2.28)	III (2.29-3.43)	IV (3.44-4.90)	V (>4.90)
ERo 2001	I (0-1.06)	88.55	8.43	1.81	1.20	0.00
	II (1.07-1.68)	26.75	55.41	14.01	3.82	0.00
	III (1.69-2.38)	2.52	16.81	60.50	15.13	5.04
	IV (2.39-3.20)	0.00	2.70	18.02	59.46	19.82
	V (>3.20)	0.00	0.00	5.56	47.22	47.22

		ERo 2010				
		I (0-1.37)	II (1.38-2.28)	III (2.29-3.43)	IV (3.44-4.90)	V (>4.90)
ERo 1991	I (0-0.95)	81.70	9.80	3.27	5.23	0.00
	II (0.96-1.47)	31.74	43.11	18.56	4.79	1.80
	III (1.48-2.10)	10.00	21.67	46.67	16.67	5.00
	IV (2.11-2.95)	1.68	9.24	21.85	49.58	17.65
	V (>2.95)	0.00	0.00	3.33	46.67	46.67