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by

Artemis TSIOPA

Born on 21 December 1993 in Athens (Greece)

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Dissertation defence committee

Dr. Geoffrey Caruso, Supervisor

Professor, Luxembourg Institute of Socio-Economic Research (LISER) & Université du Luxembourg

Dr. Philippe Van Kerm, Chairman

Professor, Luxembourg Institute of Socio-Economic Research (LISER) & Université du Luxembourg

Dr. Philippe Gerber, Vice Chairman

Research Scientist, Luxembourg Institute of Socio-Economic Research (LISER), Luxembourg

Dr. Stamatis Kalogirou, Member

Senior Data Scientist, European Court of Auditors, Luxembourg

Dr. Rosella Nicolini, Member

Professor, Autonomous University of Barcelona, Spain

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Artemis Tsiopa
University of Luxembourg
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Abstract

Cross-border commuting stands as a significant type of mobility within the fields of urban and regional studies, influencing economic, social, transportation and regional development policies. This dissertation aims to provide a comprehensive understanding of the individual and geographical characteristics that influence French residents when it comes to accepting job opportunities on the other side of the French border. By exploring various aspects of cross-border commuting, from individual-level determinants to aggregate-level effects, this research endeavors to shed light on the complexities and dynamics of this unique form of commuting.

Chapter 2 consists of a systematic literature review, where we delve into existing studies on cross-border commuting. This review allows us to identify key challenges and determinants that shape individuals' choices in engaging in cross-border work. Understanding the relevant literature serves as a foundation for the subsequent chapters, guiding our investigation towards the most crucial factors that influence cross-border commuting patterns.

In Chapter 3, we conduct a multinomial logit analysis to explore individual-level factors influencing commuting decisions for every worker in France. This examination involves considering both individual and geographic effects, such as urban and suburban environments and relative job accessibility within France, as well as different border zones. This approach allows us to gain insights into the heterogeneity of cross-border commuting decisions across various contexts.

In Chapter 4, we adopt an aggregate perspective, employing spatial interaction model estimates to investigate the impact of distance on cross-border commuting as compared to commuting within France. Utilizing a flow matrix that includes all municipalities of origin and destination within France and across the border (only for the latter), we can discern the role of distance as a determining factor in cross-border commuting patterns.

In Chapter 5, we go back to the individual level. We aim to identify the determinants of commuting distance, making a distinction between cross-border and internal commutes. This analysis employs Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR) techniques to explore the factors influencing commuting distances in different contexts.

Overall, this dissertation contributes to the growing body of knowledge on cross-border commuting by providing insights into the various characteristics that influence it. We highlight that geographical characteristics are essential to be considered by analysts, since they provide a significant added value. Moreover, the effect of commuting distance is confirmed to be an important restraining factor. The effect of crossing different borders is analyzed, as well, proving that borders are an obstacle. Nevertheless, some borders appear to be easier to cross than others. By encompassing both individual and aggregate perspectives, this research contributes to a more comprehensive understanding of cross-border commuting and its implications on individuals and regions alike.

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Chapter 1

Introduction

1.1 Commuting

As urban areas expand and human activities become more diverse and widespread, the study of human mobility patterns has gained paramount importance. People's everyday routines and tasks often require them to travel across different geographic locations (Sprumont et al., 2014). Hence, the study of mobility patterns has become indispensable (Sprumont et al., 2014; Isaacman et al., 2010). It is evident that human mobility is not random; rather, it follows certain regularities and patterns. Among the various characteristics of mobility, distance emerges as a prominent factor, which can either facilitate or hinder movement (Noulas et al., 2012). Consequently, transportation planning and development have emerged as vital fields, not only facilitating human mobility but also contributing to urban development (Vazquez-Prokopec et al., 2013). Moreover, the monitoring of human mobility holds significance in other domains such as migration, tourism, and the spread of diseases and epidemics (Hawelka et al., 2014). Furthermore, socioeconomic changes can influence the location, frequency, and duration of various activities (Vazquez-Prokopec et al., 2013). In the context of this dissertation, the focus is specifically on studying commuting as a distinct aspect of human mobility.

Commuting, which refers to the daily travel between workplace and residence, holds significant importance in transportation planning and geographical studies. It is considered the primary form of travel for most individuals (Zax, 1994). The distance between where people live and work, along with the trade-off between commuting and housing costs, has garnered significant attention in theories of urban spatial structure. Economic models in this field posit that households must make a choice: either live closer to their workplaces and pay higher housing costs or opt for more affordable housing and longer commutes. While monocentric models simplify this decision, polycentric models introduce additional complexities (Alonso, 1960; Clark and Davies Withers, 1999). Transportation planning plays a crucial role in reassessing this trade-off, as improvements in the transportation system have the potential to reduce commuting time and costs, enabling individuals to consider longer commuting distances (So et al., 2001; Lim and Kim, 2019). Evidence suggests that this assumption holds true across developed countries (Ali et al., 2011). Although the development of transportation networks has facilitated faster travel, it has not necessarily resulted in reduced commuting time. Instead, individuals now have the option to live farther away from their workplaces, leveraging transportation amenities and other factors of

attraction (Limtanakool et al., 2006; Korsu, 2012; Vincent-Geslin and Ravalet, 2016; Lim and Kim, 2019).

The second half of the 20th century witnessed significant urban transport improvements that had a profound impact on reducing travel time and costs, thereby weakening the constraints imposed by distance. The construction of intra-urban, inter-regional, and international highways, the widespread ownership of private vehicles, and the development of efficient public transportation infrastructure, among other factors, played a vital role in transforming daily travel into a routine activity that enables individuals to engage in events across different geographic locations (Korsu, 2012; Vazquez-Prokopec et al., 2013). It is worth noting that commuting constitutes a significant portion of individuals' travel time, accounting for approximately 25% of their overall travel time (Sprumont et al., 2014). On average, commuting durations range from 25 to 35 minutes (Schwanen and Dijst, 2002). Furthermore, social changes, such as increased female labor force participation and the rise of dual-earner households, have contributed to a higher tolerance for commuting. Studies indicate that contemporary households are less concerned with commuting than in the past, thanks to increased mobility options and greater residential choices (Korsu, 2012). However, it is important to recognize that commuting costs, including monetary, time, organizational, and psychological factors, still impose a burden on individuals (Korsu, 2012; Lim and Kim, 2019). This burden can outweigh the benefits associated with residing at a greater distance from the workplace, despite the presence of desirable residential amenities (Lim and Kim, 2019). Thus, understanding and addressing the challenges and trade-offs associated with commuting remains significant in contemporary urban contexts.

In addition to the conventional focus on commuting time, distance, and transportation modes, many researchers have shifted their attention towards examining the psychological impacts of commuting. Negative effects on job satisfaction and quality of life have been identified, including decreased performance, punctuality, and increased stress and fatigue (Stutzer and Frey, 2008; Gerber et al., 2019). Longer commutes are often chosen when offset by financial or personal rewards (Stutzer and Frey, 2008; Gerber, 2012; Pigeron-Piroth et al., 2018). However, the detrimental effects of commuting are more pronounced for "extreme commuters" (comprising 5-10% of Europeans) who spend over two hours daily commuting and experience heightened negative effects. Extreme commuting has increased by 95% between 1990 and 2000, from 1.6 million to 3.4 million individuals (Marion and Horner, 2007). This rise is attributed to high unemployment rates and limited employment information in closer proximity to their residences (Vincent-Geslin and Ravalet, 2016). Defining "extreme" commuting presents challenges, as countries use different distance thresholds (more than 167km for the USA, 83km for the United Kingdom, and 100km for the EU) or metropolitan area size for classification (Limtanakool et al., 2006; Vincent-Geslin and Ravalet, 2016). Commuting patterns also vary by transportation mode, with car users having longer commutes and train users facing longer travel times. Surprisingly, some extreme commuters express satisfaction, as they engage in relaxing, social, or productive activities during their journeys, leading to improved time management (Vincent-Geslin and Ravalet, 2016).

Numerous studies indicate that commuting time and distance are influenced by various socio-demographic factors. Gender, age, education, and socio-economic characteristics play a significant role in determining individuals' commuting preferences (Limtanakool et al., 2006; Buch et al., 2009; Vincent-Geslin and Ravalet, 2016). Men, on average, tend to have longer commutes than women, potentially due to household and childcare responsibilities, the geographic distribution of gendered occupations, and higher unemployment rates among women (Limtanakool et al., 2006; Vincent-Geslin and Ravalet, 2016; Pigeron-Piroth et al., 2018). Commuting duration generally increases with age but declines after the age of 65 (Limtanakool et al., 2006). Moreover, individuals in higher-level jobs, with higher income or education, are more likely to have longer commutes (Limtanakool et al., 2006; Pigeron-Piroth et al., 2018). Additionally, car ownership appears to be associated with

a higher likelihood of longer commutes (Limtanakool et al., 2006).

1.2 Cross-border commuting

Technological advancements, infrastructural improvements, and European policies have facilitated the emergence of a distinct form of commuting known as cross-border commuting. Cross-border commuters reside in one country but cross the borders of another country daily to reach their workplaces (Buch et al., 2009). The progression towards this phenomenon began with the Treaty of Rome in 1957, which encouraged mobility for migration and cross-border commuting purposes (Gottholmseder and Theurl, 2007). Subsequently, the Schengen Agreement of 1985 eliminated border controls among European countries, initially starting with Luxembourg's neighboring nations (Carpentier, 2012; Chasset et al., 2019). In 1993, the European Common Market policy was established to further enhance interconnectedness between countries (Mathä and Wintr, 2009; Terlouw, 2012). Measures such as the common currency, the European Free Trade Association, and the Interreg programs have been implemented to reduce discontinuities and promote collaboration among European countries (Carpentier, 2012; European Commission, 2017). The Interreg programs, specifically Interreg A and Interreg B, are instrumental in fostering cross-border cooperation. Interreg A focuses on neighboring regions classified under different member-states, and aims to address common challenges and facilitate regional development and growth. On the other hand, Interreg B encompasses larger areas composed of regions from multiple member-states, and supports cooperation and investing in diverse projects addressing various vital topics (European Commission, 2016). These agreements and policies are intended to weaken the impact of borders and promote European cohesion (Bouwens, 2004; Buch et al., 2009; Mathä and Wintr, 2009; Gerber, 2012; Terlouw, 2012).

Cross-border interactions among residents of different European countries have a long history, dating back to the Middle Ages, with cross-border trade flourishing from the 16th century (Terlouw, 2012). Nevertheless, this trend has changed notably since the late 18th century, when people started to become more oriented towards their own country, showing indifference to cross-border interactions (Bouwens, 2004). Cross-border commuting has historically been limited, despite its potential, with the majority of cross-border commuters residing within a 20km radius of the border (Terlouw, 2012). In 1999, only 1.5% of the active population in EU border regions, amounting to 500,000 individuals, were cross-border commuters, and the overall percentage in the labor force was 0.2% (Bouwens, 2004; Mathä and Wintr, 2009). However, in recent years, there has been a notable increase in the number of cross-border commuters. In 2017, out of the 150 million individuals living in border regions, 2 million individuals were engaged in cross-border commuting (Halmos, 2018). Luxembourg, in particular, attracts a significant number of cross-border commuters, with approximately 45% of the country's employees being cross-border workers, amounting to over 160,000 individuals (Sprumont et al., 2014; Halmos, 2018). These commuters mainly originate from France (50%), Belgium (25%), and Germany (25%) (Halmos, 2018).

While the freedom of movement within EU countries has been established for decades, borders still exist, albeit with weakened administrative forms to the extent that it can be difficult to discern crossing into a different country (Halmos, 2018). Nonetheless, borders continue to hold symbolic significance, representing existing differentials among member states (Paasi and Prokkola, 2008; Carpentier, 2012; Gerber, 2012; Mathä et al., 2017). As social constructs, borders delineate areas with shared history, culture, language, political and administrative systems, and above all, national identity (Bouwens, 2004; Schwab and Toepel, 2006; Paasi and Prokkola, 2008; Buch et al., 2009). Overcoming obstacles such as social security, taxation, pension rights, and diploma recognition, which vary across borders, is essential to facilitate cross-border commuting (Bouwens, 2004; Halmos, 2018; European Commission, 2016). Insufficient and unsynchronized public cross-border

transportation services, coupled with disparate ticketing and pricing systems, further hinder the growth of cross-border commuting (Chasset et al., 2019). The presence of strong national identities, fortified by language, culture, and historical factors, presents a significant obstacle. State sovereignty, often rooted in violent histories, continues to be celebrated and cherished (Paasi and Prokkola, 2008). Lack of proficiency in the language of the destination country also poses a substantial barrier, influencing the decision to become a cross-border commuter, while adequate language skills can serve as a motivating factor for working across borders (Buch et al., 2009).

1.3 Overview, Structure and Goals

This dissertation aims to comprehensively study the phenomenon of cross-border commuting, which is impacting an increasingly significant number of individuals. The first step is to provide a comprehensive framework and examine the unique characteristics, drivers, patterns, effects, and requirements associated with cross-border commuting, through an extensive systematic literature review. By doing so, we aim to identify specific research gaps and areas of focus. Our analysis, provides supplementary information, shedding light on the geographical focus of cross-border commuting studies. It becomes evident that the literature predominantly centers on European case studies, which is understandable given the higher prevalence of cross-border commuting in Europe. Chapter 2 of this dissertation provides a detailed presentation of this systematic literature review, serving as a solid foundation for the subsequent chapters.

To empirically understand cross-border commuting, we choose France as the focal point for the next three chapters of this dissertation. France serves as an ideal case study due to its prominence as the origin country for a significant majority of cross-border commuters in Europe, as established in the existing literature. Moreover, France shares borders with multiple neighboring countries, Belgium, Luxembourg, Germany, Switzerland, Italy, Spain, Andorra, and Monaco, making it a highly relevant and diverse setting for studying cross-border commuting dynamics. By focusing on France's extensive border regions, we can gain valuable insights into the patterns, determinants, and challenges associated with cross-border commuting across a variety of contexts and territorial settings.

Following Chapter 2, the study shifts its focus to investigating individual, household, and geographical determinants that contribute to the possibility of engaging in cross-border commuting, at an individual level, in Chapter 3. We use individual-level data encompassing all employed individuals residing in the border facade of France, specifically within a 50km zone from the country's borders. By employing multinomial logit models, we effectively highlight these determinants and their impacts on cross-border commuting decisions. Notably, in this chapter we prove the significance and the major added value of geographical factors (i.e. geographical zones), which are often overlooked in existing research. We emphasize their crucial contribution in shaping cross-border commuting patterns, shedding light on the importance of considering geographical characteristics when studying this phenomenon.

The next phase of the research expands to an aggregate level, delving into the examination of border effects on commuting distance, in Chapter 4. Although borders are recognized as a substantial obstacle in the literature, they have not been empirically explored. By quantifying the impact of borders on commuting distance, we aim to provide valuable insights and contribute to a better understanding of this crucial aspect. Initially, we examine commuting flows for individuals residing in mainland France and commuting either within the country or across borders, utilizing spatial interaction models. Subsequently, we focus on a zone within 100km of the borders with Belgium, Germany, Luxembourg, and Switzerland, where we identify varying strengths of border effects based on the destination.

Subsequently, with a clearer understanding of commuting distances, we return to the individual level to investigate the determinants of commuting distance, in Chapter 5. Our approach includes the incorporation of local models, allowing for a more focused analysis of the effects on a municipality level. Similar to Chapter 3, we focus on the border facade of France, 50km from the borders. This approach reveals the emergence of border zones with similar characteristics, providing additional insights and contributing to a more nuanced understanding of cross-border commuting dynamics.

By addressing these research objectives, this dissertation seeks to advance the current knowledge base on cross-border commuting, filling gaps in the literature, and providing valuable insights that can inform policy-making and enhance our understanding of this increasingly important type of mobility. The thesis employs two scales of analysis (individual and aggregate level), which together contribute to a comprehensive understanding of cross-border commuting. These scales shed light on the fact that cross-border commuting is influenced by both individual (i.e. individual characteristics and preferences) and aggregate factors (i.e. policies and regional politics). Furthermore, cross-border commuting has implications at both the individual level (i.e. commuting costs) and the aggregate level (i.e. need for policies, integration, transportation infrastructure). By considering these dual perspectives, the thesis provides a holistic view of cross-border commuting and its multifaceted impacts. Figure 1.1 serves as a navigational tool, providing an overview of the thesis structure.

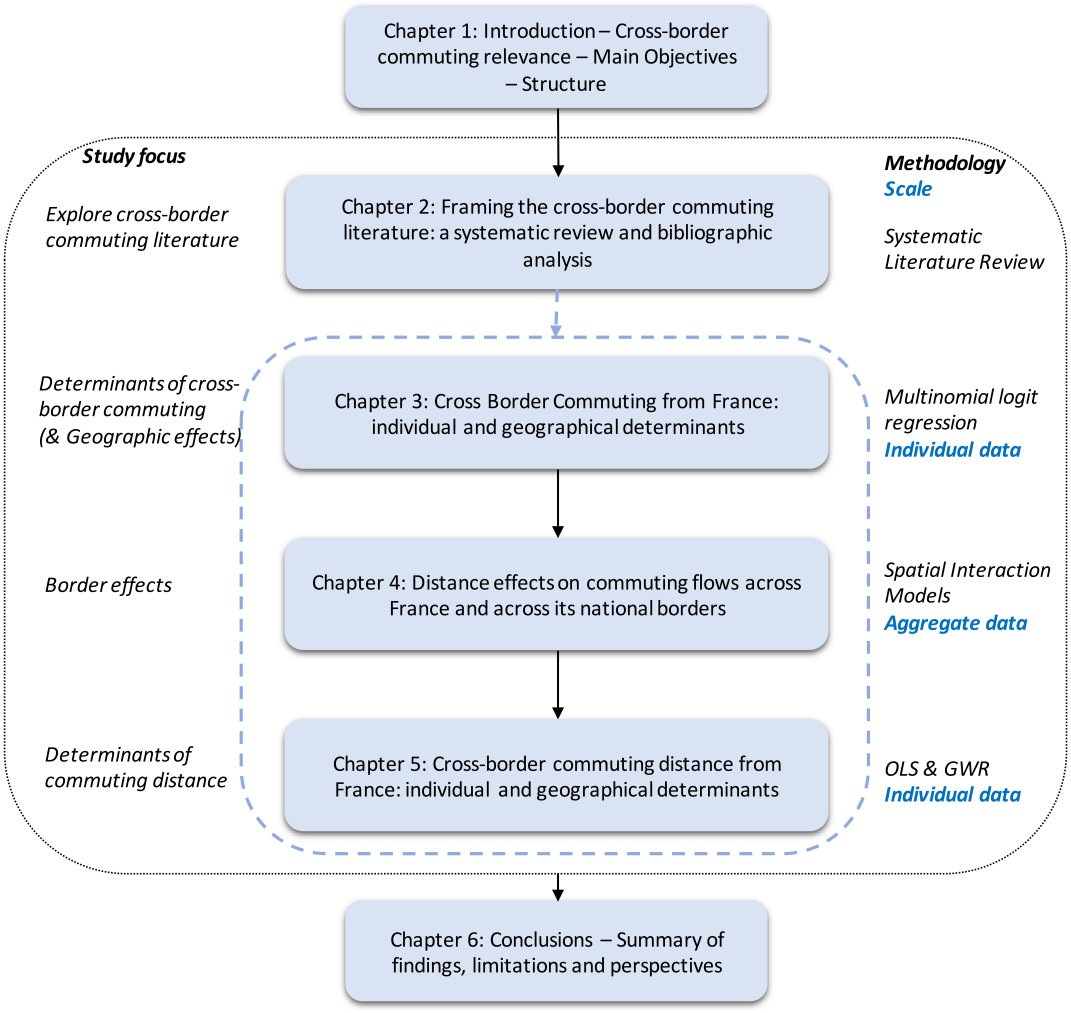

Figure 1.1: Structure of the thesis

Figures 1.2 to 1.5, provide a geographical overview of the upcoming four chapters. These figures shed light

into the areas under study, revealing the spatial distribution of residences and workplaces examined in each chapter. Moreover, they provide a geographic lens through which each chapters' results can be comprehended, bridging the connection between the data and its geographical context.

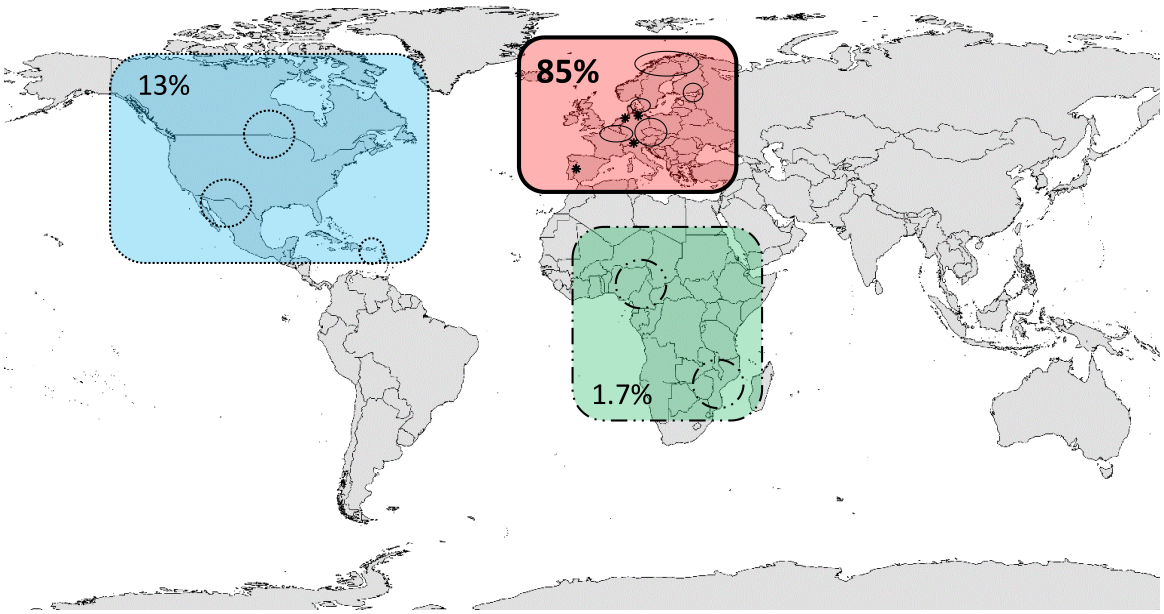

Figure 1.2: Systematic Literature Review Geography (Chapter 2)

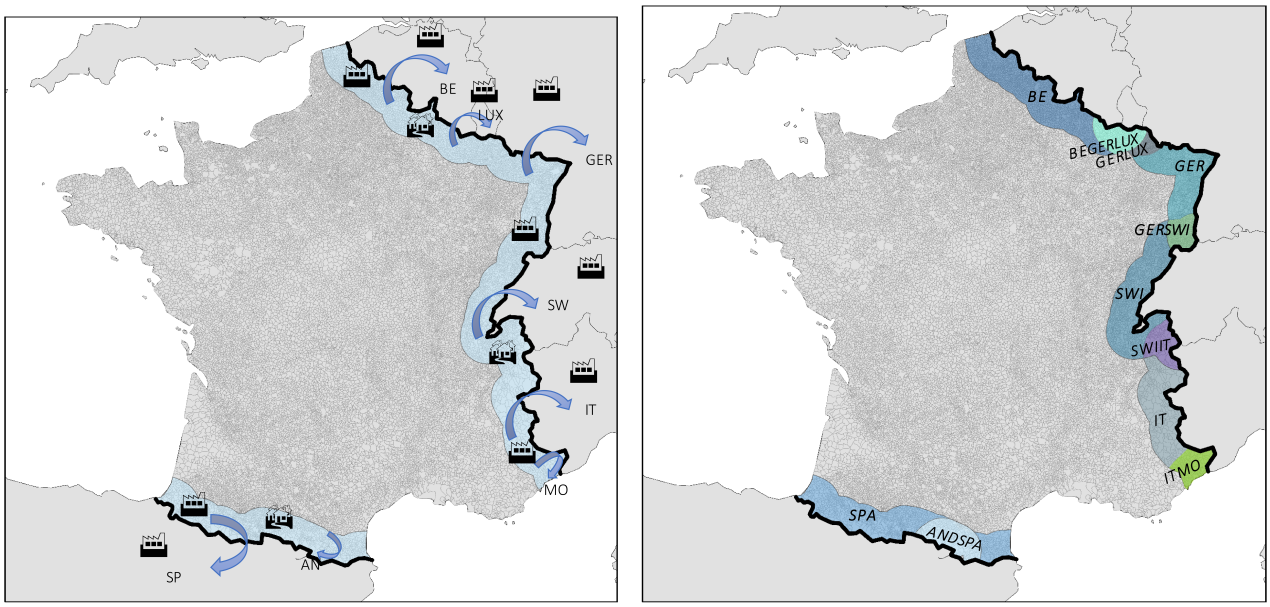

Figure 1.3: Chapter 3 Geography (left: study area; right: border zones)

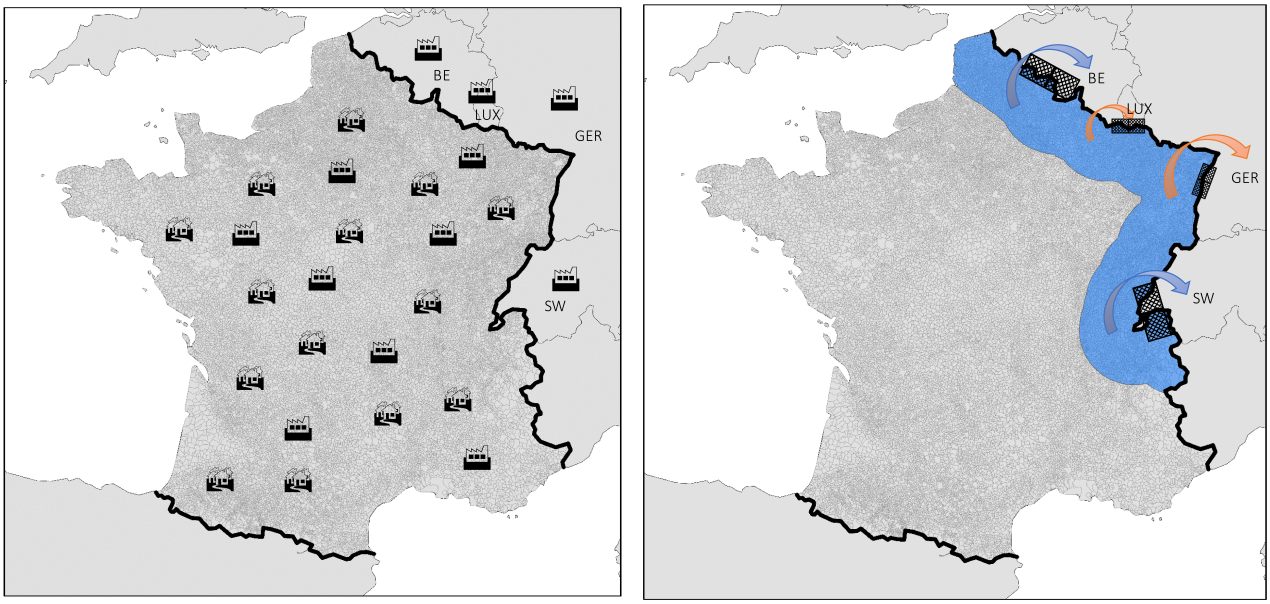

Figure 1.4: Chapter 4 Geography (left: study area; right: cross-border commuting study area and visualization of main findings)

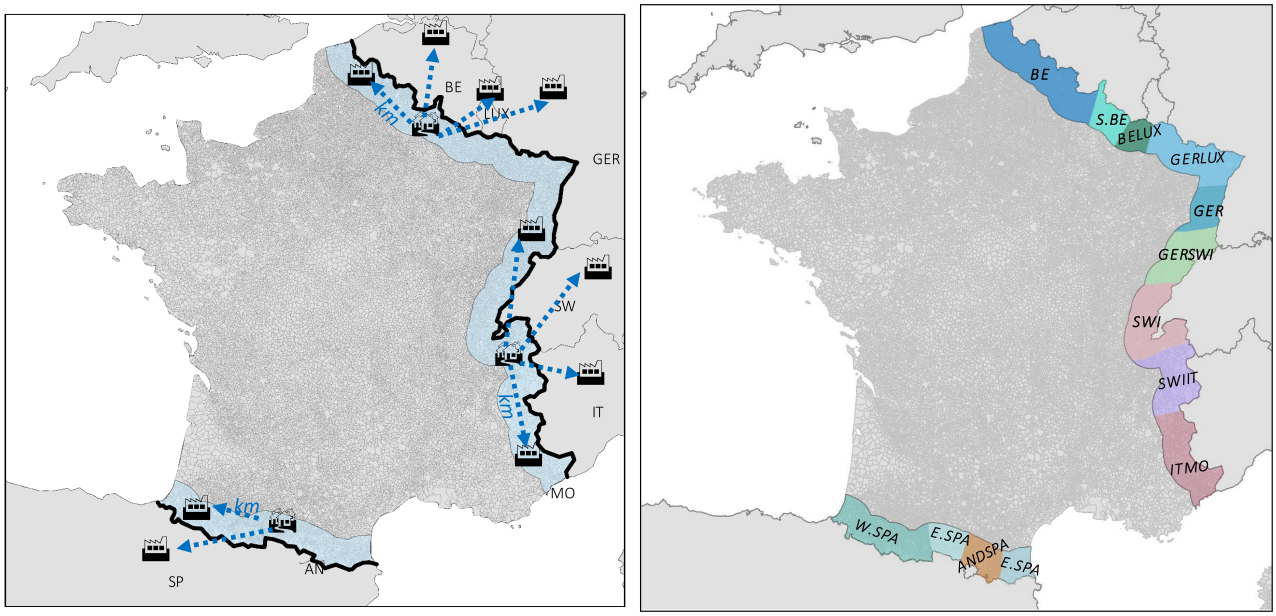

Figure 1.5: Chapter 5 Geography (left: study area; right: identified border zones)

Chapter 2

Framing the cross-border commuting literature: a systematic review and bibliographic analysis

Abstract: [1] Commuting emerges from the unequal distribution of work and residential locations and its negative effects on society require integrated urban and transport policies. Cross-border commuting is a version of commuting whereby workers benefit from job opportunities on the other side of a national border. It is growing and calls for even higher level of policies integration. Studies about the functioning and governance of border regions are also increasing but remain fragmented along a large variety of cases. There is little explicit understanding of how cross-border commuting is affected and affects border regions and about how decision trade-offs differ from within standard regions. We assemble the first comprehensive cross-border commuting literature corpus from a systematic review. We identify key topics and methods, derive commonalities and specificities compared to internal commuting, and consolidate findings though a mapping of evidences. We identify knowledge gaps and particularly find a need to further understand the decision to commute or to move or the specific role of the border, a need to connect policies more explicitly to sustainability and social issues, and a need to build homogenized datasets to apply comparable methods across cases and similarly to internal commuting research.

[1] This chapter is currently undergoing revisions for re-submission as an article to the journal "Transport Reviews". The authors of the article are: Artemis Tsiopa, Philippe Gerber, and Geoffrey Caruso.

2.1 Introduction

Commuting is the regular completion of a trip between workplace and residence (Cambridge Dictionary, 2022). It is a transport demand derived from the unequal distribution of work and residential locations. The commuting distance itself results from the way individuals and households resolve the tension between transportation costs (time) and residential costs (Alonso, 1960; Straszheim, 1987; Fujita, 1989), and commuting involves a specific mode depending on the availability at both places of residence and work. An over-reliance on commuting by car brings major environmental and social costs for cities and regions, making commuting an issue at the forefront of urban and transport planning. Despite non-work related activities contributing additional daily trips, and despite recent digitisation trends that may reduce work journeys, commuting remains a key challenge for urban regional policies. The problem is acute and difficult to solve for a given urban region, because transport improvements that reduce the separation between workplaces and residences may in turn increase the attractiveness of more remote residential places, and thus commuting. Integrated land use, housing and transport planning policies are therefore needed. The task becomes even more complicated as soon as the daily spatial system considered by households encompasses several administrative and political units, and not least national boundaries.

Cross-border commuting (CBC) involves a large population. Border regions cover 60% of the EU territory and host 40% of its population (Medeiros, 2019). Some 1.4 million individuals live in one EU country and work in another; that is, i.e. 0.6% of all employees (European Commission, 2017). CBC has increased sharply over recent decades in the EU, following several European integration policies aimed at reducing the barrier effect of borders: notably the Schengen Agreement (Terlouw, 2012), the common currency (Carpentier, 2012), the European Free Trade Association and cooperative Interreg programmes (European Commission, 2017). All have facilitated the choice for individuals to seek employment across a border and benefit from a job or wage opportunity lacking in their place of residence (Bouwens, 2004; Terlouw, 2012).

While providing economic opportunities, CBC also challenges the sustainability of cross-border metropolitan regions (Decoville et al., 2022), similar to the way in which internal commuting (IC) challenges urban and transport policies in 'standard' urban regions [2]. Integration policies have encouraged CBC, but coordination to tackle its effects — such as excess urbanisation, car dependence or public transport provision — is likely to be harder to put in place than in standard contexts.

Given these challenges and the increasing CBC trends, we aim to consolidate the CBC literature accumulated over the years, mostly from case specific analyses or comparisons, and to organise general trends, drivers or effects in a coherent framework. By providing this first framework for the CBC field, and by contrasting findings and methods to those in the IC literature, we identify important gaps and research needs and stress mechanisms or policies that are specific to the cross-border setting.

We first create a comprehensive CBC corpus from a systematic bibliographical search (Section 2.2) and complement this with cited references about IC. The full corpus table and complete bibliographical information are available at 10.5281/zenodo.7347333. Second, in Section 2.3, we structure the corpus based on the research objectives, topics, methods and geography of the case studies of the papers identified. In Section 2.4, we then thoroughly discuss the topic and sub-topics that have emerged. It should be noted, however, that while we attempt to cover all areas of the corpus, we do not cite every single paper of the corpus in the present text for conciseness. We build a knowledge map along the discussion to summarise current findings, stress knowledge gaps and suggest research avenues in Section 2.5.

[2]For the rest of the chapter, we refer to cross-border commuting as CBC and to internal commuting as IC.

2.2 Building a cross-border commuting corpus

We established the CBC corpus after a systematic search within different bibliographic databases in line with PRISMA (Liberati et al., 2009). We complement this 'CBC corpus' with a derived 'IC corpus'. Our search steps are presented in Figure 2.1 and detailed below, as they already provide interesting hints concerning the literature.

2.2.1 Cross-border commuting corpus

First, we systematically searched Scopus and Web of Science (WoS) for titles, keywords and abstracts containing the following boolean: 'cross* AND border* AND commut*'. The search was limited to articles and books published in English up to and including 2021. The Scopus search resulted in 166 papers, from which 59 were retained after qualitative inspection. The selection was based on whether the abstracts were accessible at all, showed that commuting was one of the main topics and that there was a cross-national dimension. The same process with WoS resulted in 28 additional papers from which 5 were selected, making a total of 64 papers.

In the second stage, we broadened our search by removing 'cross*' from the query, as the terms 'border*' and 'commut*' alone could potentially hint at commuting across a border. The Scopus results increased from 166 to 394, from which two publications were added to the collection after abstract inspection. Similarly, one additional publication was added from WoS. In the third step, we retrieved supplementary publications from Google Scholar using the plain phrases: 'cross border commuting OR commuters'. The first 100 results were considered, and after a rapid drop in relevance and much overlap, a total of 30 papers were added to the main corpus.

After step 3, we noted the absence in the corpus of recent work on CBC around Luxembourg and Switzerland (two countries where CBC is high). The word 'border' itself appeared to be replaced by 'transnational' or 'frontiers', which we conjecture is related to the French-speaking community of researchers in these regions. We therefore applied a fourth and a fifth search step using the expressions 'commut* AND transnational', and then 'commut* AND frontier' in both Scopus and WoS. After removing overlaps and inspecting abstracts, 8 papers were added to the corpus. Lastly, a sixth step was added after we noted that the word 'mobility' is used instead of commuting by some authors, linked to the idea that the journeys are made for work purposes. After applying the boolean 'cross AND border AND mobility AND (work* OR labor)' and after inspecting abstracts, 10 further papers were added. After all the steps, we ended up with a total CBC corpus of 115 publications.

2.2.2 Derived commuting corpus

In order to contrast the topics, methods and findings of the CBC literature with the IC literature, we needed a reasonably sized corpus about commuting. Unsurprisingly, a basic 'commut*' search alone returns a vast body of literature (over 90,000 in Scopus). While this was totally expected, our CBC corpus of 115 papers, or even the raw result of around 500 papers dealing with both 'borders' and 'commuting', are disproportionately low given that around 40% of citizens (in the EU) actually live near borders. While there is a growing and significant body of literature on CBC, we already find that it is relatively small compared with its potential societal implications, and it is thus timely to frame and reinforce this literature. For feasibility, we chose to build a comparative IC corpus from the CBC corpus references themselves. This involves both a limitation and an advantage, since key topics and methods may be missed although the most direct existing links can then be identified. We matched the 5,022 references cited by the 115 publications of the CBC corpus to the general 'commut*' search in both Scopus and WoS, and 174 papers matched both lists. Some 37 of these had already

been selected within the CBC corpus and 23 others were excluded because commuting was not primary. Our derived commuting corpus thus comprises 114 publications. This again is a somewhat low number, suggesting a relative disconnection of the researchers involved in cross-border analyses from the methods and topics applied in the fields where commuting-related issues are generally discussed (such as transportation, urban economics, urban studies, regional science and spatial planning).

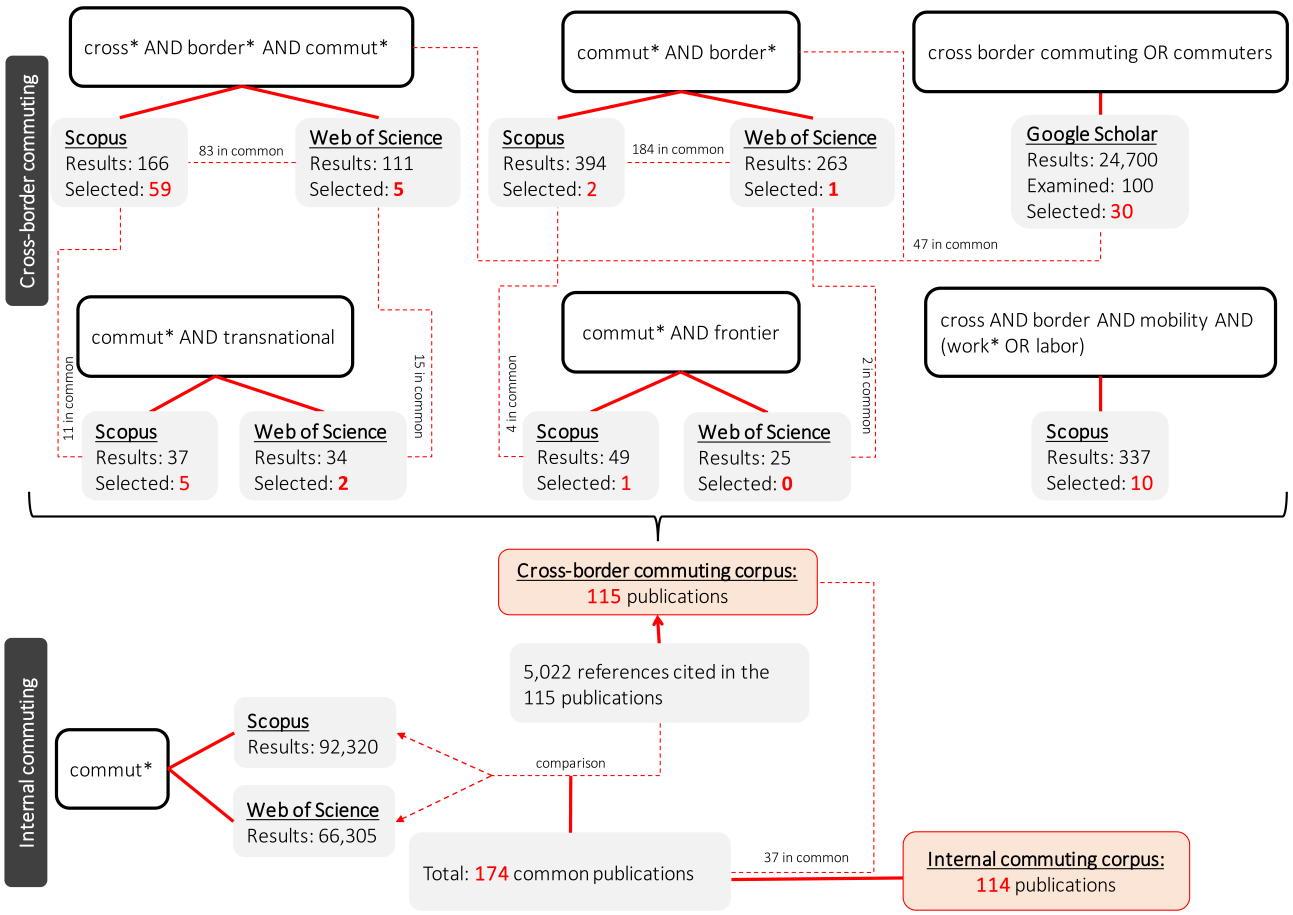

Figure 2.1: Systematic corpus identification method

2.3 Main objectives, places and methods in the corpus

The two assembled corpora can be similarly structured along a first tier of four topics: commuting 'patterns', 'determinants', 'impacts' and 'policies'. Some papers pursue several of these four topics, and Figure 2.2 shows a tabulation of the 115 CBC and 114 IC papers in line with these. References are numbered as of the supplementary data available at 10.5281/zenodo.7347333. Before turning to discussing each topic (Section 2.4), we first analyse the geographical distribution of the case studies and methods applied. For reading clarity we avoid general referencing to the papers in this section, but provide a geography and methods tag in the corpus data.

2.3.1 A largely European-focused body of literature

The colours used in Figure 2.2 correspond to different geographical regions. The CBC literature focuses massively on European regions, with 85% of cases. The US border is then considered in most remaining cases

(13%), whilst only two publications are devoted to commuting trends between African countries. These numbers are roughly in line with the relative volumes of flows: about 1.4 million in the EU in 2017, and half a million between Mexico and the USA (Pries, 2019). One could think, however, that it is the complexity of the issues and the need for policies, rather than flow volumes that should command more research. The geographical concentration may also relate to a lack of harmonised data across borders, thus making it quite likely that CBC flows in the global South are under-reported and analysed. One could further hypothesise that these are counterbalanced by international residential migration. In any case, the scarcity of papers here is a signal and a call for urgently getting to grips with the potential daily cross-border flows in the Global South.

Within Europe, some specific cases are paid more attention. The cross-border flows from Belgium, France and Germany to Luxembourg attract the greatest interest (approximately 10% of the corpus (14 papers)). Next, all with a similar importance (8 publications), are the Sweden-Denmark Oresund case, the Estonia-Finland border, and the Czech Republic, Hungary and Slovakia to Austria borders. Out of the 115 publications, only 6 analyse CBC in the European area as a whole. The literature is thus largely dominated by case studies and comparisons. We can potentially explain this as being due to the difficulty to obtain harmonised data across a continent, especially where spatial granularity or individual information is needed. Cross-European surveys exist, but suffer from geographical information that is too aggregate (e.g., Eurostat (2016); Fries-Tersch et al. (2018)) for local border effects to be understood. As expected, our general IC corpus is more balanced, especially between Europe and the USA.

2.3.2 A qualitative body of literature in need of refined quantitative data

The CBC literature is slightly dominated by qualitative methods (56 papers) over quantitative methods (51 papers, italicised in Figure 2.2). This contrasts sharply with the IC literature, which is very largely quantitative (90%), even in our derived corpus led by qualitative research. One could assume borders add a complexity that makes some quantitative methods unsuitable. In fact, given the breadth of quantitative methods elsewhere in social sciences, we instead believe it is here the effect of both (i) a focus on governance and coordination issues (which de facto requires a qualitative understanding of policy actors), and (ii) the fact that the additional complexity induced by borders requires finer data for quantitative analysis that is simply not available today. Panel data at the individual scale, for example, is rarely accessible across countries, or simply the definition of individual variables across national censuses may differ and require a great deal of effort to assemble. Comparatively, smaller qualitative surveys and interviews across a bi-national space may seem more feasible.

Within the qualitative set itself, we find a notable diversity of techniques: in-depth, open-ended and semi-structured interviews, focus groups, online questionnaires, fieldwork, observations, social media investigations, opinion polls, surveys and content analysis of literature. The target groups are primarily cross-border commuters. Yet a significant number of cases also address stakeholders, administrative officials, business owners and actors involved in public transport policies. Migrants, residents of cross-border regions, security officials and local elites make up the smaller remainder of the target groups.

Within the quantitative set, the techniques are also very diverse. The great majority of publications use mostly descriptive statistics of aggregate flows, or build and describe indicators. Yet gravity models for flows, simplified destination choice models or traffic flow simulations are also found, as well as complementary explanatory or predictive multiple regression analyses (ordinary models with and without fixed effects, interval-censored, or models from the poisson, probit or logit families) at a geographically aggregated scale or at the individual level. In contrast to the IC literature, we did not find more advanced models treating endogeneity for example, or

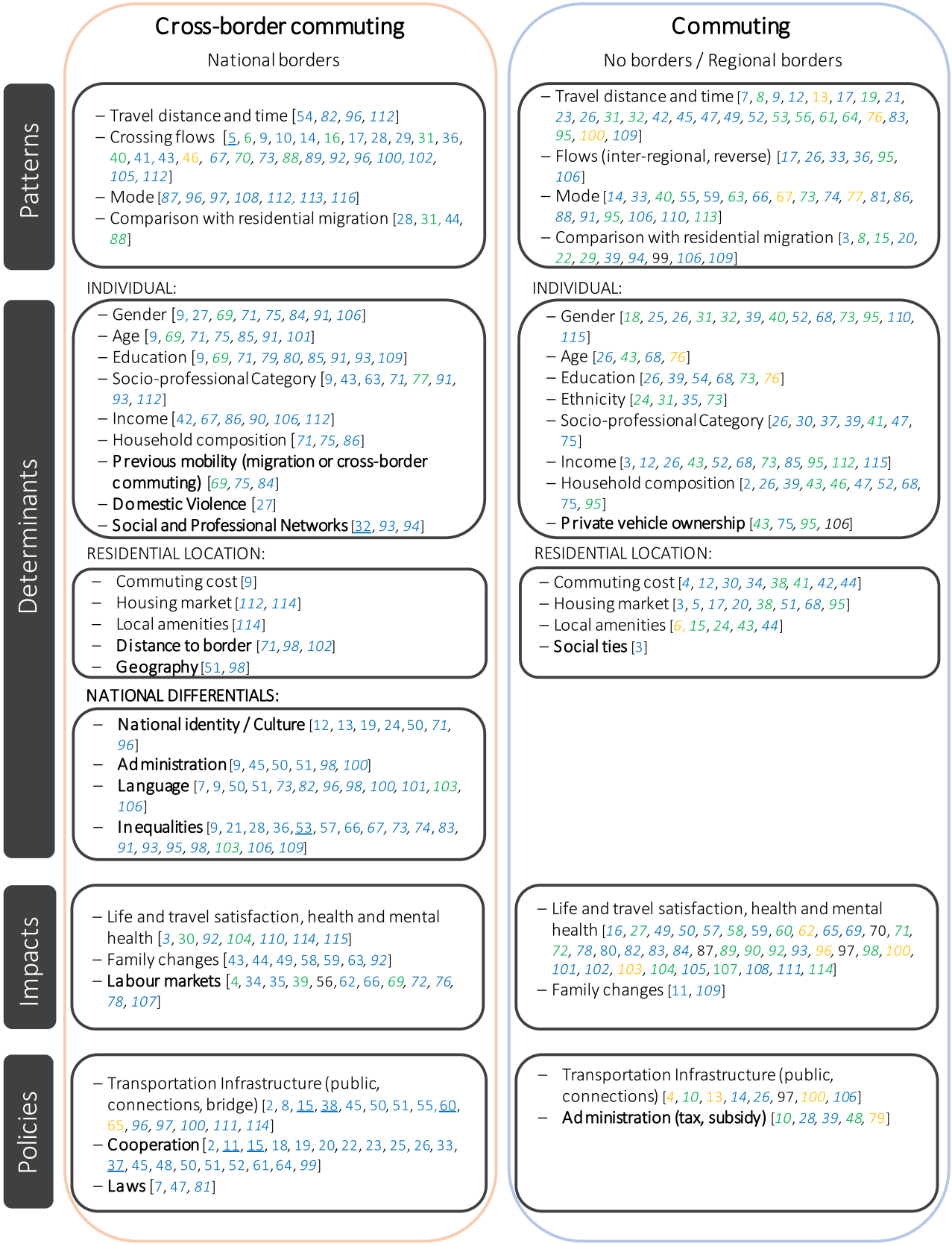

Figure 2.2: Structure of the corpora

simulation models of partial or general equilibrium. Quantitative techniques and theoretical formalism thus seem generally less advanced here, maybe again because fitting such methods is also data demanding.

The main sources of CBC data are surveys and censuses. Other sources include aggregate official statistics, mobile positioning data and data produced from interviews. Compared with IC publications, recourse to national social security and company records are missing, while these are probably among the most complete sources at the individual level. However, again they are not integrated across countries.

It should be noted that because of the diversity of techniques, the variety of data sources and the relatively low overall number of quantitative CBC papers, a statistical meta-analysis dedicated to the drivers of CBC soon appeared impossible. There is no clear way to compare the coefficients of models across several papers at this stage. More and more similar models need to be implemented across cases and more data and codes have to be shared within the cross-border research community.

2.4 Subtopics and evidence

We now proceed to the content of the CBC corpus along its four main topics. We identify subtopics, and stress findings and gaps in contrast with the IC literature. Subtopics are reported and related to each publication in Figure 2.2.

2.4.1 Patterns

Some 28.7% of the CBC papers include a description of commuting patterns through cartography or the tabulation of flows. We classify these descriptions along four subtopics: ‘travel distance and time’, ‘flow volumes’, ’transport modes’ and ‘commuting vs residential migration trends’.

Travel distance and time

Distances and times are much less focused on in the CBC literature compared with the IC equivalent, as if introducing the border would relatively decrease the importance of distance in decision-making compared with traditional urban or transport literature. The negative effect of distance on the likelihood of being a cross-border commuter is clear (Mathä and Wintr, 2009), although important variations across cases make it difficult to associate a definite time or distance range to CBC. As examples, the median CBC time from Sweden to Norway is 60 minutes (Möller et al., 2018), and the mean commute from Belgium to Luxembourg is 44 minutes (Carpentier, 2012). The average CBC duration is roughly twice the average for IC — as per our derived corpus, 22 minutes in Germany (Stutzer and Frey, 2008) or Luxembourg (Carpentier, 2012), and 29 minutes for Chicago (Wang and Hu, 2017). Some individuals even accept longer commutes in order to avoid crossing the border (Pieters et al., 2012). It is argued that the distance to the border can even affect the level of integration (Drevon et al., 2018). Yet the closer the commuters live to the border, the more similar their total trip duration is to IC (Möller et al., 2018). A longer distance or time can therefore not be seen as a key characteristic of CBC.

The IC literature investigates journey time effects in much greater detail than the CBC literature. There is no equivalent in the latter, for example, of studies that examine wage elasticities of distance, or how job opportunities vary with commuting distance, while these are analysed in IC contexts (e.g., Rouwendal (1999); Zax (1991); Van Ommeren and Rietveld (2005)) especially for long distances (e.g., Rouwendal (1998); Green et al. (1999); Sandow and Westin (2010); Joly and Vincent-Geslin (2016); Morris and Zhou (2018)). How does distance sort households by wages in a CBC context? How does it relate to the fact that homeowners are more

likely to accept a longer or cross-border commute (Rouwendal and Rietveld, 1994; Carpentier, 2012; Morris and Zhou, 2018). As we show in Section 2.4.2, the literature investigates the reasons for CBC and some of the determinants align with determinants of longer trips, but little is devoted to understanding CBC distances and times beyond descriptive statistics, and eventually little is known about the decision trade-offs between housing and transport costs in cross-border contexts.

Crossing flows

Regular CBC flows originate from the early twentieth century due to unequal development and differentials in labour market attractiveness across a border (Knotter, 2003, 2014a). In the EU, harmonisation and cooperation policies subsequently facilitated and increased CBC flows. These flows are hence a matter of efficiency in the labour market and lead to a better allocation of skilled resources (employees) over a territory (Heinz and Ward-Warmedinger, 2006). However, being critical, we note that potential impacts on the fair allocation of people in the housing market (affordability, segregation) are not present in this facilitating story, despite likely effects for non-cross-border workers in border areas.

Many researchers present details or orders of magnitudes for flows and changes in flows, demonstrating the increasing societal importance of CBC. One recent example is Cavallaro and Dianin (2020), who find an 81% increase of CBC flows between 2012 and 2018 in Europe. In terms of the proportion of total employment, Luxembourg has by far the greatest, with over 45% of employed people being cross-border commuters (Mathä and Wintr, 2009) and an increase of about 4 per cent every year between 2005 and 2019 (STATEC, 2020). Switzerland comes second (8% of employment) and Austria third (4%) (Fries-Tersch et al., 2018), followed by a series of much smaller bi-national connections.

CBC flows are not limited to Europe, and working facilitation policies have also existed in North America (Hochman, 2005) permitting intense daily flows from Mexico (and Puerto Rico) to the US (e.g., Herzog (1990); Duany (2002)), especially for the manufacturing sector (Kopinak and Soriano Miras, 2013). This is a key difference to Europe, where there is s greater variety of sectors in CBC, depending on which border zone is considered. The trend is also very different: cross-border employment at the USA border is significantly decreasing (Orraca Romano, 2015; Konrad, 2015).

Mode Choice

Cross-border commuters rely massively on cars. As an example, about 88% of commuters from Belgium to Luxembourg travel by car (Carpentier, 2012). The suggested reasons are largely in line with the car-dependence literature, with a further focus on transport infrastructure, including parking at destination (Enaux and Gerber, 2014; Ma et al., 2015), and mostly stressing the lack of public transport provision (Schiebel et al., 2015; Möller et al., 2018; Cavallaro and Dianin, 2019). This adds a border complexity to the more traditional density effects in public transport provision (Schwanen and Mokhtarian, 2005; Limtanakool et al., 2006).

There are also important individual dimensions with regard to mode choices, relating to costs (Verplanken et al., 2008) and income (Wang and Hu, 2017), and the interaction between residential location and commuting choice Limtanakool et al. (2006). There is no tangible measurement or cross-tabulation for these effects in CBC, or any evidence of how these trade-offs would vary relative to intra-national contexts. This is a surprise, especially since finer individual aspects of the decision-making process have been analysed for CBC — for example, the effect of environmental concerns and beliefs on public transport choice (Enaux and Gerber, 2014). As pointed out by Gerber et al. (2018), recognising that public transport is environmentally friendly does not

seem to convince most cross-border workers to stop using their car. This type of conclusion calls for a fuller understanding of CBC mode choices, including financial and time costs across the different modes and across different socio-economic groups. Such analyses are clearly missing in the CBC literature at this stage. In addition, there are contradictions in the literature regarding the increase or decrease of car use for longer CBC trips (Carpentier, 2012; Gerber et al., 2018). The distance effects mentioned above thus also need to be integrated in the perspective of mode choice.

Comparison with residential migration

A substantial number of papers in our derived IC corpus look at the tension between migration (a residential move) and commuting (daily mobility). This tension is surprisingly less present in relative terms in the CBC literature, whereas we expected it to be even more important since daily journeys across a border bear additional burdens that, everything else equal, may tip the balance in favour of relocation.

Migration occurs when individuals leave one combined housing and labour market for another and acquire a more beneficial combination of house prices and employment (Zax, 1994; Van Ommeren et al., 1997). These markets, together with household and individual preferences (Haas and Osland, 2014; Van Ommeren et al., 1997), moving costs (Romani et al., 2003), urban structure and amenities, exurbanisation (Renkow and Hoover, 2000) or school quality (Siim and Assmuth, 2016) determine the decision between commuting and migration. Two-earner households tend to be less likely to move than single-earner ones (Van Ommeren et al., 1999; Limtanakool et al., 2006; Paci et al., 2010), while higher-educated and younger individuals are more likely to choose to migrate (Paci et al., 2010). What those tensions become in border contexts is seldom analysed, but interestingly some authors indicate that CBC can be considered as a first step towards a future migration (Friberg, 2012; Kopinak and Soriano Miras, 2013; Telve, 2016). A related question is: Who is actually willing or capable of migrating and who is stuck or willing to stay at the other side of the border? Around Luxembourg, for example, housing price differentials across the border and housing supply strategies seem to prevent some of the migration (Carpentier, 2012; Gerber et al., 2017; Van Egmond and Wirtz, 2020), although these effects are not explicitly modelled. Similarly, immigrants from Mexico to the US have a higher income than cross-border workers (Orraca Romano, 2015). There is definitely a need for relevant research to report CBC flows in comparison with migration, but also to shed light on these numbers with preferences and budget constraints.

2.4.2 Determinants

The largest part of the CBC corpus investigates the determinants for cross-border commuting. Three categories of determinants are investigated in the literature: individual or household level, residential place characteristics and variations of attributes at the larger national scale.

Individual Determinants

Gender is a strong determinant of CBC commuting (Ortiz and Contreras, 2011; Huber and Nowotny, 2013), as it is for IC and longer IC journeys. Women are less likely to engage in CBC, resulting in men representing 58 to 81% (in our corpus) of cross-border workers (Alegria, 2002; Greve and Rydbjerg, 2003; Crane, 2007; Paci et al., 2010; Huber and Nowotny, 2013; Mooses et al., 2020; Hars and Simon, 2016; Nowotny, 2010). Even though long distance is not a clear feature of CBC, there are parallel findings in the IC literature that women tend to undertake shorter journeys (White, 1977; Clark et al., 2003; Crane, 2007; Sandow, 2008; Sandow and Westin,

2010; Wheatley, 2014; Broersma et al., 2020) and share similar reasons, such as greater childcare responsibilities (Gottholmseder and Theurl, 2007; Wheatley, 2014; Broersma et al., 2020) or more risk adverse (Nowotny, 2010).

Younger individuals commute more across borders (Huber, 2014). The average age of cross-border commuters is between 35 and 40 (Alegria, 2002; Greve and Rydbjerg, 2003), after which the willingness to engage in CBC decreases (Gottholmseder and Theurl, 2007; Nowotny, 2010; Hars and Simon, 2016). The effect of educational attainment level is somewhat contradictory. Seven studies (De Gijsel and Janssen, 2000; Alegria, 2002; Greve and Rydbjerg, 2003; Gottholmseder and Theurl, 2007; Sandow, 2008; Huber, 2014; Hars and Simon, 2016) show that CBC increases in line with education level, but Wiesbock and Verwiebe (2017) show that the majority of cross-border commuters have medium educational qualifications, and Huber (2014) indicates they are less educated than migrants and internal commuters. Compared with the IC literature, one must also add a barrier effect due to diploma recognition (De Gijsel and Janssen, 2000) and more generally skills transfers across borders (Huber, 2012a,b).

Similar to education, income can be both a push and a pull factor, increasing or limiting CBC depending on the labour market on both sides of the border. Higher wages across the border increase CBC (Bode et al., 1994; Van Ommeren and Rietveld, 2005; Mora and Davila, 2011; Carpentier, 2012; Broersma et al., 2020), whereas a higher wage expectation at home restrains CBC (Nowotny, 2014). Broersma et al. (2020) quantify that a 1% increase in the wage difference across a border increases CBC by 19%. This effect, however, may not be linear: at the low-income end, even low wages across a border can be attractive to worse-off individuals on the other side of it, as long as their living standard would increase (Wiesböck, 2016). At the upper-income end, we know from the IC literature that individuals may accept longer commutes and extra costs (e.g., Baccaïni (1997); Sandow (2008)).

With regard to household composition, the literature shows that individuals who live with children (or care-requiring members) are less likely to commute across a border (Gottholmseder and Theurl, 2007; Nowotny, 2010). The presence of another cross-border commuter in the household does not affect the decision unless there are also children (Gottholmseder and Theurl, 2007). While living alone increases the probability of longer internal commutes in standard settings (e.g., Paci et al. (2010)), it does not increase the likelihood of commuting over a border (Nowotny, 2014). Other individual effects specific to the CBC literature include peer networks that facilitate administration or finding a job on the other side of the border (Gonzalez-Gomez and Gualda, 2014; Verwiebe et al., 2017; Wiesbock and Verwiebe, 2017), comparison with residential migration (Alegria, 2002; Nowotny, 2010; Huber and Nowotny, 2013) as discussed above, and domestic violence in the context of the US-Mexico border (Ortiz and Contreras, 2011).

Residential Location

Several attributes of residential location determine the likelihood of CBC. However, while considering the distance to the border, commuting costs and the housing prices at the residential location, there is a chicken and egg effect (endogeneity and self-selection) that is difficult to uncover. This difficulty is known in IC (e.g., Van Ommeren et al. (1997)), but is mostly not analysed for CBC. As mentioned above, there is an obvious effect of the distance to the border in terms of the decision to become a cross-border commuter: in very close proximity — 10 km for Chilla and Heugel (2022) or Bello (2020) — CBC is more likely (Gottholmseder and Theurl, 2007). Given that the standard IC literature shows the resulting commuting distance also depends on wages (e.g., Van Ommeren et al. (1999, 2000); Rouwendal and Meijer (2001); Rupert and Wasmer (2012)), an interaction between distance and a potential wage gap is to be expected in CBC. Although suggested (e.g., Greve

and Rydbjerg (2003)), this interaction has not yet been quantified.

Even within short distance ranges, other geographical variations matter. Mountains obviously make transportation more difficult (Medeiros, 2018; Chilla and Heugel, 2022), but also amenities such as urban quality or landscapes that keep workers from moving their residence and thus encourage CBC (Gerber et al., 2017), in the same way that it would encourage longer commutes in the IC literature (e.g., Rouwendal and Meijer (2001)).

In principle, both job accessibility and amenities are reflected on the housing market, and the decision to commute is thus a simple trade-off between housing and commuting costs. However, further discrepancies seem to arise because of the border, making the market particularly more attractive on one side of the border. This is reported around Luxembourg (e.g., Carpentier (2012); Gerber et al. (2017)), but the exact reasons for abrupt changes in housing prices (non-continuity) are not fully understood, even if planning or supply side rigidities exist in that case (Paccoud et al., 2022).

National Differentials

National differences can be both a driving force and an obstacle to CBC. First, like any other spatial interaction, CBC flows result from an imbalance between an origin and a destination. This imbalance can be local and can emerge from the daily urban system, but can also stem from differences at the larger national or regional scales. CBC flows are high when there is an unequal level of income, taxation and employment between regions (Mathä and Wintr, 2009; Decoville et al., 2010; Friberg, 2012; Decoville et al., 2013; Knotter, 2014a; Hars and Simon, 2016; Mathä et al., 2017; Chilla and Heugel, 2022; Broersma et al., 2020; Comerio et al., 2020). Although not necessarily quantified, these are by far the most frequently reported source of CBC flows in the literature. Some authors also stress the effect of more general differences in levels of economic development and poverty (Bohm and Opiola, 2019; Wiesbock and Verwiebe, 2017; Orraca Romano and Vargas-Valle, 2020). Others stress the role of general inequalities in housing markets and living costs (Bode et al., 1994; De Gijsel and Janssen, 2000; Greve and Rydbjerg, 2003; Buch et al., 2009; Pires and Nunes, 2018) that prevent people from moving and thus foster CBC.

Second, national borders by definition also create administrative, political and legal differences, which are clearly reported to function as obstacles to CBC (Greve and Rydbjerg, 2003; Decoville and Durand, 2016; Medeiros, 2018; Svensson and Balogh, 2018; Chilla and Heugel, 2022; Cavallaro and Dianin, 2020). National borders sometimes also parallel important cultural differences. Further, van der Velde and van Houtum (2004); Van Houtum and Van Der Velde (2004); Paasi and Prokkola (2008); Svensson and Balogh (2018) or Petrjánošová and Lášticová (2011) suggest the existence of a mental border or the importance of a feeling of belonging that reduce CBC. Individual open mindedness towards other cultures then seems to favour CBC (Gottholmseder and Theurl, 2007).

Lastly, language similarities or differences are a significant incentive or deterrent to CBC and very often stressed in the literature (Nahrstedt, 2000; Greve and Rydbjerg, 2003; Mathä and Wintr, 2009; Pieters et al., 2012; Medeiros, 2018; Möller et al., 2018; Svensson and Balogh, 2018; Chilla and Heugel, 2022; Broersma et al., 2020; Cavallaro and Dianin, 2020; Orraca Romano and Vargas-Valle, 2020). Ethno-linguistic minorities are also found to be more willing to commute across a border (Mooses et al., 2020).

2.4.3 Impacts

Three types of impacts of CBC emerge from the corpus: impacts on travel and life satisfaction, on family balance and on the labour market. The absence of specific analyses on the environmental or societal impacts of CBC via

car use or urbanisation is quite notable. These issues are somewhat present, however, within policy oriented or general challenges papers such as Durand et al. (2020), mentioning residential segregation, urban sprawl or extreme commuting as negative impacts.

Life and travel satisfaction

The effect of commuting on travel and life satisfaction was the object of a recent review by Tao et al. (2022). It is also an important part of our IC corpus (40 publications), with a further focus on longer commuting generally showing it is associated with lower travel satisfaction (Sposato et al., 2012; Gerber et al., 2017; Gorman-Murray and Bissell, 2018; Zhu et al., 2019; Chatterjee et al., 2020), lower life satisfaction (Stutzer and Frey, 2008; De Vos, 2019; Jacob et al., 2019) or higher stress (Stone and Schneider, 2016). Again here, CBC cannot be equated to longer commuting, as a positive impact on life satisfaction is generally found for the former. More precisely, Haindorfer (2020) find that individuals perceive their living conditions have improved after CBC in comparison with other workers at the origin place. Nonnenmacher et al. (2021) find CBC workers have an improved health index compared with non-cross-border workers. The improvement is associated with wages and the premium obtained after crossing the border. More surprisingly it also holds after controlling for wages, which the authors relate to a self-selection process: healthier workers are more likely to engage in CBC. With regard to the mode of commuting — which is another aspect of satisfaction (Tao et al., 2022) — the results are mixed, arguably from different CBC contexts: greater travel satisfaction is found when public transport is used for CBC around Luxembourg (Gerber et al., 2020), while public transport commuters report feelings of boredom, frustration and powerlessness at the Mexico-US border (Rodríguez and Curlango Rosas, 2013).

Family changes

CBC has a noticeable effect on household roles and family relationship dynamics (Siim and Assmuth, 2016) and sometimes causes disruptions (Michniak, 2016). CBC affects the commuter her/himself, but also the other household members; for example, in their support role in communication and networking, or in the need for learning languages (Telve, 2019a,b). Children seem also to be more confused, especially when CBC is carried out weekly rather than daily (Siim and Assmuth, 2016). The within-family balance is also affected by the behavioural attributes of the person who commutes: some develop a more independent (selfish) behaviour due to the mobility (Frigren and Telve, 2020), whereas others become more involved in family life, especially when the job comes with additional advantages such as additional parental leave or flexible work (Telve, 2018).

Labour markets

The literature often generally emphasises how the opening of borders triggers economic development in border regions and their increasing role in national labour markets (e.g., Mathä et al. (2012); Herzog and Sohn (2014); Durand et al. (2020)). Some research has been carried out more specifically on how CBC affects labour markets. Unemployment rates are found to decrease because of CBC in the origin regions and increase in destination regions (where cross-border workers are preferred) (Ericson, 1970; Pierrard, 2008), or they lead to the creation of more jobs, thereby reducing unemployment (Pierrard, 2008). However, wages do not seem to be affected by the presence of cross-border commuters (Moritz, 2011). Some effects are also found on the dynamics of the labour markets, with more flexibility in the presence of cross-border commuters (Tsapenko, 2018; Klatt, 2014). One could argue that there is self-selection, and people are attracted to the more flexible labour markets. Yet cross-border labour markets should not be mistaken for globalised labour markets, associated with residential

migration (Gerber, 2012). In the US-Mexico case, Alegria (2002) also reminds us that CBC workers participate in — and thus influence — two labour markets: that of their destination, from which they receive their wages, and of their origin, where they usually spend these wages (Knotter, 2014b).

2.4.4 Policies

Transportation infrastructure is the obvious policy topic common to the two corpora. Cooperation and integration policies are fairly specific and represent a very large proportion of the CBC literature. Yet the effect of administrative differences is also not limited to crossing national borders.

Transportation Infrastructure

Different authors stress that stakeholders understand the role of transportation systems in supporting regional economic growth (Decoville and Durand, 2016; Dorry and Decoville, 2016; Iweze, 2020). The development of public transportation across borders then appears as a key policy challenge and calls for cooperation and planning (Durand and Nelles, 2014). Research clearly emphasises that public transportation is currently insufficient to cope with increasing CBC (Medeiros, 2018; Möller et al., 2018; Svensson and Balogh, 2018; Medeiros, 2019; Christmann et al., 2020; Gerber et al., 2017) including by residents of rural areas (Cavallaro and Dianin, 2020). The latter echoes issues of public transport efficiency or affordability discussed in the IC literature (e.g., Pooley and Turnbull (1999); Coulson et al. (2001)).

In addition to public transportation, road infrastructure development is also discussed in the CBC literature (Medeiros, 2018), including heavy infrastructure such as bridges (Westlund and Bygvrå, 2002; Balogh and Pete, 2018) or underwater tunnels (Schmidt, 2005). While there is a clear agreement in transport research in general that building more roads is not a sustainable long-term solution for cities, or a solution to congestion, this is barely seen in the CBC literature. This does not mean that it is ignored, but instead that the focus is set at the inter-regional transport scale rather than framed as an urban question where the effect of a derived demand is probably clearer. CBC is actually a mix of both an inter-regional question and an urban question — albeit spanning two countries — but transport policy questions seem largely framed under the first domain.

Cooperation

Cooperation between border regions is the most documented policy topic within the CBC literature. It includes (but is not specific to) commuting. The primary issue emerges from the fact that policies aimed at 'removing' borders are undertaken at national level and may thus ignore effects on border regions themselves (Paasi and Prokkola, 2008; Yndigegn, 2011; Prokkola, 2011; Decoville et al., 2010; Dorry and Decoville, 2016; Medeiros, 2018; Svensson and Balogh, 2018). More specifically, the imbalance between the governing level and the area concerned by CBC seems to arise from a lack of interest in promoting cross-border cooperation (Decoville and Durand, 2016), a lack of experience of policy-makers regarding the specificities of cross-border settings (Matthiessen, 2004; Svensson and Balogh, 2018), or insufficient funding (Terlouw, 2008; Medeiros, 2014). Researchers suggest that local governments should be put in charge of cooperation policies (Schmidt, 2005), that mutual trust must be increased (Sohn, 2014) and that policies should be based on market needs rather than political wishes (Lofgren, 2008). They also suggest an increased role for cross-border institutions, organised networks (Klatt and Herrmann, 2011; Cavallaro and Sommacal, 2019) and programmes such as INTERREG (Medeiros, 2018). Other than general cooperation policies, some domain-specific ones may also indirectly impact

on commuting behaviour or residential mobility over the border; for example, shared health facilities (Herzog, 1990), digital services (Soe, 2017, 2018), discounted tolls (Knowles and Matthiessen, 2009) or technology-based border controls (Morchid and O'Mahony, 2019).

Laws and administration

The relative location of firms and households, and hence commuting costs and flows, can be affected by subsidies and tax incentives that vary across space (e.g., Coulson et al. (2001)). In CBC contexts, these spatial variations are the norm rather than the exception. CBC is ruled by several national laws and multi-national agreements (work permits, taxation laws, etc.). As documented mostly for the EU (Nahrstedt, 2000; Montaldo, 2017), tax and social security laws are the two key sources of imbalances between CBC workers and residential workers that influence the decision to locate in the employment country or not, and thus affect CBC. Nahrstedt (2000) examined the legislation and related conflicts, and notes that cases have been usually resolved in favour of CBC workers, and thus that imbalances tend to decrease over time. The rise of flexible working time and teleworking may, however, add new dimensions to these issues in the short term. Nahrstedt (2000) also mentions that discrimination may arise in domains other than income and social security, such as investment or property allowances. In addition, CBC may in turn significantly impact on social security systems (family, pensions, etc.) themselves, although this seems to be reported only for Luxembourg where the proportion of cross-border workers in the labour force is very high (Labouré, 2019).

2.5 Discussion

We have taken stock of the literature on CBC, a growing but still limited body of literature with respect to its spatial and demographic importance. We have so far described its key topics, subtopics methods and content. We now summarise and frame its main findings (2.5.1) to discuss gaps and stress a number of development opportunities of the field (2.5.2).

2.5.1 Knowledge summary

In Figure 2.3, we build a visual summary in the form of a knowledge map showing the main connections between the different topics discussed in the CBC literature and summarising the results of our content analysis. The knowledge map is based on the subtopics identified in Figure 2.2. Oriented connectors are used to represent agreements in the literature and a + or – sign indicates whether a positive or a negative effect is found for the subtopic.

It is evident that the majority of agreed connections that can currently be traced in the literature are between the determinants and the level of flows crossing a border. In addition, the evidence related to individual effects and residential location effects on crossing flows are very similar to the evidence found for internal commuting. In that sense, CBC is a very standard form of commuting, albeit more intense and sharing similarities with longer distance commuting. Similar to a longer commute, CBC is more likely for men, those of developing career age, those with higher education and those with fewer children. Residential distance to the border acts as a commuting cost, just as a standard distance to jobs. National differences then add complexity in determining the commuting probability for an individual, mostly adding a barrier via language (culture) or administrative differences.

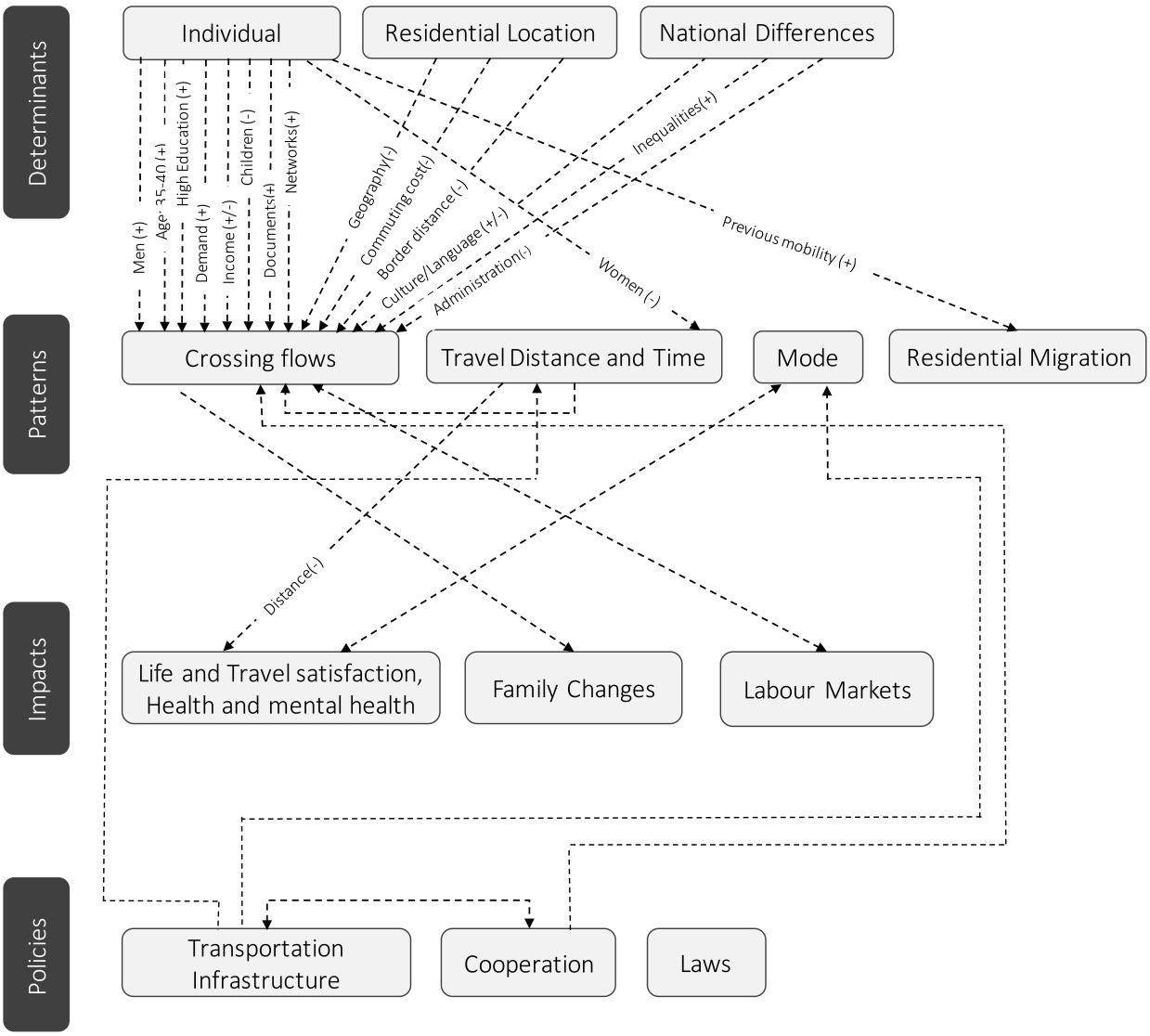

Figure 2.3: Cross-border commuting literature knowledge map

At a more aggregate scale, the pattern of distances and time (accessibility) in turn impacts on the feasibility of CBC flows. Similarly, aggregate flows are indirectly influenced by cooperation policies that smooth out administrative differences or support cross-border infrastructures. Flows, however, are both impacted by and impact on labour markets, in that imbalances in job availability create flows, and these flows in turn create further imbalances. Transportation modes for commuting across borders are surprisingly barely connected with individual characteristics. Distance and mode choice effects on life and travel satisfaction have been identified in CBC, but whether the individual determinants of mode choice differ in a CBC setting or a standard setting still needs to be identified after controlling, for example, for accessibility effects or cross-national differences. What is currently agreed is that there is insufficient public transport infrastructure provision across borders, and this is not notably different from a conclusion one could also infer for internal commuting, given current sustainability challenges.

From the policy side, it can be clearly identified in the literature that transport provision policies must affect travel distances and times, ultimately reducing costs to individuals. Integration policies are intended to overcome national differences that are seen as barriers at the individual level, especially from the labour market perspective.

We can then see cooperation policies as an instrumental (sub-)policy to improve both integration and transport policies.

2.5.2 Future research directions

First and most striking in our mapping attempt is probably the many missing or under-examined links between the subtopics. For example, how is residential migration (vs commuting) affected by residential characteristics (local labour markets, housing supply, neighbourhood quality, local amenities, etc.), accessibility or vehicle ownership? How are travel times and distances linked with modes? How do cooperation and differences in laws affect life or travel satisfaction or mental health in cross border areas? Since these are links within existing and identified CBC topics, we believe these are research questions for which answers are in close reach.

Second, there are topics or subtopics that are simply absent to date. Commuting by car typically, and over long distances in particular, is not without impact on the environment and the planet. Pollution effects or the contribution to CO2 emissions (and their accounting in one or the other side of the border) are not yet part of the CBC impacts literature, for example. Equity, segregation or housing markets also seldom appear. After comparing with our IC corpus and references, the field seems to work a little in isolation, stressing the specificities due to a border but somehow downplaying the issues and challenges that apply to standard commuting, and thus not fully benefiting from more general findings and methods. In addition, it remains to be seen to what extent policies are entirely novel because of the CBC context, or whether environmental, social and urban planning policies applied in other contexts would work well.

Third, the effects of the distance to the border and ultimately the spatial extent of the cross-border particularities have not been sufficiently explored. Rather than a singularity, cross-border commuting could be seen in a more continuous way in space, gradually equating to standard commuting and with national discontinuities being treated in the same way as any other administratively varying factor. Where differences remain, this perspective would highlight the need for more focused (infrastructure, labour, housing, etc.) policies and the geographic space where increased cooperation is needed.

Fourth, more elaborate empirical studies are in need to deepen the links identified above. It seems essential that the results of the qualitative research (surveys of actors, commuters, etc.) are examined further and supported by quantitative empirical evidence. Quantitative evidence could also be built from more advanced methods (econometric, spatial analytics, simulation, etc.) that can be found in standard urban and transport literature dealing with commuting. It is also equally important to reflect on how the individual effects identified quantitatively can feed into or be triggered by the qualitative research, which to date has been more focused on governance than on individual behaviour. Along similar lines, it is important to remember that Europe is over-represented in the field, especially with regard to scales of governance and cooperation polices.

Fifth, a key challenge to further empirical research is the lack of comparable data. This probably partly explains why most studies stress specificities of cases rather than seeking a more general understanding of the effects of borders on commuting. Direct comparative research remains rare, and potential analyses over wider territories lack the necessary geographical granularity. The wide variety of variables and data types adds to a lack of agreed standard methodologies across cases. Both factors make a meta-analysis impossible at this stage, but we believe that working towards comparable mapping, models, estimations and surveys across many cross-border areas must be encouraged.

It also appears there has not been a major effort regarding data in the field, and almost no use of social media data. In Europe, continued investment in making census data available at a 1 km grid (Eurostat, 2023) rapidly

improve the situation, provided the cross-border complexity is not lost in the process. At the global scale, the approach used within the GHSL framework is also an important step forwards, since attention is paid to avoid border biases (Maffenini et al., 2020).

Lastly, it is crucial to monitor changes in CBC flows and determinants after new events, such as the COVID-19 pandemic and the increase in teleworking. The closing of borders and different national strategies affected cross-border commuting and decreased trust in the capacity of cooperation between neighbouring countries (Novotný, 2021; Novotný and Böhm, 2022). Teleworking and more generally new patterns of work are heavily debated these days and likely to affect commuting traffic, patterns and impacts everywhere. In cross-border areas, such changes could heavily shift the balance towards residing out of the country of work, with transportation costs having less weight in the decision-making process.

2.6 Conclusions

In this chapter, we have offered the first extensive systematic literature review of cross-border commuting. Cross-border commuting is an increasing reality that challenges urban development and transport policies exactly where cooperation and integration is difficult. Everywhere, commuting results from the relative separation of jobs and residential places, but borders add discontinuities that stress the difference between the qualities of jobs and residential places. They stress even more the need for integrated land use and transport policies, with the added complexity of labour market, administrative or cultural differences. Although it is understudied, in the same way as other places, cross-border areas also face the contemporary sustainability and social challenges.

We assembled the comprehensive corpus of scholarly work related to cross-border commuting (made available as 10.5281/zenodo.7347333), and organised it under its four main topics and a series of subtopics. We have provided a content analysis for each topic, as far as possible keeping an eye on how it compares with internal commuting. We argue the field needs consolidation and more cross-fertilisation with urban and transport approaches and studies in non-cross-border areas.

We suggest the field develops towards (1) estimating the missing links between components of its current system, (2) explicitly embracing sustainability and social challenges related to any urban and transport development, (3) more clearly identifying the spatial areas where borders lead to behavioural or policy specificities, (4) obtaining stronger and comparable quantitative evidence and their links to qualitative understanding, (5) homogenising data and approaches, and lastly (6) considering recent changes due to more flexible working patterns, as they are likely to be even more impactful in border areas than elsewhere.

Chapter 3

Cross Border Commuting from France: individual and geographical determinants

Abstract: [1] Cross-border commuting is a key attribute of border spaces with impacts on labor and housing markets, transport flows and urban development. It challenges both the welfare and sustainability of those demographically important regions, where people can potentially decide to work on one or the other side of the border. Studies of the determinants of cross-border commuting are either devoted to a single specific border zone or are spatially aggregated when dealing with several countries. This impedes a nuanced understanding of spatial heterogeneities, especially of how proximity of the border and geographical effects interact with individual characteristics for deciding on a workplace. In Europe, France is by far the largest 'sending' country in volume of cross-border workers and has eight continental borders. We contribute the first analysis of cross-border commuting for the entire border facade of France using individual data and fine-grained residential locations. We estimate models that include individual, household, and sector characteristics, as well as municipality attributes to capture the urban environment (core, suburbs, exurbs) of workers and their location relative to jobs within France. We add the proximity to the border and interact variables with the different cross-border zones (i.e. France-Spain, France-Switzerland) to identify any specificity of destination countries.

[1] This chapter will be submitted as a journal article by the authors: Isabelle Pigeron-Piroth (University of Luxembourg), Artemis Tsiopa, and Geoffrey Caruso.

3.1 Introduction

Commuting plays a vital role in connecting the geographical gap between one's workplace and residence. It resolves spatial differences in job opportunities and housing costs or quality between the place of residence and the place of work. While commuting is primarily observed within urban areas, where it even serves as a defining characteristic, it also takes place between different urban regions and between cities and rural areas. Consequently, the individual determinants of commuting may vary according to the degree of urbanisation and the geographical context.

Commuting operates within a certain distance range, where residential relocation or disregarding job opportunities come into play. On an individual level, longer commutes entail higher costs, necessitating higher salaries, workplace benefits, or lower living expenses. On a societal level, longer car commutes have negative effects, prompting sustainability-focused policies to reduce the distance between homes and workplaces while supporting labor market mobility. These policies encourage public transportation use and relocation to employment centers, though housing impacts must be considered. Understanding commuting choices requires detailed spatial information encompassing job proximity, transportation, amenities, nature, and housing prices. Fortunately, there is now a range of spatial data available at fine scales, which are utilized in urban and transportation research focused on specific urban regions.

However, there are also a significant number of more complex cases, particularly in Europe, where differences in job availability, housing costs or transport provision are exacerbated by the proximity of national borders and where comparable disaggregated data are rarer. Some 1.4 million workers (European Commission, 2017) reside in one EU country and work in another, mostly in border regions. Border regions are generally defined at an aggregate administrative level (such as NUTS2), leading to an estimate that 40% of the EU28 population lives in a border region (Medeiros, 2019). An important percentage that contrasts with the low 0.9% of cross-border workers in the total EU28 workforce (Ludden and Jeyarajah, 2019), despite decades of efforts to reduce barriers to cross-border employment or trade (including the Schengen Agreement (Terlouw, 2012), the Euro (Carpentier, 2012) or specific labour mobility or transport programmes such as EURES or TEN-T (Ludden and Jeyarajah, 2019)).

However, upon closer examination of border demography, there emerges a notable divergence from initial expectations. While it is anticipated that around 30% of the European population resides within a 50km radius of a continental EU border (Figure 3.1), there is a significant dispersion around this average. Within a 10km proximity to a border, where the majority of cross-border commuting occurs (Gottholmseder and Theurl, 2007; Chilla and Heugel, 2022; Bello, 2020), the percentage drops to around 10%. This observation highlights the significance of considering the spatial organization of population and job distribution, specifically the urban structure, on both sides of each border. It is evident that infra-regional data is essential to fully comprehend these dynamics.

As depicted in Figure 3.1, the population of France living in a border region falls below the EU average with a percentage of 20%. This is primarily due to the fact that a large portion of the border facade of France consists of an extensive 3,500 km of maritime coastlines. Despite having a lower number of border regions, France, with eight neighboring countries, is the country with the highest number of out-commuters (438,000) followed by Germany (286,000) (Eurostat, 2016). Notably, in France, the majority of cross-border commuters (approximately 383,000 individuals in 2016, according to INSEE) reside within a maximum distance of 50km from a border. This implies that 13% of the individuals living in the French border area, engaged in a polarized commute, cross the border to reach their workplace.

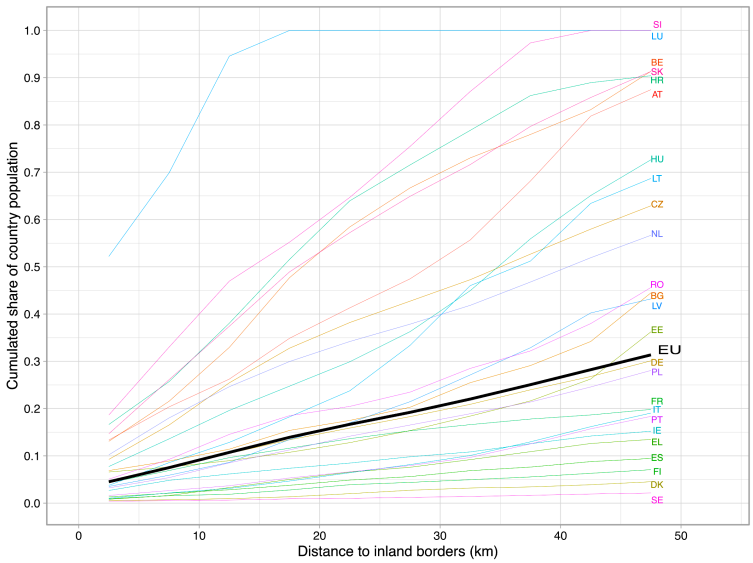

Figure 3.1: Population within different distance bands of inland borders in Europe. Computed by the authors based on

The majority of research on the determinants of commuting in border areas tends to focus in a specific border zone (case studies) where generalization about this specific kind of home-work commute is difficult or even impossible because of the different effects involved at the origin and destination territories (Gottholmseder and Theurl, 2007; Buch et al., 2009; Mathä et al., 2017; Pires and Nunes, 2018; Chilla and Heugel, 2022). Moreover, some of the analyses are conducted at a very aggregate level, without taking neither the individual nor the territorial diversity into account (Huber, 2014; Broersma et al., 2020; Edzes et al., 2022).This represents a significant limitation. The aggregation hides important geographical variations within local contexts, particularly regarding factors such as distance to the border, level of urbanization, and job availability in residential areas. Specifically, the distance effect (distance to the border) is rarely taken into account to explain the cross-border commutes (Gottholmseder and Theurl, 2007; Ahrens et al., 2020; Chilla and Heugel, 2022). These omissions are notable weaknesses that need to be addressed to gain a more comprehensive understanding of commuting dynamics in border regions.

In this chapter, firstly, we aim to examine the factors that influence commuting patterns to the other side of the border and assess how these differ from commutes within France. Secondly, we seek to explore potential variations in these key factors across different geographical zones along the French borders. The presence of distinct regional labor markets and job opportunities in neighboring countries offers individuals the opportunity to expand their employment options beyond national borders. Through our analysis, we aim to uncover any significant differences in these factors and their implications for commuting decisions.

Our study contributes to empirical research on cross-border commuting in multiple ways. Firstly, we utilize individual-level census data at the municipal level to examine the determinants of all commutes, both within and outside France. Secondly, we analyze the entire French border zone, encompassing eight neighboring countries, to consider the heterogeneity of living and working areas and overcome specific regional effects. Our objective is to improve understanding of the factors driving cross-border commutes compared to commuting within France, while also capturing the unique characteristics of each geographical zone. By incorporating new variables, models, and a recent dataset, we aim to build upon previous research (Pigeron-Piroth et al., 2018) and enhance our understanding of the relationship between job availability, commuting patterns, and local labor markets.

In the remainder of the chapter we present our spatial and population data selection, as well as the methodologies we use, and we raise hypotheses based on literature results (3.2). Results are presented and discussed in section 3.3, starting with a descriptive analysis to identify overall spatial heterogeneities, followed by a series of logistic regressions, including zonal effects in order to identify determinants of cross-border commuting and their geographical variation. Finally, in section 3.4 we present some concluding remarks about this work and its impacts on border regions, aiming at understanding the jobs and labour force allocation and its variation along the french border facade.

3.2 Data and Methods

We use data from INSEE (Mobilités Professionnelles, 2016) at an individual level for the entire employed population living in the border facade of France ($\geq$ 50km from any land border) and having a commute. We consider three types of determinants for the commutes (cross-border or inside France):

1. Individual and household (at individual level): To measure the effect of personal and family determinants on doing a cross-border commute compared to the commute inside France.

2. Territorial: To capture the specificity of the residential place (i.e. urban area or isolated commune without an attraction pole) and the job availability around the municipality of residence. These determinants are rarely analyzed and they are of great interest to better measure the attraction of the employment pole, and the lack of employment as an explanatory factor of the commutes (especially the cross-border ones).

3. Border variables: Distance to the border (to measure the impact of the proximity of the border on cross-border commutes). Dividing the French border facade in 11 zones depending on the proximity to different foreign countries. The aim is to measure the attraction of different employment poles and the diversity of the commutes along the French border.

3.2.1 Population and zones

Our population contains all individuals having a job, residing in the border facade of France (almost 3 million people). While most of them work in France, some cross the border for work purpose. To understand the determinants of this cross-border commuting, we made certain choices regarding the population and analysis. Firstly, we defined the continental border facade as comprising municipalities with a Euclidean distance of less than 50km between their centroid and the nearest national border line. Secondly, we specifically examined commuters, excluding non-commuters to allow for a comparison between cross-border and domestic commutes within France. Additionally, our analysis focused on polarised commutes, which involve commuting to an employment pole. To account for potential spatial heterogeneity resulting from proximity to different countries (with varying job opportunities, cultures, and languages), we defined eleven geographical zones (as depicted in Figure 3.2).

3.2.2 Dependent variable: Cross-Border Commuting

The dependant variable we analyze in this chapter is the performing a cross-border commute or not (commute inside France). The heterogeneity of the border facade (as territorial and individual structure) is also a way to understand the various effects of the proximity of the border but also local and individual effects. The share of

cross-border commuters is 34.8% near Switzerland, 19.3% near Luxembourg, and 0.1% near Italy, Andorra and Spain (See Appendix, Table 3.6). Indeed the municipalities near Luxembourg, Germany and Switzerland are the most impacted by cross-border commutes (Figure 3.2). Near these countries, the closer the border the higher the share of cross-border commuters. Whereas municipalities near Belgium, Italy or Spain are little concerned by cross-border commutes. This reveals the inter zones heterogeneity, and the variety of the push and pull factors in each of them.

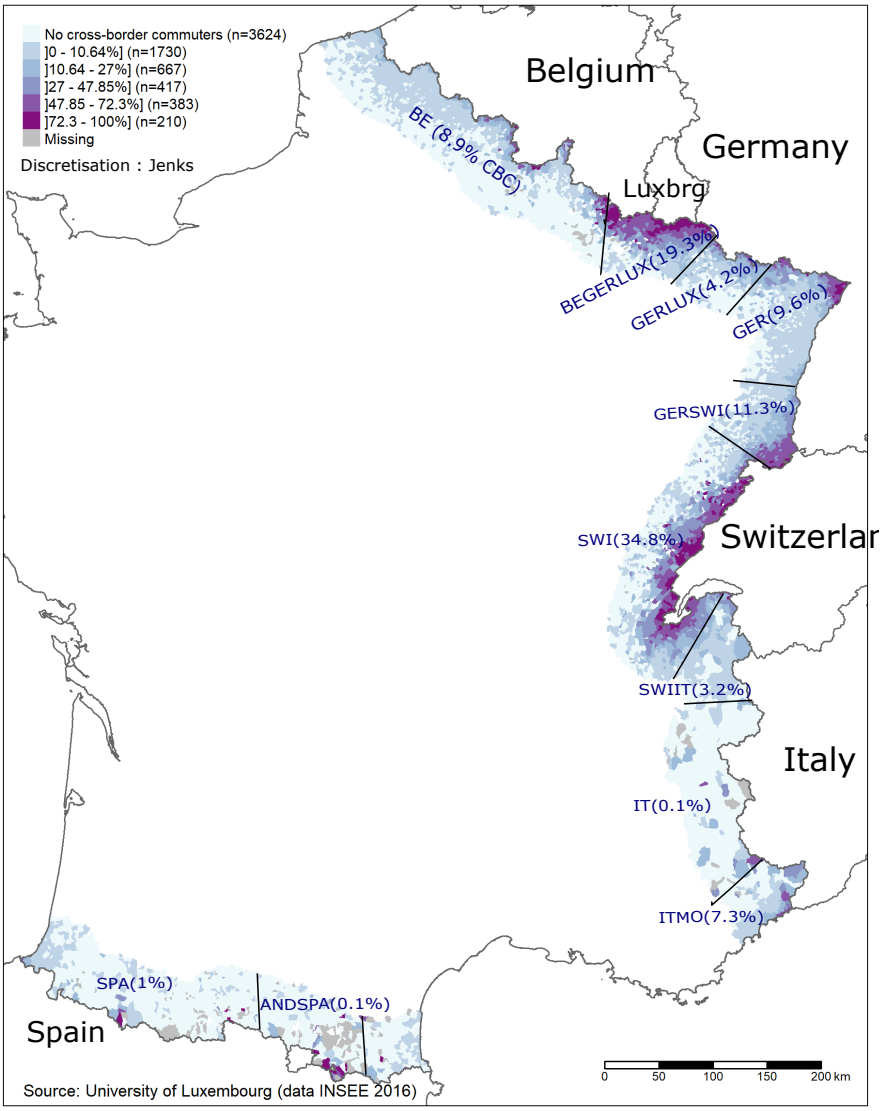

Figure 3.2: Share of cross-border commuters among polarised commutes per municipality of residence in France (2016)

3.2.3 Potential determinants and hypotheses

Our analysis reveals notable distinctions between commuters within France and cross-border commuters in terms of individual and territorial characteristics (see Appendix, Table 3.6). Drawing from existing literature and our findings, we have identified several potential factors that may influence commuting patterns, both across the border and within France. Specifically, individual characteristics such as gender, age, professional status, activity sector, and educational attainment, along with variables related to housing, such as home ownership, household

size, and the number of cars per active individual in the household, are of particular interest in explaining these commuting behaviors and highlighting differences between the two groups of commuters.

Individual and household variables: abilities to cross the border and activity-related considerations.

Based on the findings of the systematic literature review conducted in Chapter 2, it is evident that cross-border commuting is predominantly undertaken by men, especially those in the age range of 40. Building upon these insights, we anticipate that our analysis will reveal a higher likelihood of men in the age groups of 30-39 and 40-49 engaging in cross-border commuting. The relationship between education and cross-border commuting is more intricate, as suggested by the literature. Consequently, we anticipate observing a higher probability of individuals with higher education levels and professional skills opting for cross-border commuting.

The employment sector plays a significant role in cross-border commuting, but its impact varies across regions. Sectors that are well-developed and appealing in neighboring regions tend to attract more commuters, while the public sector generally has the lowest appeal due to administrative and legal obstacles (Gottholmseder and Theurl, 2007). In Austria, the service sector and construction industry increase the likelihood of cross-border commuting (Wiesbock and Verwiebe, 2017), while specific historical industries in Luxemburgish and Swiss regions (i.e. pharmacy in Basel, watch making in Neuchatel) attract French workers (Bolzman et al., 2021). Overall, we expect industry, trade/services, and construction sectors to be the primary sectors attracting cross-border commuters.

Household composition plays a role in the decision to engage in cross-border commuting. The presence of children in the household or the responsibility of caring for older family members tends to reduce the likelihood of cross-border commuting. While our database lacks specific information on household composition and the age of children (some of them can already be professionally active), we focus on the number of people living in the household, assuming that individuals in single-person households may find it easier to cross the border for work purposes. Moreover, based on the literature, we expect both car and home ownership to have a positive effect on cross-border commuting.

The descriptive statistics of commuters within France and cross-border commuters support our hypotheses (see Appendix, Table 3.6). Cross-border commuters are predominantly male, in the age groups 30-49, highly educated with professional diplomas, and employed in the industry, trade and services sectors. As far as the household characteristics of cross-border commuters are concerned, homeowners (indicating higher financial status) and tenants (suggesting greater flexibility) are slightly over-represented among cross-border commuters. Furthermore, the number of cars in the household appears to facilitate cross-border commuting.

Urban geography variables: some push factors.

The territorial characteristics of the residential areas are essential to consider in our analysis. To capture these aspects, we utilize a typology of residential places based on residence-workplace commutes developed by INSEE (Zonage Aires Urbaines, INSEE, 2010). This typology allows us to compare commutes within and outside functional commuting basins, known as urban areas. Our hypothesis is that the level of attraction to a local center varies among individuals, implying that residents of isolated municipalities in the border region are more inclined to seek job opportunities on the other side of the border.To maintain consistency and avoid circular reasoning, we chose to utilize the Zonage Aires Urbaines (ZAU) established in 2010, instead of the more recent Zonage en Aires d'Attraction des Villes (ZAAV) introduced in 2020. The latter includes areas where

the central point is located in a foreign country (Basel, Charleroi, Geneva, Lausanne, Luxembourg, Monaco, and Saarbrücken). Based on existing literature and descriptive statistics (see Appendix), we expect a higher prevalence of cross-border commuting among individuals residing in isolated municipalities and multipolarized municipalities (not solely attracted by a single employment center).

Furthermore, we incorporate the availability of jobs within a 25km radius of the municipality of residence as an independent variable. This variable was calculated by dividing the total number of jobs within this radius by the total number of employed individuals in the area, categorized by educational attainment (low = no diploma or professional diploma, high = French baccalaureate or higher degree). Subsequently, for each individual, we determined the ratio of low or high-level jobs based on their educational attainment. A ratio less than 1 indicates a lower proportion of suitable jobs compared to the number of active individuals residing within a 25km radius, considering their educational level. We hypothesize that the availability of jobs near the individual's place of residence influences the likelihood of crossing the border to seek employment, particularly when considering the educational level. In Table 3.6 (refer to Appendix), we observe a lower job availability ratio for cross-border commuters, indicating a relatively limited number of available jobs in proximity to their municipality. This raises a fundamental question regarding cross-border commuting: Are these individuals seeking a particular job opportunity that is lacking in their local area? If so, cross-border commuting may serve to create a more balanced labor market.

Border variables: Distance and Geographical Zones.

Distance is a major determinant of the commutes. Here we measure the distance to the border as a first step to see the effect of the border (and its proximity) on doing a commute across the border or not, and to approach the role of barrier (or on the contrary attraction) of the border. We are aware that some employment poles abroad are directly at the border (Geneva, Basel) and others further away (Luxembourg). The distance in meters is calculated between the centroid of the municipality of residence and the nearest land border point.[2] The distance to the border (nearest border point) is indeed much lower for cross-border commuters (average = 8.7km) than for individuals commuting within France (average = 20.7km from the border) (See Appendix, Table 3.6).

Moreover, in order to measure the potential attraction of different neighboring employment poles, the French border facade is divided in eleven zones according to the proximity of one, two or three neighboring countries. This division of the border facade is an added-value for the analysis of the determinants of the cross-border commutes, as a way to underline the variety of the cross-border labor markets along the French border facade, and to take into account the proximity of different neighbouring countries. Following Dumeignil et al. (2021), it is necessary to underline and study the localized labor markets, and how fragmented and different they are in their needs of labor force. This division of the border facade in different zones also takes into account the morphology (i.e. mountains, sufficient connections or not).

3.2.4 Methods

The initial phase of the analysis involves examining the summary statistics to assess potential statistical variations among variables across different zones, representing various cross-border environments. Our objective is to uncover the heterogeneity that exists within these cross-border zones. To accomplish this, we employ mean tests

[2]We used the ln of this distance (because the distribution was not normal) expressed in 100 meters (to avoid the values < 1 and the negative log)

and present the results in a contingency table (refer to Appendix, Table 3.6) for each variable utilized in our analysis.

The next step involves conducting logistic regressions. Initially, we include individual and household characteristics as independent variables, and then we progressively introduce urban geography variables and border-related variables. This gradual addition of variables, aims to increase complexity slowly, in order to observe the added effect of each group of variables up to a model with zones-fixed effects (random intercepts per zone). Logistic regression is advantageous in this context as it allows us to analyze a qualitative dependent variable, rather than a continuous one (Walsh, 1987). In our case, the dependent variable indicates whether an individual is a cross-border commuter or not, representing a binary qualitative variable (yes or no).

$$log(\frac{\pi}{1-\pi}) = \beta_0 + \beta_1 x_1 + ... + \beta_k x_k \tag{3.1}$$

where $log(\frac{\pi}{1-\pi})$ is the natural logarithm of the odds, the ratio of probabilities (DeMaris, 1995), the probability of being a cross-border commuter in this case.

Thirdly, we employ an interaction terms approach to investigate the influence of contextual variables that exhibit substantial variation across zones. We introduce interactions between the zones and the type of commune, as well as between the zones and the distance to the border, and finally between the zones and the available jobs within a 25km radius of the individual's municipality of residence. This allows us to explore how these effects may differ across different zones, providing a more nuanced understanding of the factors at play.

Fourthly, we conduct a visual inspection (through maps) of residuals to identify any unmeasured effects that may exhibit a spatial structure beyond the variables related to distance, urban geography, and zone effects. By examining the residuals, we aim to detect any spatial patterns or dependencies that could indicate the presence of additional factors influencing the outcome variable. This analysis helps ensure that our model adequately captures the observed spatial variation and provides insights into any potential spatially correlated factors that may be influencing the cross-border commuting behavior.

3.3 Results

3.3.1 A heterogeneous facade

We examine the socio-economic characteristics of cross-border commuters across zones (Table 3.1) and analyze the role of urban geography and border variables, both overall and within specific zones. This analysis allows us to understand the variations in socio-economic factors and the influence of geographical and border-related variables on cross-border commuting behavior.

The French border facade exhibits diverse profiles of cross-border commuters. In certain zones, the majority of cross-border commuters are male individuals with an industrial background. For instance, 53.4% of cross-border commuters near Belgium are workers, with 37% employed in the industrial sector and 30% possessing a professional diploma. Similar trends are observed near Germany. On the other hand, near Switzerland, Luxembourg, and Monaco, there is a significant presence of intermediate professions and employees, as well as a higher proportion of individuals with higher diplomas. The urban geography also varies across zones. Most cross-border commuters near Monaco, Switzerland, or Spain reside in urban areas, while a considerable number live in isolated communes near Andorra or Italy. This pattern is also notable near Germany.

Within the French border facade, a significant proportion of cross-border commuters reside in close proximity to the border. Approximately 48.5% of cross-border commuters live within a 5km distance from the border,

Table 3.1: Description of variables per Zone for Cross-border commuters only (% in columns)

	BE	BEGERLUX	GERLUX	GER	GERSWI	SWI	SWIIT	IT	ITMO	SPA	ANDSPA
Men	70.6	59.4	64.0	67.1	63.8	59.3	58.5	62.2	58.5	60.8	51.9
Women	29.4	40.6	36.0	32.9	36.2	40.7	41.5	37.8	41.5	39.2	48.1
20-29	18.7	18.1	14.6	9.7	11.9	18.0	13.1	23.0	14.8	8.9	9.2
15-19	0.7	0.3	0.4	0.6	0.5	0.5	0.4	2.0	0.5	0.4	0.0
30-39	31.0	31.3	28.1	17.4	21.9	32.0	33.7	5.2	27.2	29.2	33.6
40-49	29.3	32.0	28.9	32.1	32.0	27.6	30.9	46.4	30.9	33.6	22.5
50-59	18.4	17.1	23.5	33.4	28.9	18.7	19.1	21.4	22.9	22.5	30.6
60-69	1.9	1.3	4.5	6.7	4.8	3.3	2.7	2.0	3.7	5.4	4.1
Workers	53.4	30.0	36.6	45.1	38.0	25.6	23.3	12.0	18.2	16.2	11.3
Farmers	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0
Artisans	2.1	1.7	2.3	2.3	1.8	2.5	2.0	10.4	2.5	8.0	18.5
Management Employees	9.9	13.0	16.5	14.8	17.2	20.6	18.9	36.2	21.6	20.9	19.1
Self-employed Managers	0.5	0.6	1.1	1.0	0.4	0.8	0.9	2.0	0.8	3.3	2.0
Intermediate professions	21.7	23.8	22.5	20.4	23.9	29.6	34.8	17.7	25.7	30.0	23.4
Employees	12.4	30.8	20.9	16.3	18.6	20.9	20.1	21.7	31.1	21.5	25.6
Trade, transport, services	39.0	64.0	56.3	39.1	44.2	52.3	50.5	73.7	66.7	58.4	45.9
Agriculture	0.5	0.1	0.1	0.3	0.2	0.3	0.3	0.0	0.1	0.5	0.0
Industry	36.9	15.5	27.1	43.9	38.9	23.5	18.8	7.6	7.1	16.3	9.2
Construction	7.3	9.7	6.9	7.7	7.6	6.3	8.5	6.5	9.2	5.3	9.2
Public Administration, Education, Health	16.2	10.6	9.6	8.9	9.1	17.6	21.9	12.3	17.0	19.4	35.7
No Diploma	19.0	12.1	15.0	15.8	11.9	9.6	7.0	6.0	15.5	10.1	19.4
Professional Diploma	29.9	26.2	28.3	39.5	36.9	23.6	23.6	10.0	18.3	15.3	9.2
Secondary Education	21.1	20.3	17.9	16.0	17.0	19.4	18.2	11.6	19.1	25.0	19.5
High Degree	30.0	41.4	38.8	28.8	34.3	47.4	51.2	72.4	47.1	49.7	51.9
Owners	69.5	72.6	68.9	76.9	77.6	69.3	79.0	85.6	59.9	77.7	83.6
Tenants	18.7	22.5	24.1	20.2	19.9	27.8	18.7	14.0	35.2	19.5	13.4
Low-cost Tenants	11.8	5.0	7.0	2.9	2.5	3.0	2.3	0.4	5.0	2.8	3.0
2 in the household	22.4	24.4	30.5	32.6	31.3	27.6	23.8	25.1	26.8	23.9	31.7
1 pers	11.2	13.8	14.9	12.7	15.2	18.2	11.3	7.2	17.1	16.9	8.2
3 and +	66.4	61.7	54.6	54.8	53.5	54.1	64.9	67.7	56.1	59.2	60.1
At least one car/employee (FALSE)	17.4	14.3	17.6	15.7	12.6	14.2	9.0	33.2	44.0	22.2	25.7
At least one car/employee (TRUE)	82.6	85.7	82.4	84.3	87.4	85.8	91.0	66.8	56.0	77.8	74.3
Ratio jobs/active 25km around the commune (mean)	1.0	0.6	0.8	0.8	0.8	0.6	0.8	0.8	0.9	1.0	0.8
Urban area	84.9	57.2	78.4	53.0	79.5	83.5	95.5	36.7	99.4	92.3	6.1
Isolated commune	2.9	8.0	4.1	23.5	1.9	12.3	1.0	51.3	0.6	4.7	87.8
Multipolarized commune	12.2	34.8	17.5	23.5	18.6	4.2	3.5	12.0	0.1	3.0	6.1
Distance to the border (mean in km)	6.7	9.9	15.7	7.5	8.4	7.2	17.1	26.6	8.8	9.7	9.9

For all the displayed variables the Chi-square independence test is significant (Ho rejected with $p<0.001$). Data: INSEE, Fichier Mobilités Professionnelles 2016. Calculations of the authors.
Population: People living in France at maximum 50km from land borders and having a professional activity outside the commune of residence.

and 69.5% live within 10km. As the distance increases beyond 20km, the number of cross-border commuters decreases substantially in most zones. Notably, near Italy, the distances covered are longer compared to other areas (Figure 3.3). However, it is near Luxembourg where the lowest percentage (38.5%) of cross-border commuters reside directly at the border.

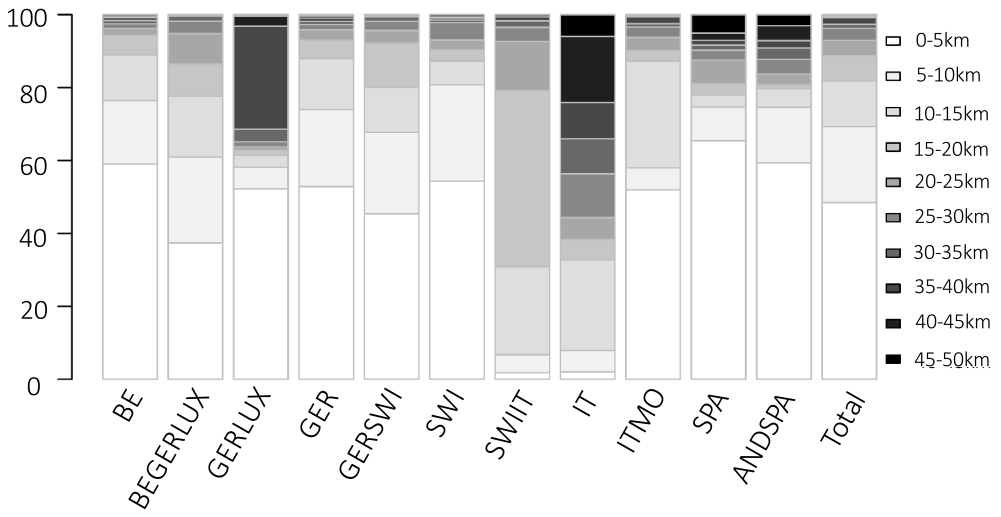

Figure 3.3: Cumulative percentage of cross-border commuters according to the distance to the border for each Zone

3.3.2 Influencing factors

Based on the regression analysis of individual and household variables, several conclusions can be drawn. In line with literature and our assumptions, being a woman has a negative effect on the cross-border commute (-0.106), like being a young active (-1.105) compared to the 30-49 years old who, as assumed, are the most concerned. Among various professional statuses, workers exhibit the strongest association with cross-border commutes, while other statuses have comparatively weaker effects. Additionally, working in the industry sector positively influences cross-border commuting, aligning with our hypotheses. Regarding education, individuals with a high degree diploma display the highest coefficient (0.133), indicating a positive impact on cross-border commuting.

Regarding the household variables, the regression results reveal interesting findings. Compared to the homeowners (used as a reference group), the renters and especially the low-cost tenants have the most negative coefficients for the cross-border commutes (-0.931). This supports our hypothesis that homeownership increases the likelihood of cross-border commuting by decreasing the willingness to relocate. Additionally, having at least one car per active person has a positive impact on cross-border commutes compared to commutes within France. Cars are the primary mode of transportation for commuters, especially for those crossing the border. Furthermore, the size of the household negatively affects cross-border commuting, with households consisting of three or more people, likely indicating the presence of children, having the most negative coefficient.

By incorporating urban geography variables into the analysis, we gain insights into the influence of the residential place on cross-border commuting. One notable finding is the strong negative effect of job availability around the municipality of residence on cross-border commutes, indicated by a coefficient of -6.924. This suggests that as the ratio of available jobs to active people within the vicinity of the commune increases, the likelihood of engaging in cross-border commuting decreases significantly. This finding underscores the significance of employment opportunities in the local area as a push factor for cross-border commuting, and it demonstrates the high explanatory power of this variable compared to others in our analysis.

The urban geography of the municipality of residence plays a significant role in cross-border commuting patterns. Living in isolated municipalities within the border facade has a positive impact on cross-border commutes, indicating that these areas experience a lack of employment opportunities or attraction poles within

France, prompting individuals to seek employment across the border. In contrast, residing in multipolarised municipalities has a negative effect on cross-border commutes, likely due to the presence of multiple job opportunities within the local area, reducing the need to travel across the border for employment.

Finally, we introduced the distance to the border as an additional explanatory variable. Consistent with our expectations, the coefficient for distance to the border is negative (-0.842), indicating that the likelihood of cross-border commuting decreases as the distance to the border increases. This variable has an impact on the other coefficients, particularly in relation to urban geography. The negative coefficient for job availability around the municipality is reduced from -6.924 to -5.767, although it remains the highest coefficient in the model.

3.3.3 Average zonal disparities

The coefficients of our fourth model are presented in Figure 3.4, highlighting the diversity of the zones along the French border. In this model, some coefficients are negative, such as -0.829 for Italy and -0.169 for Spain, indicating a negative impact on cross-border commutes in these zones. Factors such as mountains, lack of nearby cross-border employment opportunities, and limited road/train connections contribute to this negative effect.

On the other hand, the coefficients for all other zones are positive. The highest coefficient is observed near Luxembourg (2.492 in BEGERLUX), indicating a significant impact of living in this zone on cross-border commutes. Similarly, the coefficients for French municipalities near Monaco (1.949) and Switzerland (1.892 for SWI, 1.878 for GERSWI, 1.823 for SWIIT) are also high. The presence of common industrial activities, strong transportation connections, shared language, and the attractiveness of cross-border employment poles with significant wage differentials (e.g., Luxembourg, Monaco, Geneva, Basel) contribute to the substantial impact of these zones on cross-border commutes.

3.3.4 Interconnection between effects and zone

Among the four models tested, Model 4 proves to be the most effective. It incorporates individual and household variables, the urban geography of the municipality of residence, the distance to the border, and the geographical zone effect. This comprehensive model yields only 9.7% of incorrect predictions, outperforming the first model which had an error rate of 12.7%. The majority of the incorrect predictions are false negatives, meaning that Model 4 incorrectly predicts individuals to commute within France when they are actually cross-border commuters.

The inclusion of the zonal effect has a significant impact on the explanatory power of the other individual variables in the model. The effects of being a woman, belonging to the 30-49 age group, having different professional statuses, possessing a professional diploma or a high degree, are all reinforced in Model 4. Additionally, the effects of living in an isolated commune (0.578 in Model 4 compared to 0.377 in Model 1) and the distance to the border (-0.915 in Model 4 compared to -0.842 in Model 3) are magnified. However, the effect of job availability around the commune, although still strong (with the highest coefficient), is lower in Model 4 (-3.075) compared to Model 1 (-6.924) which included only individual variables.

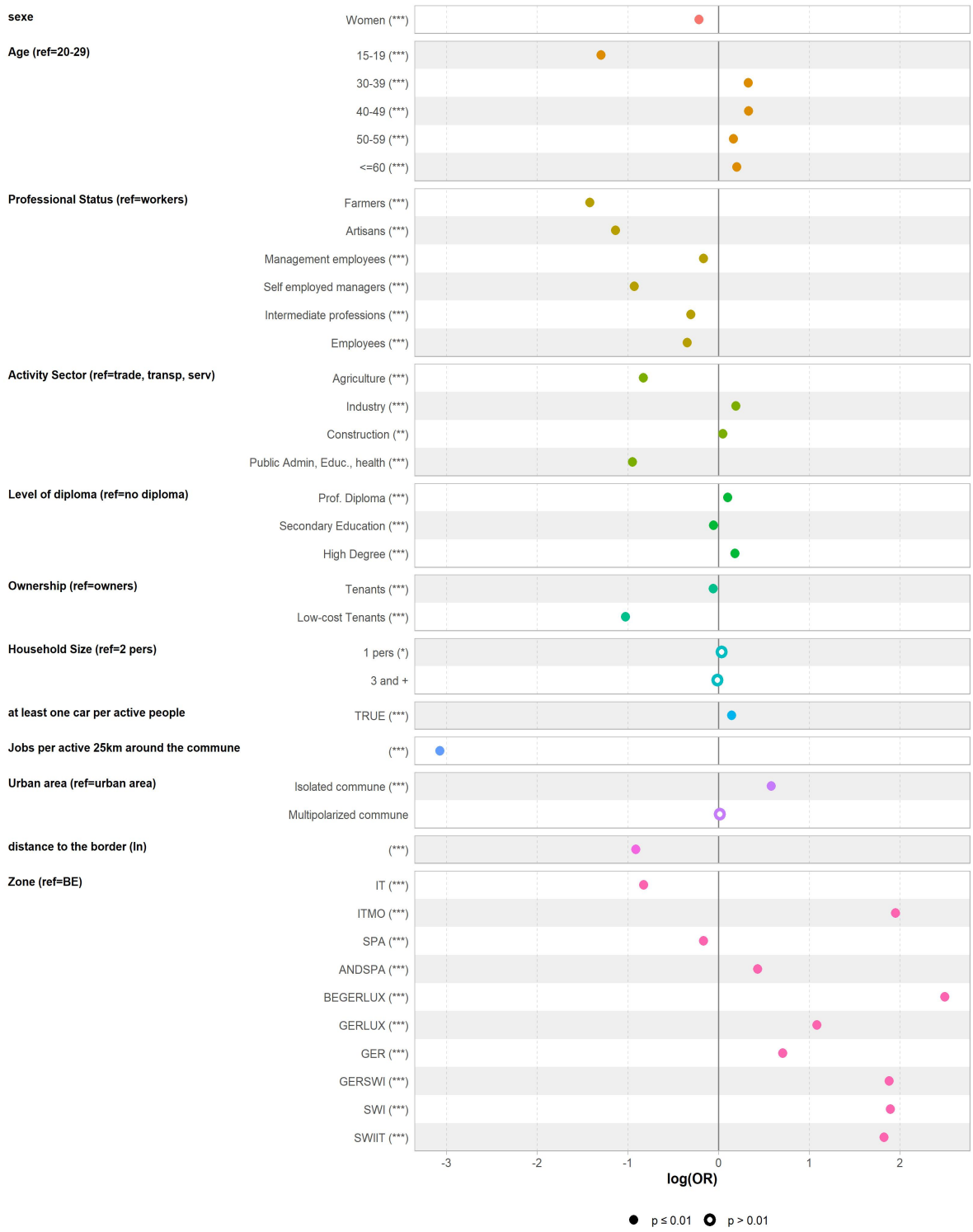

Figure 3.4: Graphical representation of the coefficients of model4

Table 3.2: Results of the 4 Logit models

	Model1	Model2	Model3	Model4
(Intercept)	-1.763(***)	4.349(***)	7.081(***)	3.809(***)
	(0.018)	(0.030)	(0.033)	(0.040)
Female	-0.106(***)	-0.147(***)	-0.182(***)	-0.218(***)
	(0.008)	(0.009)	(0.009)	(0.009)
15-19 *(ref= 20-29)*	-1.105(***)	-1.204(***)	-1.218(***)	-1.298(***)
	(0.048)	(0.053)	(0.052)	(0.053)
30-39	0.296(***)	0.323(***)	0.320(***)	0.327(***)
	(0.011)	(0.013)	(0.013)	(0.013)
40-49	0.281(***)	0.329(***)	0.337(***)	0.329(***)
	(0.011)	(0.013)	(0.013)	(0.013)
50-59	0.098(***)	0.169(***)	0.171(***)	0.161(***)
	(0.012)	(0.014)	(0.014)	(0.014)
60-69	0.198(***)	0.277(***)	0.228(***)	0.199(***)
	(0.021)	(0.025)	(0.025)	(0.025)
Farmers *(ref= workers)*	-1.220(***)	-1.361(***)	-1.386(***)	-1.421(***)
	(0.154)	(0.169)	(0.164)	(0.169)
Artisans	-0.967(***)	-0.923(***)	-1.020(***)	-1.138(***)
	(0.023)	(0.026)	(0.026)	(0.027)
Management employees	-0.157(***)	0.027(*)	-0.047(***)	-0.167(***)
	(0.013)	(0.015)	(0.015)	(0.015)
Self employed managers	-0.823(***)	-0.666(***)	-0.802(***)	-0.932(***)
	(0.040)	(0.046)	(0.045)	(0.046)
Intermediate professions	-0.266(***)	-0.190(***)	-0.226(***)	-0.309(***)
	(0.011)	(0.012)	(0.012)	(0.013)
Employees	-0.154(***)	-0.168(***)	-0.248(***)	-0.347(***)
	(0.011)	(0.013)	(0.013)	(0.013)
Agriculture *(ref= Trade, transp., serv.)*	-0.969(***)	-1.034(***)	-0.952(***)	-0.832(***)
	(0.066)	(0.074)	(0.073)	(0.076)
Industry	0.214(***)	0.120(***)	0.144(***)	0.190(***)
	(0.009)	(0.010)	(0.010)	(0.011)
Construction	-0.003	-0.034(**)	0.050(***)	0.047(***)
	(0.014)	(0.016)	(0.016)	(0.017)
Public Admin, Educ., health	-0.983(***)	-1.020(***)	-1.035(***)	-0.951(***)
	(0.010)	(0.012)	(0.012)	(0.012)
Prof. Diploma *(ref = No Diploma)*	0.007	0.001	0.079(***)	0.100(***)
	(0.012)	(0.014)	(0.014)	(0.014)
Secondary Education	-0.060(***)	-0.350(***)	-0.198(***)	-0.057(***)
	(0.013)	(0.015)	(0.015)	(0.016)
High Degree	0.133(***)	-0.099(***)	0.056(***)	0.179(***)
	(0.013)	(0.015)	(0.015)	(0.016)
Tenants *(ref=Owners)*	0.058(***)	0.076(***)	0.018(*)	-0.060(***)
	(0.009)	(0.010)	(0.010)	(0.011)
Low-cost Tenants	-0.931(***)	-0.805(***)	-1.008(***)	-1.029(***)
	(0.017)	(0.019)	(0.019)	(0.019)
1 pers *(ref= 2 in the household)*	0.133(***)	0.125(***)	0.084(***)	0.033(**)
	(0.011)	(0.013)	(0.013)	(0.014)
3 and +	-0.087(***)	-0.049(***)	-0.032(***)	-0.015
	(0.009)	(0.010)	(0.010)	(0.010)
At least one car/employee (ref=FALSE)	0.137(***)	-0.008	0.095(***)	0.141(***)
	(0.009)	(0.011)	(0.011)	(0.011)
Job availability		-6.924(***)	-5.767(***)	-3.075(***)
		(0.026)	(0.024)	(0.032)
Isolated commune *(ref= urban area)*		0.377(***)	0.234(***)	0.578(***)
		(0.018)	(0.018)	(0.020)
Multipolarized commune		-0.304(***)	-0.086(***)	0.013
		(0.012)	(0.011)	(0.012)
Dist. to the nearest border (ln/100m)			-0.842(***)	-0.915(***)
			(0.004)	(0.004)
BEGERLUX *(ref= BE)*				2.492(***)
				(0.019)
GERLUX				1.081(***)
				(0.024)
GER				0.704(***)
				(0.016)
GERSWI				1.878(***)
				(0.017)
SWI				1.892(***)
				(0.016)
SWIIT				1.823(***)
				(0.023)
IT				-0.829(***)
				(0.121)
ITMO				1.949(***)
				(0.018)
SPA				-0.169(***)
				(0.033)
ANDSPA				0.427(***)
				(0.092)
$PseudoR^2$	4.55%	22.23%	31.37%	36.68%
Observations	774,990	774,732	774,732	774,732
				Note: *p<0.1; **p<0.05; (∗ ∗ ∗)p<0.01

Source: INSEE, Fichier Mobilités Professionnelles 2016. Calculations of the authors.
Population: People living in France at maximum 50km from land borders and having a professional activity outside the commune of residence.

3.3.5 Geography of the unexplained

The residuals for Model 4 were calculated at the municipal level to assess where the model either overestimates or underestimates the share of cross-border commutes. These residuals represent the difference between the observed and estimated percentages of cross-border commutes. The majority of the residuals fall within a narrow range of slight overestimation or underestimation by the model, as depicted by the light blue and orange colors in Figure 3.5. This indicates that the model provides a close fit to the observed share of cross-border commutes in these municipalities.

The municipalities that are underestimated by the model (orange and red colors) are typically located near foreign employment poles such as Mons (B), Luxembourg, Sarrebruck, Karlsruhe, Basel, or Geneva. These areas have higher observed shares of cross-border commutes than what the model predicts. Conversely, the municipalities that are overestimated by the model (dark blue color, comprising 221 communes) face geographical barriers such as mountains (Alps, Pyrenees) and/or have limited connections to foreign employment poles. In these areas, the model predicts a higher share of cross-border commutes than what is observed.

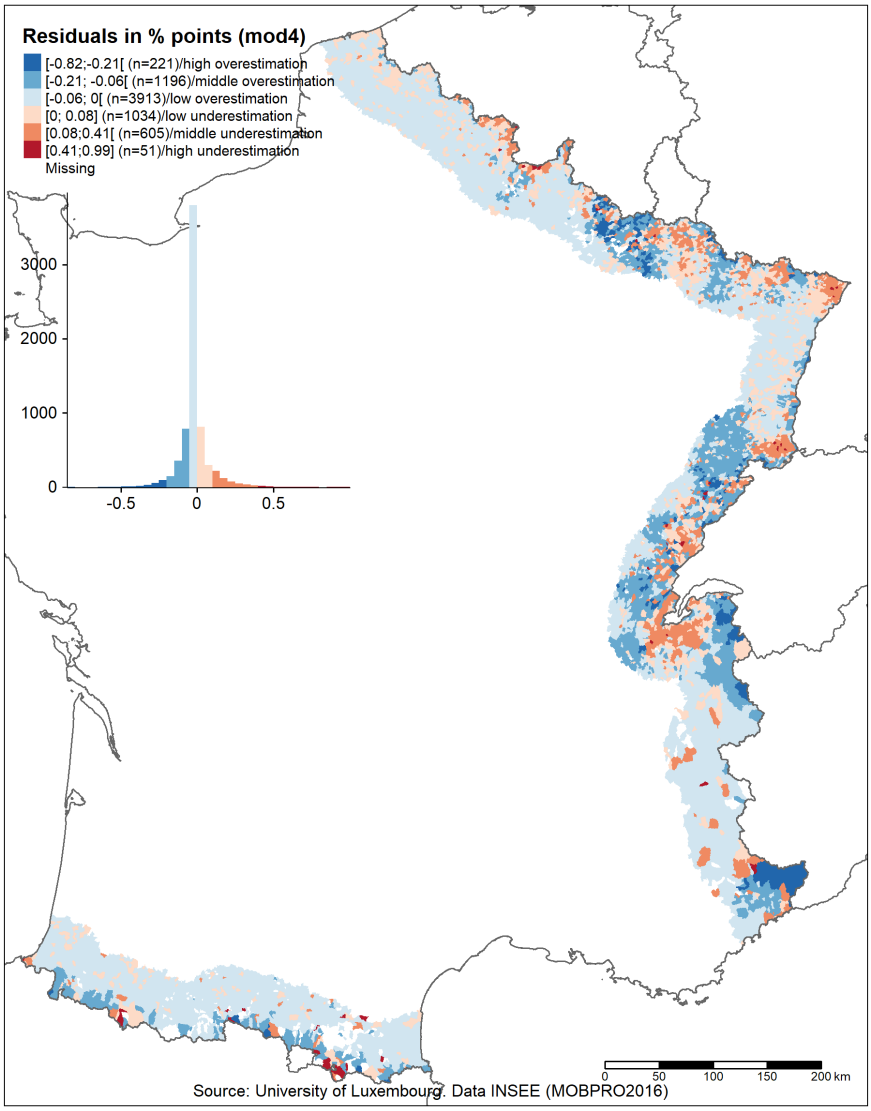

Figure 3.5: Absolute Residuals of model4 per municipality

3.3.6 Interaction of the Zones

To examine the interaction between geographical zones and various variables, we selected categorical variables such as activity sectors and the type of municipality, along with quantitative variables like distance to the border and job availability around the residence. These interactions help us understand how different factors contribute to cross-border commutes across specific zones.

Table 3.3: Interaction Between Zone and Activity Sector

	Trade	Agriculture	Industry	Construction	Public Admin
BE:	-1.799(***)	-1.684(***)	-0.952(***)	-1.540(***)	-2.354(***)
	(0.024)	(0.084)	(0.024)	(0.030)	(0.026)
IT :	-1.940(***)	-9.960( )	-3.139(***)	-2.972(***)	-3.576(***)
	(0.078)	(17.004)	(0.232)	(0.250)	(0.182)
ITMO:	0.471(***)	-1.092(***)	0.096(***)	0.474(***)	-0.348(***)
	(0.023)	(0.227)	(0.033)	(0.033)	(0.027)
SPA:	-1.560(***)	-2.777(***)	-1.696(***)	-2.329(***)	-2.504(***)
	(0.030)	(0.229)	(0.046)	(0.073)	(0.042)
ANDSPA :	-1.055(***)	-9.996	-1.646(***)	-1.371(***)	-1.576(***)
	(0.075)	(20.824)	(0.155)	(0.159)	(0.083)
BEGERLUX :	1.300(***)	-0.633(***)	0.630(***)	1.401(***)	-0.520(***)
	(0.023)	(0.148)	(0.026)	(0.030)	(0.026)
GERLUX :	-0.017	-0.987(***)	-0.707(***)	-0.380(***)	-1.834(***)
	(0.026)	(0.266)	(0.030)	(0.047)	(0.036)
GER :	-0.998(***)	-1.461(***)	-0.299(***)	-0.647(***)	-2.063(***)
	(0.024)	(0.105)	(0.024)	(0.031)	(0.028)
GERSWI :	0.319(***)	-1.150(***)	0.740(***)	0.444(***)	-0.851(***)
	(0.023)	(0.139)	(0.024)	(0.032)	(0.028)
SWI :	0.373(***)	-0.415(***)	0.444(***)	0.309(***)	-0.314(***)
	(0.022)	(0.067)	(0.023)	(0.027)	(0.023)
SWIIT :	0.365(***)	-0.259	-0.025	0.209(***)	
	(0.026)	(0.168)	(0.031)	(0.041)	
$PseudoR^2$	37.31%				
Observations	774,732				
Log Likelihood	-717,310.200				
Akaike Inf. Crit.	1,434,778.000				

Note: *p<0.1; **p<0.05; ***p<0.01

Data: INSEE, Fichier Mobilités Professionnelles 2016. Calculations of the authors. Population: People living in France at maximum 50km from land borders and having a professional activity outside the commune of residence.

The analysis of activity sectors in relation to cross-border commutes reveals interesting findings (Table 3.3). Working in agriculture or public administration consistently has a negative impact on cross-border commutes across all geographical zones. However, the effect of the industry sector varies, with positive coefficients observed near Luxembourg (0.630 in BEGERLUX) and Switzerland (0.740 in GERSWI). This can be attributed to the historical presence of industries, such as chemicals and steel, in these regions, which have facilitated cross-border flows. On the other hand, the industry sector near Italy shows the highest negative coefficient (-3.139). Similarly, for the construction sector, the highest positive coefficient is near Luxembourg (1.401 in BEGERLUX), while the highest negative coefficient is near Italy (-2.972). In trade and services, once again, the BEGERLUX zone stands out with the highest coefficient (1.3).

The impact of urban geography on cross-border commutes in different geographical zones is presented in Table 3.4. The effect of living in an urban area, isolated commune, or multi-polarized commune can vary in terms of its positive or negative influence on cross-border commutes, depending on the specific geographical

Table 3.4: Interaction between Zone and Type of Commune

	Urban Area	Isolated Commune	Multipolarized
BE	-1.194(***)	-0.277(***)	-1.043(***)
	(0.053)	(0.064)	(0.055)
IT	-2.367(***)	-0.742(***)	-2.445(***)
	(0.117)	(0.105)	(0.190)
ITMO	0.810(***)	-0.773(***)	-1.915(***)
	(0.053)	(0.105)	(0.237)
SPA	-1.199(***)	-1.455(***)	-2.590(***)
	(0.055)	(0.092)	(0.105)
ANDSPA	-2.529(***)	0.561(***)	-1.487(***)
	(0.190)	(0.077)	(0.191)
BEGERLUX	1.314(***)	1.486(***)	1.526(***)
	(0.053)	(0.060)	(0.053)
GERLUX	0.040	-0.309(***)	-0.350(***)
	(0.054)	(0.089)	(0.057)
GER	-0.656(***)	0.872(***)	-0.273(***)
	(0.053)	(0.055)	(0.053)
GERSWI	0.745(***)	0.684(***)	0.685(***)
	(0.053)	(0.080)	(0.054)
SWI	0.799(***)	1.153(***)	0.553(***)
	(0.052)	(0.054)	(0.054)
SWIIT	0.760(***)	-0.493(***)	
	(0.053)	(0.108)	
$PseudoR^2$	36.98%		
Observations	774,732		
Log Likelihood	-721,210.100		
Akaike Inf. Crit.	1,442,538.000		

Note: *p<0.1; **p<0.05; ***p<0.01

zone. The highest positive effect is observed near Luxembourg (BEGERLUX) across all types of communes. In zones near Switzerland (GERSWI or SWIIT), the effect is also positive, but lower. In these zones, the type of commune has a weaker explanatory power for cross-border commutes. Conversely, near Italy and Spain, the effects are consistently negative regardless of the type of commune.

Consistent with existing literature and our previous regression model findings, the distance to the border has a negative effect on cross-border commutes. As expected, the closer the proximity to the border, the higher the likelihood of cross-border commuting. However, the magnitude of this negative distance effect varies across different geographical zones. The effect is particularly strong near Belgium, Italy, Spain, and Andorra, indicating that a shorter distance to the border significantly increases cross-border commutes in these zones. In contrast, near Luxembourg, the negative effect of distance is comparatively lower (-0.648), suggesting that the impact of proximity to the border on cross-border commuting is not as pronounced in this zone. Similarly, the distance effect is less pronounced in zones near Switzerland and Monaco, where a greater distance to the border has a smaller impact on reducing cross-border commutes compared to other zones.

The availability of jobs around the commune demonstrates a significant impact on cross-border commutes, as indicated by the highest coefficient in Model 4 (-3.075) (Figure 3.4) (Also, see Table 3.2). The analysis reveals that a lower number of suitable job opportunities in the vicinity of the commune (relative to the number of working individuals) leads to an increased likelihood of cross-border commuting. However, when examining the interaction between geographical zones and job availability, variations become apparent. Specifically, local job availability has a highly negative effect on cross-border commutes near Belgium, Italy, Spain, Andorra, and

Germany. Conversely, the effect is less pronounced in zones near Switzerland and Monaco. In these zones, the lack of local job opportunities still contributes to an increase in cross-border commutes, but to a lesser extent compared to other zones. Notably, near Luxembourg, the effect is the lowest (-1.723), indicating that job availability has relatively less explanatory power in this zone compared to others and other determinants. The

Table 3.5: Interaction between Zones & Distance to the Border; and Zones & Job Availability around the municipality

	Distance to the border	Available Jobs
(Intercept)	5.501(***)	5.575(***)
	(0.018)	(0.018)
BE	-1.194(***)	-4.685(***)
	(0.003)	(0.0015)
IT	-1.279(***)	-5.872(***)
	(0.012)	(0.078)
ITMO	-0.779(***)	-2.692(***)
	(0.002)	(0.016)
SPA	-1.219(***)	-4.816(***)
	(0.004)	(0.022)
ANDSPA	-1.102(***)	-4.387(***)
	(0.011)	(0.058)
BEGERLUX	-0.648(***)	-1.723(***)
	(0.002)	(0.020)
GERLUX	-0.844(***)	-3.576(***)
	(0.003)	(0.021)
GER	-1.015(***)	-4.084(***)
	(0.003)	(0.016)
GERSWI	-0.755(***)	-2.736(***)
	(0.002)	(0.017)
SWI	-0.772(***)	-2.714(***)
	(0.002)	(0.019)
SWIIT	-0.789(***)	-2.825(***)
	(0.003)	(0.021)
$PseudoR^2$	36.74%	36.56%
Observations	774,732	774,732
Log Likelihood	-723,971.900	-725,977.100
Akaike Inf. Crit.	1,448,022.000	1,452,032.000

Note: *p<0.1; **p<0.05; ***p<0.01

predictions at the municipal level remain consistent for all the interaction models, exhibiting a similar pattern to Figure 3.5. The majority of municipalities show minimal residuals, indicating a close fit between the model's predictions and the actual share of cross-border commutes. Some municipalities, however, experience over or underestimations near the same zones as identified in the previous analysis. At the individual level, the confusion matrix comparing the predicted probability of engaging in a cross-border commute (greater than 50%) and the actual type of commute (cross-border or within France) reveals a low percentage of incorrect predictions across all tested models (Model 4 and the four interaction models). Most of the bad predictions are false negative, meaning that the model predicts wrongly a commute within France whereas the individuals do a cross-border commute.

3.4 Conclusion and Discussion

Our analysis in this chapter, seeks to comprehend the factors that explain cross-border commutes compared to internal commutes within France, focusing on the border facade as a case study. By considering the opportunities and challenges of residing in a cross-border region, this study provides insights into the individuals who are more likely to engage in cross-border commuting for employment purposes.

The study highlights the importance of utilizing individual-level data and considering the geographical diversity in order to comprehensively understand the determinants of cross-border commutes within and outside of France across its extensive 3,000 km land borders with eight neighboring countries. The research reveals the range of factors influencing cross-border commutes, including individual and household characteristics, as well as territorial determinants such as urban geography and proximity to the border.

The variety of the determinants of the cross-border commutes clearly appears: individual and household determinants are of course essential, but territorial determinants (i.e. urban geography and proximity to the border) are a real added-value for the research on cross-border commutes. The findings emphasize the significant role of job availability within France's vicinity as a primary determinant of cross-border commutes, since it has the highest explanatory power. The presence of limited employment opportunities in the local area motivates individuals to seek employment opportunities across the border, effectively expanding the labor market. Additionally, the urban geography of the municipality of residence plays a crucial role in explaining cross-border commutes. Isolated communes that lack proximity to employment hubs within France are particularly impacted by cross-border commuting patterns.

The geographical zone in which individuals reside within France emerges as a determinant with significant diversity in its impact on cross-border commutes. Living in proximity to Italy or Spain exhibits a negative effect on cross-border commutes when compared to commuting patterns within France. Conversely, residing near Luxembourg yields the highest positive effect on cross-border commutes. However, the study's examination of the zones through interaction models reveals contrasting effects. The proximity to the border, the urban geography of the municipality of residence, and the activity sector each exhibit varying impacts on cross-border commutes. This variation in effects can be attributed to geographical, administrative and historical factors, as well as language disparities. Additionally, factors such as transportation connections, cross-border cooperation, wage differentials, cost of living, and housing availability also contribute to the decision to engage in cross-border commuting. Understanding these nuanced influences is crucial in comprehending the complex dynamics of cross-border commutes and their relationship with geographical zones.

The analysis reveals distinct characteristics of the zone near Luxembourg (BEGERLUX) that set it apart from other zones in our study. It exhibits the highest impact on cross-border commutes across various variables in Model 4. Within this zone, the interaction model shows the still strong but lowest effect of the distance to the border and the local job (un)availability on the cross-border commutes. This can be attributed to the strong pull factor of the cross-border employment opportunities in Luxembourg. The presence of a prominent employment pole in Luxembourg reduces the influence of distance to the border and job (un)availability around the municipality, despite the fact that Luxembourg-City is not situated near the border. In this zone, there is a higher proportion of cross-border commuters traveling from more distant locations, indicating a willingness to undertake longer commutes. The strong economic and industrial ties between Luxembourg and neighboring countries, the established practice of seeking employment abroad among the working population, and the attractiveness of Luxembourg as a financial hub all contribute to diminishing the explanatory power of distance and local job (un)availability around the municipality of residence within the BEGERLUX zone. These factors

highlight the unique dynamics at play in this particular border region.

Our study significantly contributes to enhancing our understanding of cross-border commutes within regional labor markets. By incorporating individual-level data to account for individual characteristics and territorial data such as the urban geography of the municipality of residence and the impact of the border, we shed light on the complex dynamics at play. Furthermore, our research addresses the inherent heterogeneity within the area of residence, emphasizing the importance of contextual factors in explaining the distribution of jobs and population. This recognition of context elements allows for a more comprehensive analysis of the allocation of employment opportunities. The high concentration of cross-border commuters along the French border, particularly in proximity to Luxembourg and Switzerland, highlights the interconnectedness of cross-border labor markets. This phenomenon provides an avenue for the labor force to traverse the border and access job opportunities abroad. Consequently, local labor market considerations in these areas must transcend national borders and adopt a cross-border perspective.

Our study provides valuable insights into regional differences and the distinct characteristics that shape cross-border dynamics and thus, it encourages the reevaluation of conventional approaches to studying these dynamics, as the influence of geographical factors is clearly substantial. This is evident in the improved performance of our models, which incorporate household variables, job availability around the municipality of residence, and geographical zones, resulting in lower residuals compared to previous models (Pigeron-Piroth et al., 2018) and increased explanatory power. In essence, our study emphasizes the need to adopt a more holistic and nuanced approach that recognizes the significance of geographical factors in shaping cross-border dynamics. This will enable researchers and policymakers to gain deeper insights into the complexities of cross-border interactions and develop more effective strategies to address the challenges and leverage the opportunities presented by these regional dynamics.

To enhance the model, several considerations can be taken into account. Firstly, it would be beneficial to incorporate a measure of the pull factor associated with the employment destination abroad. This would provide valuable insights into the attractiveness and opportunities offered by the foreign employment pole. Additionally, given the current energy crisis, it is important to consider its potential impact on gasoline prices and the subsequent effect on commuter mobility. By examining these dynamics, a more comprehensive understanding of the commuting patterns can be achieved. Furthermore, the model should account for demographic changes, specifically their influence on job availability in the vicinity of the municipality of residence. Understanding how shifts in population demographics affect manpower resources and job opportunities can contribute significantly to the analysis.

3.5 Appendix

Table 3.6: Description of variables (% in columns)

	Commuters inside France	Cross-border commuters
Men	53.2	61.7
Women	46.8	38.3
20-29	18.1	15.9
15-19	1.6	0.5
30-39	25.4	28.7
40-49	27.6	30.0
50-59	23.6	21.5
60-69	3.7	3.4
Workers	23.7	32.0
Farmers	0.2	0.0
Artisans	4.0	2.3
Management Employees	14.6	17.1
Self-employed Managers	1.4	0.8
Intermediate professions	29.1	25.8
Employees	26.9	22.1
Trade, transport, services	45.0	52.4
Agriculture	0.7	0.3
Industry	16.1	25.6
Construction	6.4	7.6
Public Administration, Education, Health	31.8	14.1
No Diploma	12.6	12.3
Professional Diploma	25.4	27.4
Secondary Education	21.0	19.0
High Degree	40.9	41.2
Owners	69.0	71.3
Tenants	21.1	24.3
Low-cost Tenants	9.9	4.4
2 in the household	27.8	27.3
1 pers	13.0	15.4
3 and +	59.2	57.3
At least one car/employee (FALSE)	20.1	16.8
At least one car/employee (TRUE)	79.9	83.2
Ratio jobs/active 25km around the commune (mean)	0.9	0.8
Urban area	85.7	76.5
Isolated commune	2.1	9.0
Multipolarized commune	12.2	14.5
Distance to the border (mean in km)	20.7	8.7
Belgium (BE)	38.8	8.9
Belgium, Germany, Luxembourg (BEGERLUX)	3.8	19.3
Germany, Luxembourg (GERLUX)	3.2	4.2
Germany (GER)	14.5	9.6
Germany, Switzerland (GERSWI)	5.4	11.3
Switzerland (SWI)	11.8	34.8
Switzerland, Italy (SWIIT)	2.6	3.2
Italy (IT)	1.2	0.1
Italy, Monaco (ITMO)	7.1	7.3
Spain (SPA)	10.9	1.0
Andorra, Spain (ANDSPA)	0.7	0.1
TOTAL	2,581,604	382,980

Notes: For all the displayed variables the Chi-square independence test is significant (Ho rejected with $p<0.001$)
Source: INSEE, Fichier Mobilités Professionnelles 2016. Calculations of the authors.
Population: People living in France at maximum 50km from land borders and having a professional activity outside the commune of residence.

Chapter 4

Distance effects on commuting flows across France and across its national borders

Abstract: Daily mobility flows, in particular commuting, have major social and environmental impacts. Understanding those flows is essential for urban and transportation planning. The acceptance of teleworking in the past few years has changed the way distance is perceived, allowing commuters to seek residential advantages at greater distances from their job places. In border regions, where income and social benefits differentials across countries add to the distance trade-off, these changes may well trigger even more substantial changes in commuting patterns. Given the current lack of robust post-COVID data, we suggest to explore internal and cross-border mobility patterns before the pandemic. More precisely, this chapter studies the mobility patterns of all commuters residing in France and compares those working within the country and across the border. The aim of this chapter is to quantify both the repelling effect of distance and identify whether it is of the same magnitude across borders. We also aim to discover spatial heterogeneity, with varying roles of the different borders of France (with Belgium, Luxembourg, Germany, and Switzerland). To that end, we first estimate spatial interaction models (unconstrained and production-constrained models) for France as a whole to retrieve the general effect of the distance then include border dummies and interactions. We also analyze residuals to identify borders' permeability.

4.1 Introduction

Commuting consists a large part of daily human mobility (Pieters et al., 2012; Haas and Osland, 2014), since, in most cases, residential and workplace locations differ (Vincent-Geslin and Ravalet, 2016). Transportation and infrastructural improvements have significantly facilitated commuting (Clark and Davies Withers, 1999), allowing individuals to seek better employment opportunities (in terms of working conditions, wages, benefits or employment sector (Van Ommeren and Rietveld, 2005; Gottholmseder and Theurl, 2007; Sandow and Westin, 2010; Vincent-Geslin and Ravalet, 2016) in smaller or greater distances. However, commuting, particularly by car, imposes substantial environmental costs on a global scale and entails health and social implications for individuals and local communities. Despite being only one component of daily trips, commuting is a major issue in urban and transport planning, due to its frequency and comparatively simpler policy objectives. The heavy reliance on cars by commuters, with over 78% utilizing this mode of transport (Wang and Hu, 2017), has significant impacts on the environment (Abrahamse et al., 2009; Morales-Betancourt et al., 2023) and congestion levels (Abrahamse et al., 2009), and thus create the need for the development of sufficient and robust public transportation (Chowdhury et al., 2018; Liu et al., 2016) and road connections (Medeiros, 2018). Moreover, the increased commuting time due to congestion can have detrimental effects on commuters, since it is associated with fatigue and higher stress levels (Stone and Schneider, 2016), higher body mass index and blood pressure (Hoehner et al., 2012), lack of adequate and high quality sleep (Walsleben et al., 1999; Hansson et al., 2011), as well as exhaustion and low self-rated health (Hansson et al., 2011).

Depending on the distance between residence and workplace, commuting may consume a notable amount of employed individuals' day. While trip distances is a key driver of time spent, it is obviously not the only one. Mode and congestion come into play and interact with distance and not necessarily in a continuous manner. Public transport, depending on access points and speed, representing gains or loss of time and more or less so for short and long trips. About 20% of commuters in the European Union, travel approximately 29km in order to reach their workplace (Giménez-Nadal et al., 2022). In Belgium, the average commuting distance is about 20km (Boussauw et al., 2012; Persyn and Torfs, 2016) and in Northern Sweden about 27km (Sandow, 2008). However, the duration of commuting trips can be unexpected, as shorter distances may require more time and longer distances, less time (Niedzielski and Eric Boschmann, 2014), depending on the congestion, the means of transport used and their scheduling (Niedzielski and Eric Boschmann, 2014; Habib et al., 2009). According to Eurostat (2020), the average commuting time, for more than 60% of European commuters, was less than 30 minutes (one-way) in 2019. In contrast, 26.3% of individuals spent between 30 minutes and one hour commuting, while only 8.1% had a commuting time of 60 minutes or more. Additionally, a small proportion of workers (4.3%) did not have to travel at all to reach their primary workplace.

The recent COVID-19 pandemic has affected commuting flows notably for more than 2 years and, it seems may durably change work patterns and commuting behavior long-term (Rüger et al., 2021). The introduction of teleworking and hybrid forms of working as an alternative to regular on-site presence, reduced significantly the emissions related to car use during the pandemic itself. This shift has also enabled many individuals to decrease their weekly commuting time. Alternatively, with commuting becoming less frequent, the distance between the workplace and residence may be less of an obstacle, potentially resulting in an increase in overall commuting distance while maintaining a similar total time spent on the road (Rüger et al., 2021).

About 20% of commuters are traveling long distances, more than 1.5 hours daily (Joly and Vincent-Geslin, 2016), in order to maintain a residence in their desired location and meet their financial and career development expectations (Rouwendal and Rietveld, 1994; Rouwendal, 1998; Green et al., 1999; Sandow and Westin, 2010;

Carpentier, 2012; Morris and Zhou, 2018). Others choose the option of commuting across the border for the same reasons. In the EU around 1.4 million individuals (about 0.6% of all the employed individuals) are cross-border commuters (European Commission, 2017). However, it is important to note that cross-border commuting is not necessarily a long-distance commuting.

The changing commuting flow patterns and frequency raise the question on whether the role of distance is changing. Long-distance and cross-border commuting flows may increase in the future, since they will not be performed daily. In this chapter, given the lack of stable data on commuting flows after the start of the pandemic, we want to establish a benchmark and investigate whether distance impacts flows in the same way within a country and across borders. This chapter aims to investigate what is the role of distance and borders on commuting flows in France. The goal is to quantify the border effect and discover whether the distance effect is the same across the border as it is within national borders.

In order to investigate the distance and border effects, we use the commuting flows matrix provided at the municipality scale by INSEE and we conducted a series of analyses. First, we explore descriptive statistics and maps for varying range of inter-communal flows and distances in order to identify key thresholds. Second, we estimate unconstrained and production-constrained spatial interaction models to assess the effect of distance. We add border dummies and interactions to examine border effects. We follow Dujardin (2001) to compare internal and crossing borders residuals. Drawing on the existing literature, we hypothesize the existence of strong border effects, which play a significant role in shaping the dynamics of cross-border commuting, by making it more challenging for individuals. Moreover, we anticipate a pronounced negative effect of distance on commuting flows. To our knowledge, there has not been any attempt so far to investigate commuting distance effects using spatial interaction models for the entire France at such a fine geographical scale. Nor has there been attempts to contrast internal and cross-border distance effects at that scale.

The chapter is structured as followed: First, we explore the literature on distance and border effects, as well as spatial interaction (Section 4.2). Then, in Section 4.3, we describe our data and their collection process, as well as the methodologies we implement. In Section 4.4, we present the results of our analyses using the different methodologies. In Section 4.5, we present our conclusions and extend the discussion. Finally, we include the appendix, which contains supplementary material.

4.2 Background literature

In this section, we aim to stress the current state of the art in terms of the effect of distance, firstly in general on commuting within national borders and then across the borders. We base this on the systematic literature review in Chapter 2, which frames cross-border commuting and compares it to commuting within national borders.

4.2.1 Distance effects on commuting

Long commuting distances have been consistently associated with lower travel (Sposato et al., 2012; Gerber et al., 2017; Gorman-Murray and Bissell, 2018; Zhu et al., 2019; Chatterjee et al., 2020) and life satisfaction (Stutzer and Frey, 2008; De Vos, 2019; Jacob et al., 2019), as well as higher stress levels (Stone and Schneider, 2016). Consequently, according to existing literature, most individuals express a desire to reduce their commuting distance and time (Clark et al., 2003), even though financial incentives and career development opportunities often lead to longer commuting distances (Zax, 1991; Van Ommeren and Rietveld, 2005). It is worth noting that those living in urbanized locations tend to accept longer commutes than those living in more rural locations (Zhu

et al., 2019). Moreover, car ownership decreases the feeling of distance, thereby leading to longer commutes (Wang and Hu, 2017). However, a workplace change, and thus a commuting distance change can sometimes lead to residential relocation (Clark and Davies Withers, 1999). In general, studies indicate that men (Crane, 2007; Paci et al., 2010) and younger individuals (Kim et al., 2005; Sandow, 2008) tend to commute more.

4.2.2 Specificities of cross border commuting and their effects on distance

Cross-border commuting is a highly dynamic form of commuting. In Central Europe, cross-border commuting flows have increased by 81% between the years 2012 and 2018 (Cavallaro and Dianin, 2020). Similarly to internal commuting, most cross-border commuters are men (Alegria, 2002; Greve and Rydbjerg, 2003) of younger age (Huber, 2014). On average, cross-border commuters spend approximately 1 hour commuting to their workplaces (Carpentier, 2012; Möller et al., 2018), which is roughly twice the average commuting time within national borders (Stutzer and Frey, 2008).

According to existing literature, distance, and especially distance to the border, has a negative effect on the probability of being a cross-border commuter (Gottholmseder and Theurl, 2007; Mathä and Wintr, 2009). A residential location that is near a border, offers individuals the possibility to cross it more easily than residents of further locations (Gottholmseder and Theurl, 2007). Workplaces located in municipalities within a 10km zone from a border, attract a significantly higher number of commuters than other locations in a greater distance (Chilla and Heugel, 2022; Bello, 2020). However, shorter distances across the border can be increased notably by the presence of territorial obstacles (i.e. mountains), which may be cause detours in the transportation infrastructure, and hence increase commuting distance (Medeiros, 2018; Chilla and Heugel, 2022). These factors highlight the complex interplay between distance, proximity to the border, and the geography of the region in shaping cross-border commuting patterns.

4.2.3 Spatial interaction and borders

Given this background, our study aims to make a valuable contribution to the field of commuting literature by addressing a significant gap that has been identified. Specifically, we seek to compare and analyze the commuting distances within a country to those of cross-border commuting, while also examining the effect of borders on these commuting patterns. To the best of our knowledge this is the first study over an entire country considering all commuting flows, including the cross-border ones at a very detailed geographical resolution, in NUTS 2 municipalities. In order to accomplish this, we employ a classical spatial interaction approach, as of Dujardin (2001), which enables us to identify the effect of borders on commuting behavior.

The research conducted by Dujardin (2001) utilizes spatial interaction models to confirm the impact of the linguistic border on commuting behaviors across various administrative districts in Belgium. Similarly, the study conducted by Zaninetti (1999), focuses specifically on the relationship between commuting and distance within the context of Paris. By employing a gravity model, the study provides compelling evidence that distance acts as a obstacle to the increase of commuting.

4.3 Data and Methods

4.3.1 Data

In order to conduct our comprehensive analysis, we rely primarily on data provided by INSEE for the year 2018 (Mobilités professionnelles en 2018 : déplacements domicile - lieu de travail). The dataset contains information on all individuals residing in France who are actively employed. It allows us to examine their commuting patterns, whether they commute within their municipality of residence, outside their municipality of residence or across the border.More specifically, the data includes the origin and destination municipalities for each commuting pair, along with the corresponding number of flows. This data allows us to investigate the spatial patterns and intensity of commuting flows between various locations in France and beyond. To complement our dataset, we include shapefiles from Eurostat and the Geoservices portal (geoservices.ign.fr). These shapefiles provide essential geometries, allowing us to precisely trace the boundaries and shapes of French municipalities. Moreover, they enable us to incorporate the geometries of destinations located outside of France that function as cross-border commuter endpoints. This supplementary data not only enhances the visualization of commuting flows, but is also essential for the spatial analysis we conduct.

In order to represent the municipalities inside and outside France effectively, instead of using polygones, we calculated the centroids of the municipalities. Based on these centroids, we estimated the Eurclidean distance between each origin and destination municipality. This distance provides a measure of proximity or spatial separation, which is an essential element for the spatial interaction models that we will conduct. Additionally, we computed the distance of each municipality's centroid to a different external border of France (borders shared with Belgium, Germany, Luxembourg, Switzerland, Italy, Spain and Andorra). By integrating these calculations and data sources, we constructed a spatial interaction matrix of flows between origins and destinations. For the calculation and representation of the data, we employed the Lambert 93 (RGF93) coordinate system, which is the official projection system used to map France.

Throughout the analysis, we use the described dataset, without the diagonal. The diagonal, consists of the cells in our spatial interaction matrix for which the municipality of origin is the same as the municipality of destination. Consequently, in this case the distance between the origin and the destination is zero, given that we used the centroid of each municipality. By excluding the diagonal elements, we ensure that our analysis focuses on meaningful spatial interactions between distinct municipalities. This approach allows us to capture and examine the dynamics of interactions that involve actual spatial separation, facilitating a more accurate understanding of the relationships between different geographic entities.

4.3.2 Methods

Maps of flows

In the first part of our analysis, we create a series of maps, in order to study the flows between the various origins and destinations. The purpose of these maps is to examine the different spatial patterns and dynamics of commuting flows. Thus we used different flow and distance thresholds. The flows are visually represented as lines of different intensity, which corresponds to the volume of flows. Furthermore, we employ different colors, in order to represent flows ending within the French territory and flows that lead across the border. The visualization of the flows between origins and destinations at different thresholds, enables us to unravel the spatial relationships, to identify key corridors, and to detect emerging patterns.

Spatial Interaction Models

The main part of our analysis revolves around the estimation of spatial interaction models, which serve as powerful tools for understanding and measuring the patterns and dynamics of commuting flows.To do this we use the spatial interaction matrix of flows between origins and destinations that we previously constructed.

Spatial interaction models have been and continue to be a invaluable tool in social sciences serving a wide range of applications of location analyses (Pooler, 1994). According to Fotheringham (2001) spatial interaction models can be defined as mathematical representations of spatial flows, which aim to study or predict the movement of people or goods between different locations. In essence, spatial interaction models can be considered as an extension of a gravity model (Wilson, 1971).

The fundamental tool of a spatial interaction model is the creation of a matrix that consists of combinations of origins (*i*) and destinations (*j*). In order to represent the number of trips *Tij* between origins and destinations as a function of the distance between them and their characteristics, we need to measure their distance, the number of flows between them, the number of flows originating from each origin (propulsion) and the number of flows arriving in each destination (attraction) (Fotheringham, 2001). This information is organized within a spatial interaction matrix (Figure 4.1), where each cell represents the volume of flows between a specific origin and a specific destination. The sum of each row provides the total amount of flows originating from each origin and the sum of each column represents the total amount of flows directed towards each destination (Fotheringham and O'Kelly, 1989). This matrix enables the quantitative analysis of spatial interaction patterns, revealing the flow volumes between various origin-destination pairs.

Destinations / Origins	1	2	...	j	...	J	Total *i*
1	T_{11}	T_{12}	...	T_{1j}	...	T_{1J}	O_1
2	T_{21}	T_{22}	...	T_{2j}	...	T_{2J}	O_2
...	...	...	...	...	...	...	...
i	T_{i1}	T_{i2}	...	T_{ij}	...	T_{iJ}	O_i
...	...	...	...	...	...	...	...
I	T_{I1}	T_{I2}	...	T_{Ij}	...	T_{IJ}	O_I
Total *j*	D_1	D_2	...	D_j	...	D_J	Total flows

Figure 4.1: Spatial Interaction Matrix of flows between origins (*i*) and destinations (*j*)

The Unconstrained model provides valuable insights into the dynamics of interactions by allowing a more comprehensive understanding of the role of distance and the role of the unique features of the origins and destinations.(Fotheringham and O'Kelly, 1989; Dujardin, 2001). The model is mathematically formulated as follows:

$$T_{ij} = k v_i^{\mu} w_j^{\lambda} d_{ij}^{\beta} \tag{4.1}$$

with

$$k = \frac{T}{\sum_i \sum_j v_i^{\mu} w_j^{\lambda} d_{ij}^{\beta}} \tag{4.2}$$

where T_{ij} is the estimated number of the active population residing in location i and working in location j, v_i is the propulsion of the origin i, w_j is the attractiveness of the destination j, d_{ij} is the distance between origin i and destination j, μ, λ and β are parameters that show the relationship between the variables and T_{ij}, and k is a factor ensuring that the amount of observed and estimated flows is equal (Dujardin, 2001; Fotheringham, 2001).

In this chapter, our analysis employs three different approaches within the framework of the unconstrained model: the log-normal regression, the Poisson regression and a regression incorporating the power function. First, in order to transform the unconstrained model into a linear form, we adopt a logarithmic transformation of Equation 4.1. Simply by taking the logarithms of both sides of the equation, we arrive at the log-normal regression form that we employ for our analysis:

$$lnT_{ij} = k + \mu lnv_i + \lambda lnw_j - \beta lnd_{ij} + \epsilon_{ij} \tag{4.3}$$

where ϵ is an error term that follows a normal distribution a mean of 0 (Oshan, 2022). By assuming a log-normal distribution, we can account for the asymmetry and potential outliers in the data, leading to more robust and accurate estimations.

Given that the flows in our spatial interaction matrix represent counts of people and should be treated as discrete entities, we opt for the application of a Poisson regression. This model is considered suitable for modeling count data and effectively addressing the potential issue of taking the logarithm of zero-valued flows that can arise. Thus, it is often preferred over the log-normal model. This approach enables us to model the relationship between the predictors and the expected count of interactions, providing valuable insights into the underlying dynamics. We utilize the form of the Poisson model as suggested by Dennett (2018):

$$\lambda_{ij} = exp(k + \mu lnv_i + \lambda lnw_j - \beta lnd_{ij}) \tag{4.4}$$

where λ_{ij} is the dependent variable, the estimate of T_{ij}. This means that there is a logarithmic link between the dependent variable and the linear combination of the logged independent variables (Dennett, 2018). Consequently, this implies that changes in the independent variables are associated with proportional changes in the dependent variable.

In addition to the log-normal and the Poisson regression, we explore the implementation of a power-function model (Equation 4.5) as the third approach in our analysis. However, it is important to acknowledge that this particular model has received criticism for potentially introducing heteroscedasticity issues as a result of the logarithmic transformation (Fotheringham and O'Kelly, 1989). This refers to the unequal spread of residuals or error terms across different levels of the independent variables, violating the assumption of homoscedasticity.

$$lnT_{ij} = lnk + \mu lnv_i + \lambda lnw_j - \beta d_{ij} \tag{4.5}$$

Both the log-normal and power-function models yield an R^2 measure, which quantifies the extent to which the model's independent variables can predict the observed flows. However, the Poisson model does not provide an explicit R^2 value. In order to address this limitation, we employ a $PseudoR^2$ measure, as suggested by Faraway (2016), to assess the explanatory power of the Poisson model. This measure allows us to evaluate the model's ability to account for the observed variations in the data. Furthermore, this measure enables us to

make a meaningful comparison between the three regression approaches. The calculation of the $PseudoR^2$ is performed using the following equation:

$$PseudoR^2 = 1 - \frac{Residual\ Deviance}{Null\ Deviance} \tag{4.6}$$

The three different approaches discussed earlier for calculating the unconstrained spatial interaction model serve as the foundation for creating three unique forms of models. Each model form offers a different perspective and insights into the dynamics of spatial interactions.

1. First, we perform a series of regressions. Each of them has a different subset of the dataset, based on the destination country. More specifically, we perform a log-normal, a Poisson and a power-function model for the subset of the dataset for which the destination is Belgium, France, Germany, Luxembourg or Switzerland. By analyzing each subset individually with these models, we can uncover country-specific relationships, which enhances the richness and depth of our understanding of the results for each destination country.

2. Second, using the whole dataset (without the diagonal) we add an interaction term in the models. We perform the log-normal, the Poisson and the power-function models adding the element of multiplying the variable of attractiveness with the variable that shows the country of destination. By considering this interaction term, we aim to discern how the attractiveness of an destination varies based on the specific destination country, enabling us to better comprehend the country effects.

3. Finally, building upon the previous model, we introduce a different interaction term, which involves multiplying the variable of spatial separation (distance) with the variable that shows the country of destination. This model allows us to explore how the distance effect varies across different destination countries.

The Production-Constrained model serves as a valuable tool in cases where we have information about the volume of flows that originate from each origin and their distance to their corresponding destinations, but the total flows arriving in each destination are unknown. This model allows us to uncover the production dynamics, thereby enriching our understanding of spatial interactions (Fotheringham and O'Kelly, 1989; Fotheringham, 2001). We opt for this model as it allows us to control only for the production side, the flows originating from France, but we are unable to control for the destination side, which may extend beyond the boundaries of France. The model is represented in the following form:

$$T_{ij} = O_i w_j d_{ij} \tag{4.7}$$

where O_i is the fixed effect of the origin, in our case the name of the municipality of origin. The Production-Constrained Model can be reformulated into a Poisson regression model using the same approach as before, allowing to effectively model the relationship between the predictors and the expected counts of interactions (Dennett, 2018).

$$\lambda_{ij} = exp(k + O_i + \lambda ln w_j - \beta ln d_{ij}) \tag{4.8}$$

Border Effects Indices

In the final part of our analysis, we direct our focus towards studying and quantifying the border effect. Our objective is to investigate whether the impact of distance on commuting flows remains consistent across the border, as we compare cross-border distances with internal distances.

The first step involves utilizing the residuals of the production-constrained models to calculate a border permeability index. The residuals represent the differences between the observed flows and the predicted flows based on the models. By analyzing these residuals, we can assess the extent to which the borders act as a barrier or facilitator to the movement of people, goods, or information between different regions. The border permeability index provides a quantitative measure that captures the degree of ease or restriction in cross-border interactions, allowing for a deeper understanding of the spatial dynamics and influences at play. In order to calculate the permeability index, we use the following formula by (Dujardin, 2001):

$$Border\,Permeability\,Index = \frac{T_{CB} - T'_{CB}}{T_{FR} - T'_{FR}} \tag{4.9}$$

where T_{CB} and T_{FR} are the total observed (from our datasets) flows towards a destination across the border and a destination within France respectfully; and T'_{CB} and T'_{FR} are the total flows towards another country or France, as predicted by our production-constrained models. CB refers to Belgium, Germany, Luxembourg or Switzerland, as destinations across the border. However, In contrast to the approach taken by Dujardin (2001), our analysis utilizes the residuals of the Production-Constrained model instead of the Doubly-Constrained model. This choice is motivated by the nature of our dataset, which lacks control over the destination variable. For this index, higher values indicate a higher level of interaction between regions and a lower border effect, while lower values demonstrate the opposite.

Upon analyzing our data, we observed a tendency of the production-constrained models to either overestimate or underestimate the distance effects on commuting flows. To address this, we introduce a second index, the border friction factor, which is also derived from the results of the production-constrained models. For this analysis, we utilize the same subsets consisting of municipalities located within a 100km distance from Belgium, Germany, Luxembourg, and Switzerland. However, for this index, we adopt a different approach by distinguishing flows directed towards France from flows directed towards each of the four other countries. To accomplish this, we create two distinct subsets for each of the four used in the production-constrained model: one consisting of municipalities located within 100km of the studied border and containing flows destined for France, and another subset comprising flows leading to that specific country. We then apply the production-constrained regression model separately to each subset. For example, we divide the subset with the municipalities within a 100km distance from Belgium to two: the first contains only the flows that lead to France and the second only the flows leading to Belgium. By assuming that the distance effect is different across the border and internally, we employ a comparative approach to assess these distinctions. Specifically, we calculate the ratio of distance coefficients to examine the border effect on commuting flows. This analysis provides a deeper understanding of cross-border interactions by quantifying the extent to which the border intensifies the influence of distance on flows and contributes to friction. Finally, we calculate the index using the following formula:

$$Border\,Friction\,Factor = \frac{\beta T_{CB}}{\beta T_{FR}} \tag{4.10}$$

where βT_{FR} is the β coefficient for the distance effect for the flows that originate from one subset of 100km distance to one particular border, leading to France and βT_{CB} is the β coefficient of distance for flows in the

same subset that lead to that particular country. For this index, lower values indicate a smaller cost of crossing the border, reflecting easier mobility and interaction between regions, while higher values indicate a higher cost, implying greater barriers and limitations to cross-border movement.

4.4 Results

4.4.1 Geography of flows

In order to visualize both commuting flows and cross-border commuting patterns, we have developed a series of maps that capture a range of inter-communal flows at different distances, enabling us to identify significant thresholds (see Appendix). By employing a color scheme, we provide a clear visual distinction between internal and cross-border commuting, allowing for a comprehensive understanding of the spatial dynamics at play. The use of white lines to represent internal flows helps to visualize the commuting flows within France. On the other hand, the yellow lines serve as a visual indication of flows across the French borders, shedding light on the extent of cross-border labor mobility and the relationship between neighboring regions. Through these maps, we acquire a better knowledge of the spatial links and relationships that occur inside and beyond the borders of France.

Flow thresholds

By examining the first flow map (for flows larger than 10), we can initially notice that the flow lines do not cover the entire France territory. This highlights that many, if not most, origin-destination combinations exhibit less than 10 commuting flows. By increasing the flow thresholds, it is obvious that the origin-destination combinations decrease significantly. Higher flows appear to be concentrated around major cities and small cities seem to disappear (See Appendix, Figure 4.4).

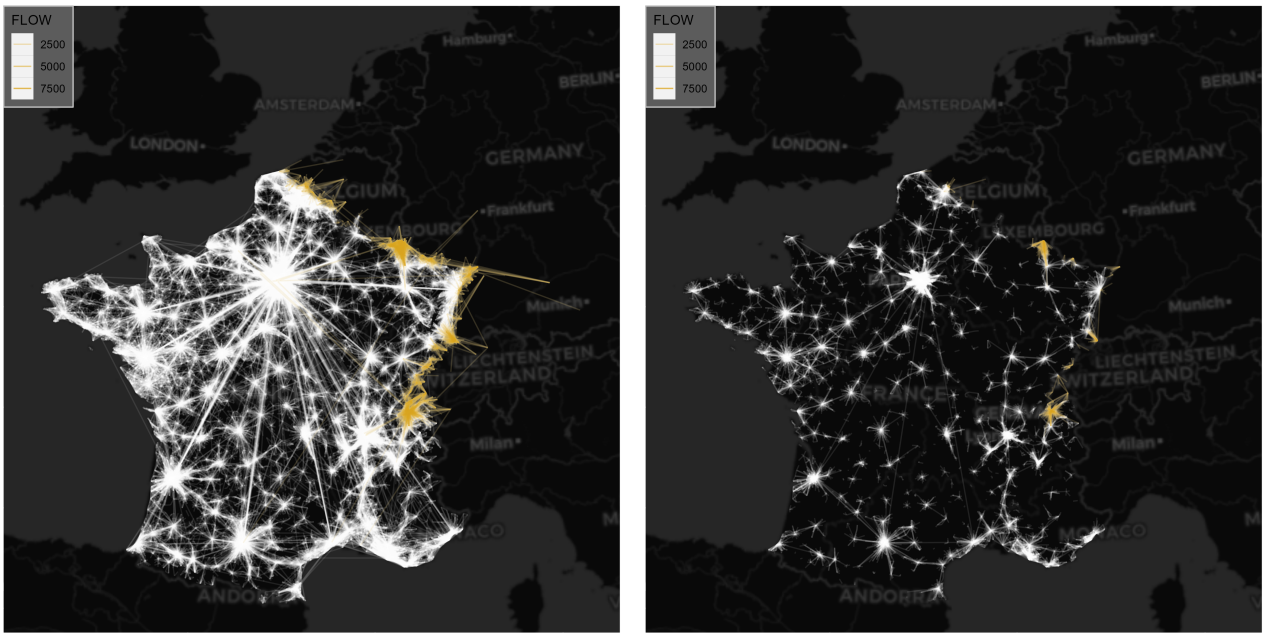

Figure 4.2: Flows from origins to destinations, higher than 20 (left) and higher than 100 (right)

Throughout all the maps, one can consistently identify the prominent French cities, including Paris, Lyon, Bordeaux, Toulouse, and Nantes. These cities serve as focal points, persistently appearing even in the maps

depicting the highest flow volumes. This underscores their crucial role as major origins or destinations of commuting flows, aligning with initial expectations. These cities consist of multiple municipalities and substantial populations, offering diverse employment opportunities. Consequently, not only do they attract commuters from longer distances, but commuters residing in these metropolitan areas travel to various destinations within the same city, as well. This phenomenon accentuates the enduring influence of the suburban effect, where individuals who reside in areas outside major cities opt to commute to the central metropolitan areas in order to access their workplaces, as described by Alonso (1960). The presence of these major cities throughout the maps highlights their significance as prominent economic centers. The constant flow activity to and from these cities reflects the dynamic nature of their labor markets, the distribution of job opportunities, and the commuting choices made by individuals residing in and around these metropolitan areas.

As far as the cross-border commuting flows are concerned, it is evident that the majority of international flows are directed towards Luxembourg and Switzerland, mainly the region of Geneva. The striking prominence of Luxembourg and Switzerland in the maps creates the illusion that they are seamlessly integrated into the urban fabric of France. Their substantial presence and inter-connectedness within the commuting flows suggest a strong functional relationship and an extended urban system that transcends national borders. This pattern prompts intriguing questions regarding the underlying determinants of these flows. Are they primarily influenced by the characteristics of the French municipalities of origin themselves, or do they stem from a strong attraction towards these specific areas? The latter possibility suggests that the characteristics of the destinations play a significant role in generating these flows. The unique characteristics of Luxembourg and the Geneva region, such as their robust economies, financial sectors, high salaries and wide range of employment opportunities, may act as strong magnets for French cross-border workers. Additionally, proximity and accessibility may play a crucial role in shaping these cross-border flows.

Distance thresholds

Analysing the flow maps that represent the distance between origin and destination, we can see that up to the distance of 100km, the major cities in France stand out prominently, similarly to the previous set of maps, reaffirming their significance as major employment hubs. As the commuting distance exceeds 100km, the flow maps reveal a gradual expansion of flows that span across the entire territory of France (See Appendix, Figure 4.5). This observation suggests a substantial presence of long-distance internal commuting flows within the country. Cross-border commuting flows are apparent across all distance ranges, demonstrating the inter-connectedness between neighboring regions. Notably, even for distances shorter than 10km, a significant number of flows can be observed crossing the border. The presence of cross-border flows across various distance ranges underscores the transnational nature of employment patterns and the interdependence between bordering regions. Furthermore, the flow maps serve to reinforce the notion that border regions, extending beyond the French boundaries, are intricately linked to the broader urban system of France.

The last map, which depicts flows for distances higher than 1000km, stands out as the most distinct, showing a notably lower number of commuting flows. Within this map, a small fraction of the flows corresponds to internal movements connecting Brittany and Provence-Alpes-Côte d'Azur. The presence of such flows can be attributed to seasonal employment opportunities in the tourism sector, particularly drawing individuals from Brittany towards Provence-Alpes-Côte d'Azur. The rest of the flows in this map represent flows across the border, originating from various locations in France and leading to different municipalities in Germany. These flows are surprising, since the distance shown is exceptionally long. These flows can be characterised as

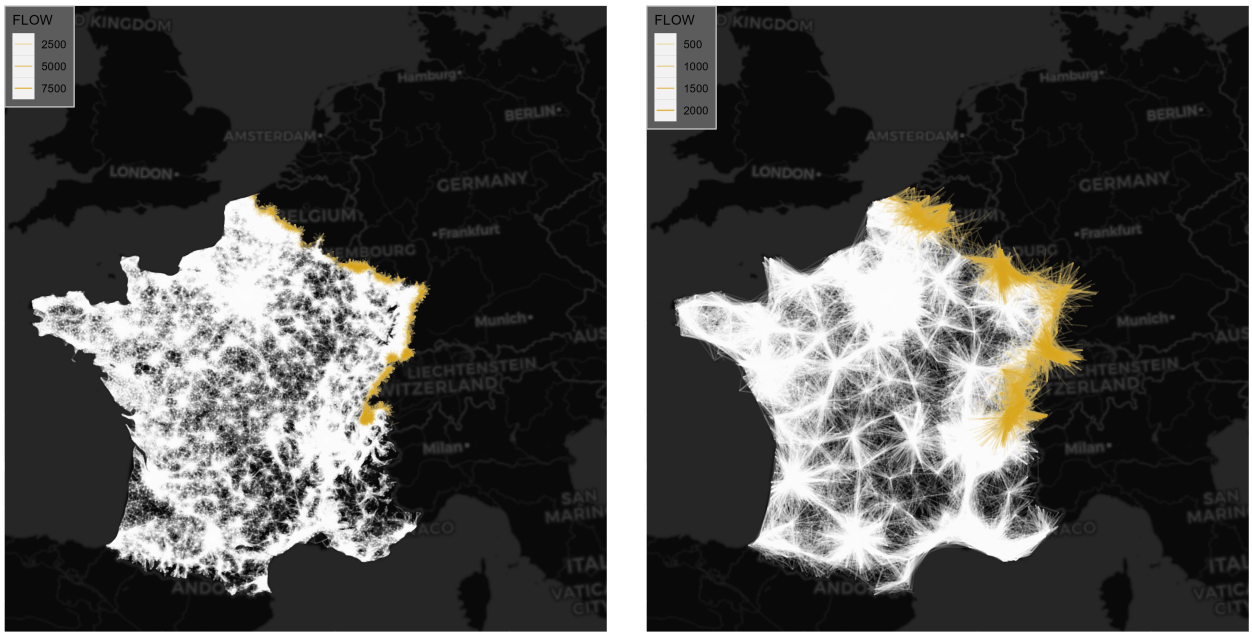

Figure 4.3: Flows from origins to destinations, distance lower than 20km (left) and between 50km and 100km (right)

extreme-commuting flows.

The findings highlight the intricate commuting patterns in France, emphasizing the significance of both short and long-distance commutes within the national borders. The gradual reduction in flows across longer distances and international borders reflects the impact of distance and potential limitations on commuting accessibility. Nonetheless, the extensive internal commuting flows indicate the ongoing economic and social inter-dependencies between different regions throughout the country.

4.4.2 Descriptive Statistics

By analyzing the key statistics of the datasets utilized in our study (See Table 4.1), we can derive meaningful insights. Notably, when calculating the average distance between origin and destination per capita, we obtain robust results across the first four models. It is remarkable that the models encompassing various destinations, origins within a 100km proximity to the border, destinations within France, and destinations within France excluding Paris, exhibit highly similar average commuting distances, around 22-23km. Particularly noteworthy is the fact that for origins located within the 100km border zone, the commuting distance compares favorably with destinations within France, even when excluding the city of Paris from the analysis. This highlights the significance of the border zone in terms of commuting patterns and emphasizes the coherence of commuting distances within this region compared to other destinations within the country.

By conducting the same analysis of calculating the distance per capita across the various subsets based on destination countries, we observe some variations in the results. Notably, for commuting across the border to Luxembourg and Switzerland, the average distance is higher compared to internal commuting or commuting towards any destination from the 100km border zone, approximately 1.5 times higher. On the other hand, for commuting to Belgium and Germany, the average distance per capita is roughly 2.5 times higher than the previous datasets, averaging around 58km. These findings suggest that commuting to Belgium and Germany as destinations entails a higher distance decay factor, which could be further investigated through the application of

spatial interaction models. The variance in commuting distances highlights the influence of destination countries on the spatial patterns of commuting and underscores the importance of considering specific destination characteristics in understanding commuting behaviors.

The remaining statistics presented in Table 4.1 pertain to pairs of origins and destinations rather than individual commuters. As such, we will not delve into further details regarding these statistics. In the next step we control for the individuals' locations and the job markets at the destinations, allowing us to gain a deeper understanding of these observed trends.

Table 4.1: Summary of statistics of datasets

A: Any destination

	All (n=918822, T= 17964770)			Within 100km of border (n=320504, T= 5628157)		
	Mean	Median	SD	Mean	Median	SD
FLOWS	19.552	5.084	85.976	17.560	5.073	83.546
log(FLOWS)	2.080	1.626	0.998	2.045	1.624	0.937
INCOMING	14202.100	2171.500	33363.220	11500.400	1630.000	31494.490
log(INCOMING)	7.729	7.683	2.065	7.430	7.396	2.038
OUTGOING	5370.130	879.850	14789.770	4512.470	729.830	15868.410
log(OUTGOING)	6.996	6.780	1.735	6.757	6.593	1.677
EUCLKM	57.012	21.619	112.288	54.591	20.468	111.355
log(EUCLKM)	3.199	3.074	1.154	3.136	3.019	1.164
EUCLKM per capita	*23.293*			*23.987*		

B: Destination France

	All (n=893618, T= 17580959)			Without Paris (n=856447, T= 15766110)		
	Mean	Median	SD	Mean	Median	SD
FLOWS	19.674	5.085	86.146	18.409	5.083	78.730
log(FLOWS)	2.084	1.626	1.001	2.072	1.626	0.977
INCOMING	14457.600	2235.000	33705.060	11378.200	2038.100	28709.760
log(INCOMING)	7.766	7.712	2.050	7.632	7.620	1.966
OUTGOING	5376.700	875.000	14803.840	4743.240	833.120	13301.290
log(OUTGOING)	6.993	6.774	1.739	6.932	6.725	1.701
EUCLKM	56.384	21.268	111.737	52.378	20.685	105.800
log(EUCLKM)	3.184	3.057	1.154	3.140	3.029	1.125
EUCLKM per capita	*22.943*			*22.384*		

C: Destination not France

Destination:	Belgium	n=4593 T= 43012.03	Germany	n=4807 T=49976.89	Luxembourg	n=4802 T=87674.22	Switzerland	n=11002 T=203147.2
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FLOWS	9.365	23.343	10.397	26.994	18.258	89.572	18.465	102.102
log(FLOWS)	1.789	0.777	1.868	0.764	2.111	0.927	1.984	0.932
INCOMING	902.339	1173.538	1272.481	2234.345	7459.450	13534.600	7601.090	19737.630
log(INCOMING)	5.795	1.679	5.648	2.021	7.496	1.765	6.490	2.320
OUTGOING	7637.800	16777.770	6182.400	18379.360	3404.470	10024.560	4393.020	12381.750
log(OUTGOING)	7.545	1.750	7.110	1.566	6.868	1.441	7.013	1.540
EUCLKM	97.475	154.417	102.927	166.510	61.627	96.048	69.058	105.083
log(EUCLKM)	3.887	1.087	3.824	1.161	3.680	0.807	3.655	0.981
EUCLKM per capita	*57.776*		*58.012*		*37.024*		*31.830*	

n=Pairs of Origins and Destinations
T=Flows

4.4.3 Unconstrained Spatial Interaction Models

Table 4.2 provides a comprehensive overview of the results obtained from the three distinct unconstrained models, which were applied to different subsets of destination countries. Upon observing the table, it becomes evident that variations exist across the models.

In order to understand the models, it is important to interpret the estimated coefficients. The Intercept estimates correspond to k, the Outgoing estimates are the μ, the Incoming estimates are the λ and the Euclidean

Table 4.2: Results of Unconstrained models per country

log-normal	Belgium	France	Germany	Luxembourg	Switzerland
(Intercept)	2.332 (***)	1.384 (***)	2.173 (***)	1.414 (***)	1.935 (***)
	(0.066)	(0.004)	(0.058)	(0.075)	(0.044)
log(INCOMING)	0.101 (***)	0.250 (***)	0.112 (***)	0.243 (***)	0.174 (***)
	(0.006)	(0.000)	(0.005)	(0.006)	(0.003)
log(OUTGOING)	-0.006	0.080 (***)	-0.006	0.190 (***)	0.066 (***)
	(0.006)	(0.001)	(0.007)	(0.008)	(0.005)
log(EUCLKM)	-0.278 (***)	-0.562 (***)	-0.234 (***)	-0.661 (***)	-0.423 (***)
	(0.010)	(0.000)	(0.009)	(0.014)	(0.008)
R^2	21%	37%	23%	38%	32%
Power function					
(Intercept)	1.507 (***)	0.661 (***)	1.487 (***)	-0.500 (***)	0.697 (***)
	(0.063)	(0.005)	(0.058)	(0.082)	(0.044)
log(INCOMING)	0.110 (***)	0.164 (***)	0.118 (***)	0.230 (***)	0.174 (***)
	(0.006)	(0.000)	(0.005)	(0.007)	(0.003)
log(OUTGOING)	-0.032 (***)	0.048 (***)	-0.024 (***)	0.168 (***)	0.053 (***)
	(0.006)	(0.001)	(0.007)	(0.008)	(0.005)
EUCLKM	-0.001 (***)	-0.003 (***)	-0.001 (***)	-0.004 (***)	-0.003 (***)
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2	12%	18%	18%	27%	25%
Poisson					
(Intercept)	1.444 (***)	-0.230 (***)	0.890 (***)	-3.600 (***)	-1.256 (***)
	(0.034)	(0.001)	(0.030)	(0.026)	(0.015)
log(INCOMING)	0.254 (***)	0.523 (***)	0.320 (***)	0.767 (***)	0.566 (***)
	(0.003)	(0.000)	(0.003)	(0.002)	(0.001)
log(OUTGOING)	0.198 (***)	0.248 (***)	0.241 (***)	0.646 (***)	0.481 (***)
	(0.003)	(0.000)	(0.003)	(0.003)	(0.002)
log(EUCLKM)	-0.619 (***)	-1.052 (***)	-0.628 (***)	-1.263 (***)	-1.099 (***)
	(0.005)	(0.000)	(0.005)	(0.004)	(0.002)
$PseudoR^2$	39.6%	66.2%	43.3%	69.2%	70.9%
	Note:				*p<0.1; **p<0.05; ***p<0.01

log-normal: $lm(log(FLOW) \sim log(INCOMING) + log(OUTGOING) + log(EUCLKM))$
Poisson: $lm(ceiling(FLOW) \sim log(INCOMING) + log(OUTGOING) + log(EUCLKM))$
Power function: $lm(log(FLOW) \sim log(INCOMING) + log(OUTGOING) + EUCLKM)$

distance estimates correspond to the β parameter.

At a first glance, a notable observation is that distance consistently exhibits a negative effect in all the models presented in Table 4.2. This finding confirms that an increase in commuting distance decreases commuting flows. Surprisingly, the strongest effects are found on commuting to Luxembourg and Switzerland, across all three approaches. The financial attractiveness of these two countries was expected to keep the negative effect of distance to a lower level. This highlights that despite the attractiveness of local characteristics, geographic proximity remains a prominent consideration for individuals when deciding on commuting destinations.

With the exception of the power-function models, distance consistently demonstrates the most substantial effect compared to attraction and propulsion, in almost all cases. This indicates that the physical separation between origin and destination plays a pivotal role in determining the volume and patterns of the flows.

It should be noted that the explanatory power of the log-normal and power-function models can be considered quite low, as their Adjusted-R^2 values are not strong. This means that the independent variables included in the models explain only a limited portion of the variability observed in the dependent variable. The log-normal models have higher overall explanatory power than the power-function regressions. The highest Adjusted-R^2

can be noticed in the log-normal model with flows to Luxembourg. Even in this model only 38% of the flows can be explained by the independent variables. Therefore, it is evident that additional variables, not included in these models, contribute significantly to the observed flows. These factors include individual, household and socioeconomic characteristics (as in Chapter 3), cultural aspects and/or individual preferences.

To facilitate a meaningful comparison between the three regression approaches, we calculate a $PseudoR^2$. By employing the $PseudoR^2$ measure, it becomes evident that the Poisson model exhibits a considerably greater explanatory power. This finding indicates that the Poisson approach has the ability to predict commuting flows with higher accuracy. This can be attributed to the fact that the Poisson model treats the data as counts, while the other two approaches as continuous data. Thus, this difference in the underlying assumptions and calculation processes generates different results, including notable differences in the coefficients of the models. Notably, the Poisson models focusing on flows within France and those directed towards Luxembourg and Switzerland demonstrate the highest accuracy in their predictions.

Table 4.3: Results of Unconstrained models with interaction term

	log-normal	Power function	Poisson
(Intercept)	1.380 (***)	0.667 (***)	-0.250 (***)
	(0.004)	(0.005)	(0.001)
log(INCOMING)	0.249(***)	0.164 (***)	0.522 (***)
	(0.000)	(0.000)	(0.000)
log(OUTGOING)	0.079	0.048 (***)	0.25 (***)
	(0.000)	(0.001)	(0.000)
log(EUCLKM)	-0.558 (***)		-1.049 (***)
	(0.001)		(0.000)
EUCLKM		-0.003 (***)	
		(0.000)	
Belgium	1.442 (***)	0.470 (***)	2.609 (***)
	(0.042)	(0.048)	(0.023)
Germany	1.490 (***)	0.562 (***)	2.213 (***)
	(0.034)	(0.390)	(0.019)
Luxembourg	0.579 (***)	-0.215 (***)	-0.532 (***)
	(0.050)	(0.057)	(0.020)
Switzerland	0.92 (***)	0.079 (***)	0.637 (***)
	(0.023)	(0.026)	(0.009)
log(INCOMING):Belgium	-0.155 (***)	-0.057 (***)	-0.260 (***)
	(0.007)	(0.008)	(0.004)
log(INCOMING):Germany	-0.148 (***)	-0.050 (***)	-0.175 (***)
	(0.006)	(0.006)	(0.003)
log(INCOMING):Luxembourg	-0.026 (***)	0.041 (***)	0.172 (***)
	(0.006)	(0.007)	(0.002)
log(INCOMING):Switzerland	-0.068 (***)	0.011 (***)	0.033 (***)
	(0.003)	(0.004)	(0.001)
R^2	37%	18%	
$PseudoR^2$			66.2%
	Note:		*p<0.1; **p<0.05; ***p<0.01

log-normal: $lm(log(FLOW) \sim log(INCOMING) * CountryDestination + log(OUTGOING) + log(EUCLKM))$
Poisson: $glm(ceiling(FLOW) \sim log(INCOMING) * CountryDestination + log(OUTGOING) + log(EUCLKM))$
Power function: $lm(log(FLOW) \sim log(INCOMING) * CountryDestination + log(OUTGOING) + EUCLKM)$

The addition of the first interaction term in the models (Table 4.3) shows that the results continue to highlight the robustness of the negative effects of distance on commuting flows. The attraction effect seems to be negative across all destination countries in the log-normal model, but positive for Luxembourg and Switzerland in the Poisson model (which has the highest explanatory power). This means, that compared with flows towards

France, which is the reference term, Belgium and Germany have a negative effect, while Luxembourg and Switzerland seem slightly more attractive than France in two out of three models. This can be explained by financial advantages associated with commuting to Luxembourg and Switzerland.

Table 4.4: Results of Unconstrained models with interaction term

	log-normal	Power function	Poisson
(Intercept)	1.400 (***)	0.663 (***)	-0.250 (***)
	(0.004)	(0.005)	(0.001)
log(INCOMING)	0.246(***)	0.164 (***)	0.522 (***)
	(0.000)	(0.000)	(0.000)
log(OUTGOING)	0.079 (***)	0.048 (***)	0.250 (***)
	(0.000)	(0.001)	(0.000)
log(EUCLKM)	-0.560 (***)		-1.051 (***)
	(0.001)		(0.000)
EUCLKM		-0.003 (***)	
		(0.000)	
Belgium	-0.490 (***)	-0.061 (***)	-0.366 (***)
	(0.043)	(0.016)	(0.018)
Germany	-0.522 (***)	0.077 (***)	-0.126 (***)
	(0.039)	(0.015)	(0.016)
Luxembourg	0.563 (***)	0.107 (***)	0.439 (***)
	(0.053)	(0.016)	(0.014)
Switzerland	0.059 (*)	0.132 (***)	0.904 (***)
	(0.029)	(0.010)	(0.007)
log(EUCLKM):Belgium	0.265 (***)		0.393 (***)
	(0.011)		(0.005)
log(EUCLKM):Germany	0.308 (***)		0.366 (***)
	(0.010)		(0.005)
log(EUCLKM):Luxembourg	-0.049 (***)		0.146 (***)
	(0.014)		(0.004)
log(EUCLKM):Switzerland	0.114 (***)		0.008 (***)
	(0.008)		(0.002)
EUCLKM:Belgium		0.002 (***)	
		(0.000)	
EUCLKM:Germany		0.002 (***)	
		(0.000)	
EUCLKM:Luxembourg		-0.0002	
		(0.000)	
EUCLKM:Switzerland		0.0003 (***)	
		(0.000)	
R^2	37%	18%	
$PseudoR^2$			66.2%
	Note:		*p<0.1; **p<0.05; ***p<0.01

log-normal: $lm(log(FLOW) \sim log(INCOMING) + log(OUTGOING) + log(EUCLKM) * CountryDestination)$
Poisson: $glm(ceiling(FLOW) \sim log(INCOMING) + log(OUTGOING) + log(EUCLKM) * CountryDestination)$
Power function: $lm(log(FLOW) \sim log(INCOMING) + log(OUTGOING) + EUCLKM * CountryDestination)$

The introduction of the second interaction term into the models (as shown in Table 4.4) further reinforces the negative impact of distance on commuting flows. Analyzing the interaction term itself, it becomes apparent that, in general, the effect of distance on cross-border commuters is stronger compared to the effect of distance for commuting within France, which is the reference factor. However, it is worth noting that for Luxembourg, the interaction effect is negative in the log-normal and power-function models, but positive in the Poisson model, which has a higher explanatory power. The former could suggests that, for Luxembourg, the influence of distance on cross-border commuters could be less favorable, indicating potential constraints or specific factors associated

with commuting to Luxembourg that outweigh the general positive effect of cross-border commuting. Such a factor could be congestion.

When considering the explanatory power of the models (Tables 4.3 and 4.4), it becomes evident that the log-normal model outperforms the power-function model in terms of its ability to explain the observed flows. Specifically, the log-normal model accounts for approximately 37% of the variations in the flows, while the power-function model explains only around 18% of the variability. Upon examining the computed Pseudo-R^2 values, it is evident that the Poisson model exhibits the highest level of explanatory power among the three models, with a value of 66.2%.

4.4.4 Production-Constrained model

Estimates

In order to implement the Production-constrained model, we carefully selected four distinct subsets from our dataset. These subsets were generated by sampling origins located within a 100km radius of each respective French border (included in our dataset): Belgium, Germany, Luxembourg, and Switzerland. By extracting municipalities situated within this 100km border zone, we targeted areas that are recognized in the literature as part of the border zone, where many cross-border commuters reside (see Chapter 3). Considering this valuable insight, our deliberate selection of origins within a 100km distance from any border significantly amplifies the border effect in our analysis. By narrowing down the dataset in this manner, and explicitly considering each distinct border, we aimed to capture the localized interactions and explore the factors influencing flows originating from these border regions. This approach allows us to gain a deeper understanding of the distinct characteristics and influences related to the proximity of the border on spatial interactions.

Table 4.5: Results of the Production Constrained models

100km distance from border to:	Belgium	Germany	Luxembourg	Switzerland
(Intercept)	0.057	0.968 (***)	0.784 (***)	0.428 (***)
	(0.080)	(0.167)	(0.040)	(0.056)
log(INCOMING)	0.647 (***)	0.620 (***)	0.602 (***)	0.644 (***)
	(0.000)	(0.001)	(0.001)	(0.000)
log(EUCLKM)	-1.178 (***)	-1.052 (***)	-1.016 (***)	-1.184 (***)
	(0.001)	(0.001)	(0.001)	(0.001)
$PseudoR^2$	75.9%	71.7%	69.4%	78.2%
			Note:	*p<0.1; **p<0.05; ***p<0.01

Model: $glm(ceiling(FLOW)\ ORIGIN + log(INCOMING) + log(EUCLKM))$

The findings derived from our model shed light on several key aspects of the spatial interactions under investigation (See Table 4.5). Notably, we observe a significant positive effect of destination attractiveness, as evidenced by the estimated parameter λ, which is over 0.6 in every model. This suggests that factors contributing to the attractiveness of the destination exert a notable influence on the magnitude of flows. In practical terms, an increase in the factors associated with a destination's allure, such as job opportunities and remuneration, are associated with an overall rise in the volume of flows.

Consistent with expectations, our analysis reveals a negative distance decay parameter β, between -1 and -1.2. This finding indicates that as the distance from the borders increases, there is a corresponding decrease in the flows. In other words, spatial separation acts as a deterrent, dampening the intensity of interactions between

regions. This distance decay effect is in line with the general understanding that increased distance presents logistical challenges, time costs, and potential barriers to commuting, ultimately leading to a decline in flows as distance expands.

By comparing the distribution of the predicted and the observed flows (See Appendix, Figure 4.6), we can assess the model's performance in capturing the observed flow patterns. The plots indicate that the models tend to underestimate the flows to a certain extent. This observation is evident from the presence of numerous data points representing the observed flows that appear above the red line, which represents the predicted values, generated by the calculated parameters of the production-constrained models. The upward deviation of these points from the line suggests that the models consistently predict lower flow values compared to the observed values. This discrepancy between the predicted and observed flows highlights a potential limitation of the models and suggests that there might be additional factors or dynamics not captured by the current model framework.

Border Effects Indices

Based on the findings obtained from the production-constrained models discussed earlier, we proceeded to calculate the permeability index for each border, namely Belgium, Germany, Luxembourg, and Switzerland. This approach allowed us to examine the impact of each border individually, as they present distinct cases with varying characteristics. The resulting permeability indices provide a quantitative measure to discern the level of interaction between neighboring municipalities, highlighting the distinctive dynamics and flow patterns associated with each border.

Table 4.6: Border Effect Indices

	Belgium	Germany	Luxembourg	Switzerland
BPI	-1.33	-0.52	-0.66	-1.47
BFF	0.52	0.40	0.23	0.69

The permeability index for the Belgium-France border is remarkably low at -1.33, indicating a significant obstruction of flows and limited interaction between the municipalities located within 100km of this border, compared to the predictions of the production-constrained model. Similarly, the permeability index for the Swiss border stands at -1.47, indicating that the border acts as a significant obstacle for cross-border commuting flows. The permeability index for the German border is -0.52, suggesting a somewhat higher but still limited level of cross-border flows in the vicinity and a lower obstruction. The border between France and Luxembourg exhibits a slightly lower permeability index of -0.66, indicating a moderate level of interaction and flows between the municipalities within a 100km radius of this border.

The calculated permeability indices across all the studied borders reaffirm the existence of a strong border effect. While the permeability index for the Luxembourg and German borders is relatively higher compared to the other borders, suggesting a significant level of interaction, they are still not considered remarkably high. This observation, as well as their negative prefix, support the notion that borders act as barriers influencing the magnitude of flows. The presence of a border effect is evident, as the permeability indices indicate that the flows are significantly constrained by the borders. The considerably more negative values of the permeability indices for the remaining borders underscore the diminished cross-border interactions, highlighting the pronounced role of the border as a constraining factor. Had there been no border barrier, it is reasonable to expect that the flows would have been higher, illustrating the influence of borders on commuting patterns.

The second index we calculate is the border friction factor, derived from the outcomes of the production-constrained models. However, in this instance, we distinguish between flows directed towards France and flows directed towards the specific country corresponding to the examined border. By employing Equation 4.10, we calculate the border friction factor for every studied border. Remarkably, Luxembourg exhibits a significantly lower index of 0.23, compared to the other countries. Germany follows with a value of 0.40, while Belgium and Switzerland display higher indices of 0.52 and 0.69, respectively. These values highlight that the cost of travelling one additional km is higher across the border. However, crossing the border to reach Luxembourg has a lower cost, which could be attributed to the income and employment benefits that individuals get by reaching Luxembourg. These findings provide further evidence to the existence of a negative border effect.

4.5 Conclusions & Discussion

The aim of this chapter was to investigate the role of distance in relation to commuting patterns both within national borders and across international borders, while also quantifying the impact of borders on commuting flows. In this study, we employed a range of unconstrained models to examine the impact of distance on commuting flows, both within national borders and across them. Our findings consistently validate the negative association between distance and commuting flows, irrespective of whether they occur internally or cross the border. However, when comparing internal commutes within France with cross-border commutes, we observed a slightly stronger distance effect in the former case. This result highlights the nuanced influence of distance on commuting patterns, affirming our hypothesis.

Second, during the analysis, we confirm our hypothesis, by verifying the presence of a negative border effect. Borders were found to act as significant obstacles for cross-border commuters, hindering the flow of individuals across them. The border indices we calculated, provide empirical evidence of this border effect, highlighting the role of borders as barriers that affect the flow of commuters. The presence of this border effect is apparent, underscoring the significance of borders in shaping commuting dynamics and underscoring the impact they have on the overall flow patterns. Specifically, the borders with Belgium, Germany and Switzerland exhibited a notable limitation on interactions. In contrast, the border with Luxembourg showed a relatively higher level of interaction, albeit still considered limited. This can be attributed to the higher attractiveness of Luxembourg.

By calculating our second border effect index, the border friction factor, we go beyond solely examining the effect of flows and consider the effect of distance. This approach enables us to gain a more comprehensive understanding of the impact of borders on commuting patterns, taking into account the challenges posed by distance and how it affects the ease of cross-border movements in specific border zones. Overall when considering commuting flows originating from the border zone (100km from the border) the border of Luxembourg seems to be more easily crossed and more attractive. Once we controlled where individuals reside and where attractive employment can be found, Luxembourg is revealed as more a more attractive destination than Belgium, which seemed more attractive at first. From the analysis of the two border effect indices, we can draw the conclusion that borders indeed have a reducing effect on commuting flows, but they also reduce the marginal effect of distance. This implies that crossing a border tends to have a decreasing effect on the cost or effort associated with traveling longer distances.

Furthermore, the series of maps depicting various flow and distance thresholds provide valuable insights. It becomes evident that Luxembourg and Switzerland exhibit characteristics that align them with the French urban system. These regions consistently attract significant commuting flows, indicating their strong integration and connectivity with the surrounding areas, as we also confirmed with the calculation of the permeability indices.

Their prominent appearance across multiple thresholds reaffirms their status as integral components of the larger French urban network.

Methodologically, it is important to acknowledge the robust explanatory power of the spatial interaction models utilized in this study across diverse geographical contexts, thereby affirming their unquestionable capabilities. Nonetheless, it becomes apparent that conventional formulations often fall short in capturing the entirety of spatial interaction, particularly when regions of interest are intersected by linguistic, administrative or other types of borders. In such specific cases, it becomes imperative to take into account regional characteristics in the calibration of spatial interaction models, by the addition of supplementary independent variables, which can improve the models by increasing their explanatory power and enabling a more comprehensive understanding of the underlying dynamics. One variable that could be considered significant is the disparity in income between origins and destinations, which renders certain destinations more attractive. However, instead of explicitly incorporating additional attributes, we interpret them as a gain in reducing the distance effect.

Overall, this research contributes to our knowledge of commuting patterns, the impact of borders, and the importance of considering regional characteristics in spatial interaction models. It provides valuable insights for policymakers and planners in understanding the complexities of commuting dynamics and facilitating more efficient and effective transportation systems.

4.6 Appendix

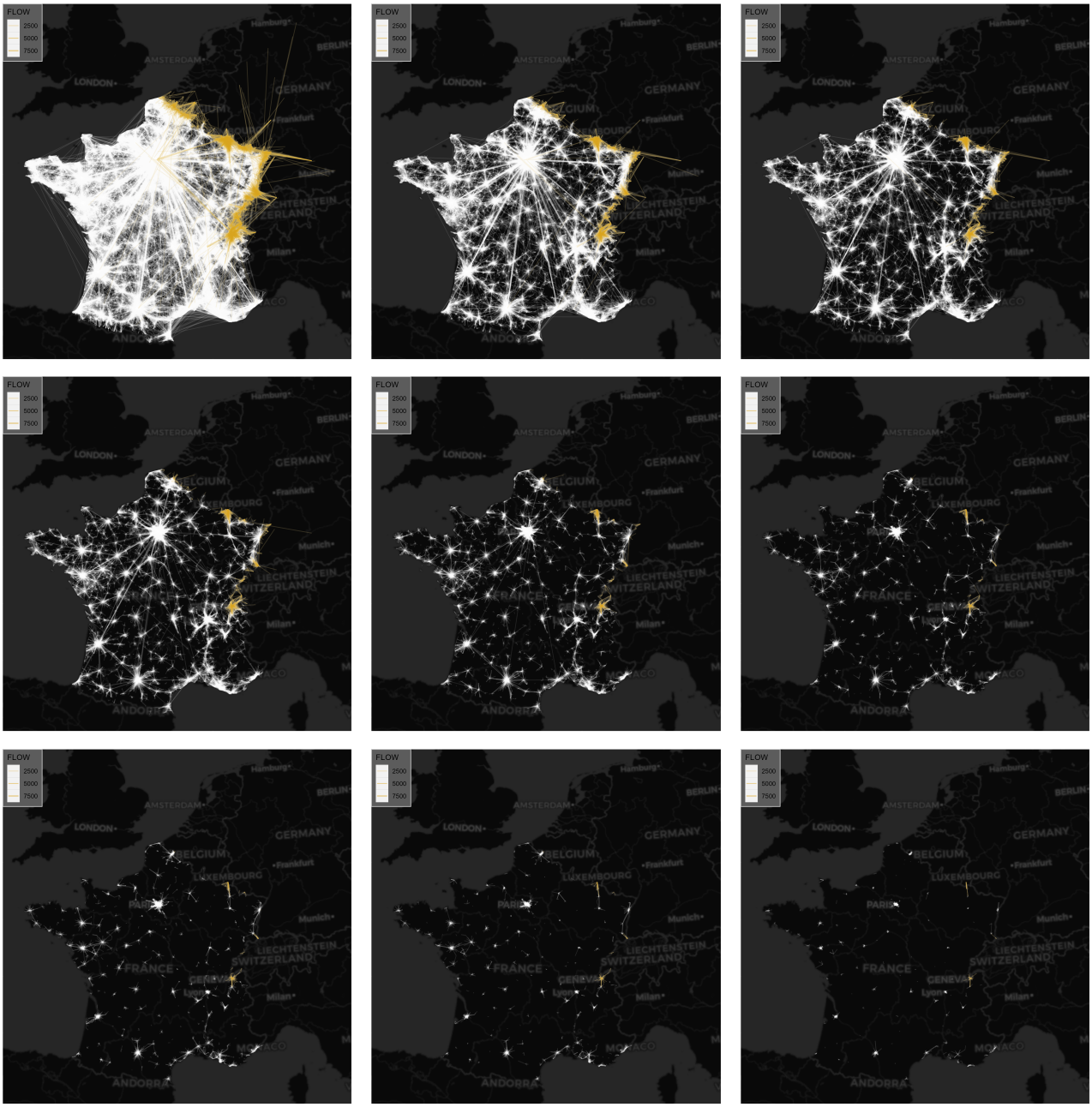

Figure 4.4: Flows from origins to destinations ($Flows \geq 10, 20, 30, 50, 100, 200, 300, 500, 1000$)

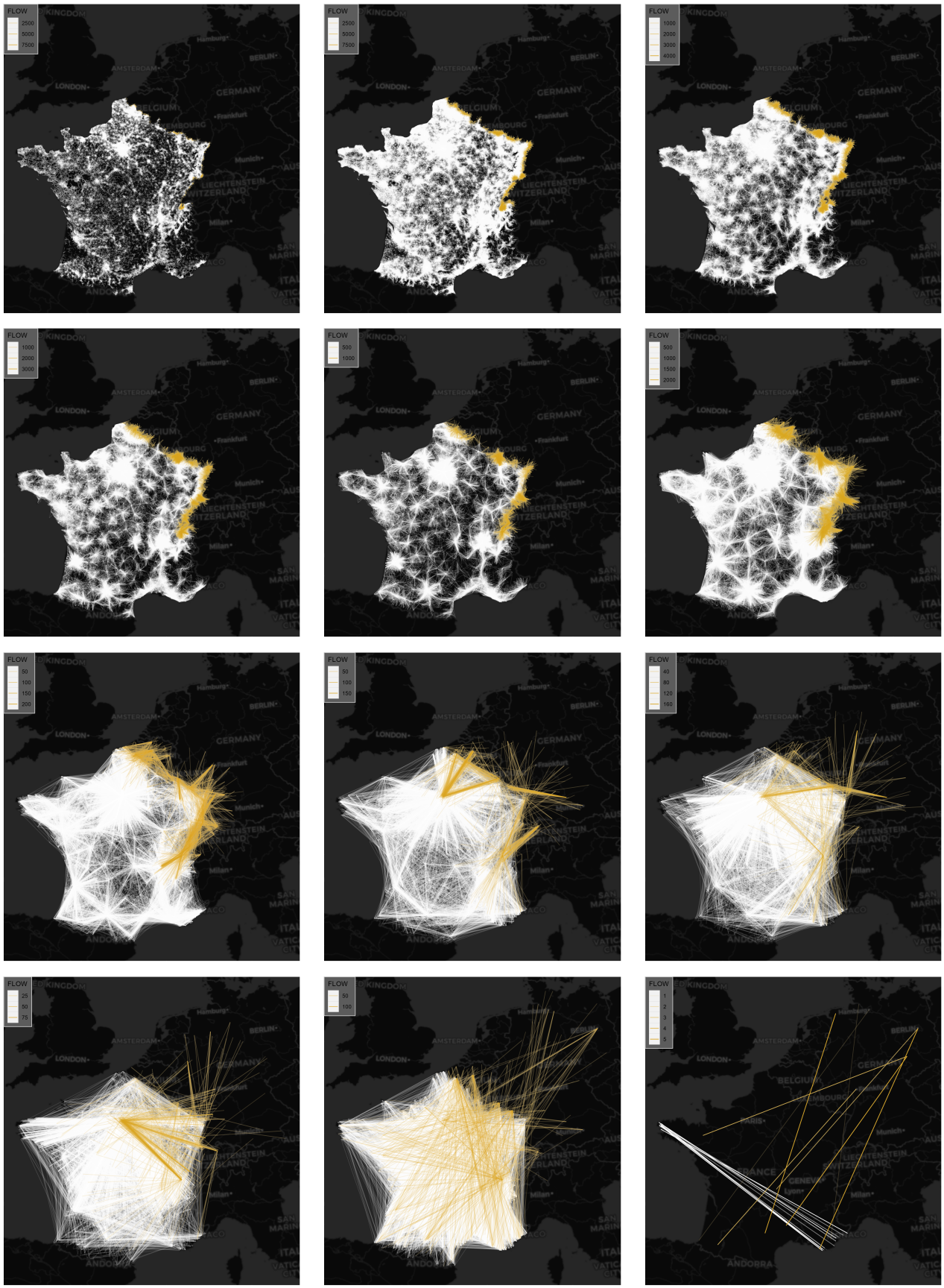

Figure 4.5: Flows from origins to destinations ($Distance \leq 10km, 10-20km, 20-30km, 30-40km, 40-50km, 50-100km, 100-200km, 200-300km, 300-400km, 400-500km, 500-1000km, \geq 1000km$)

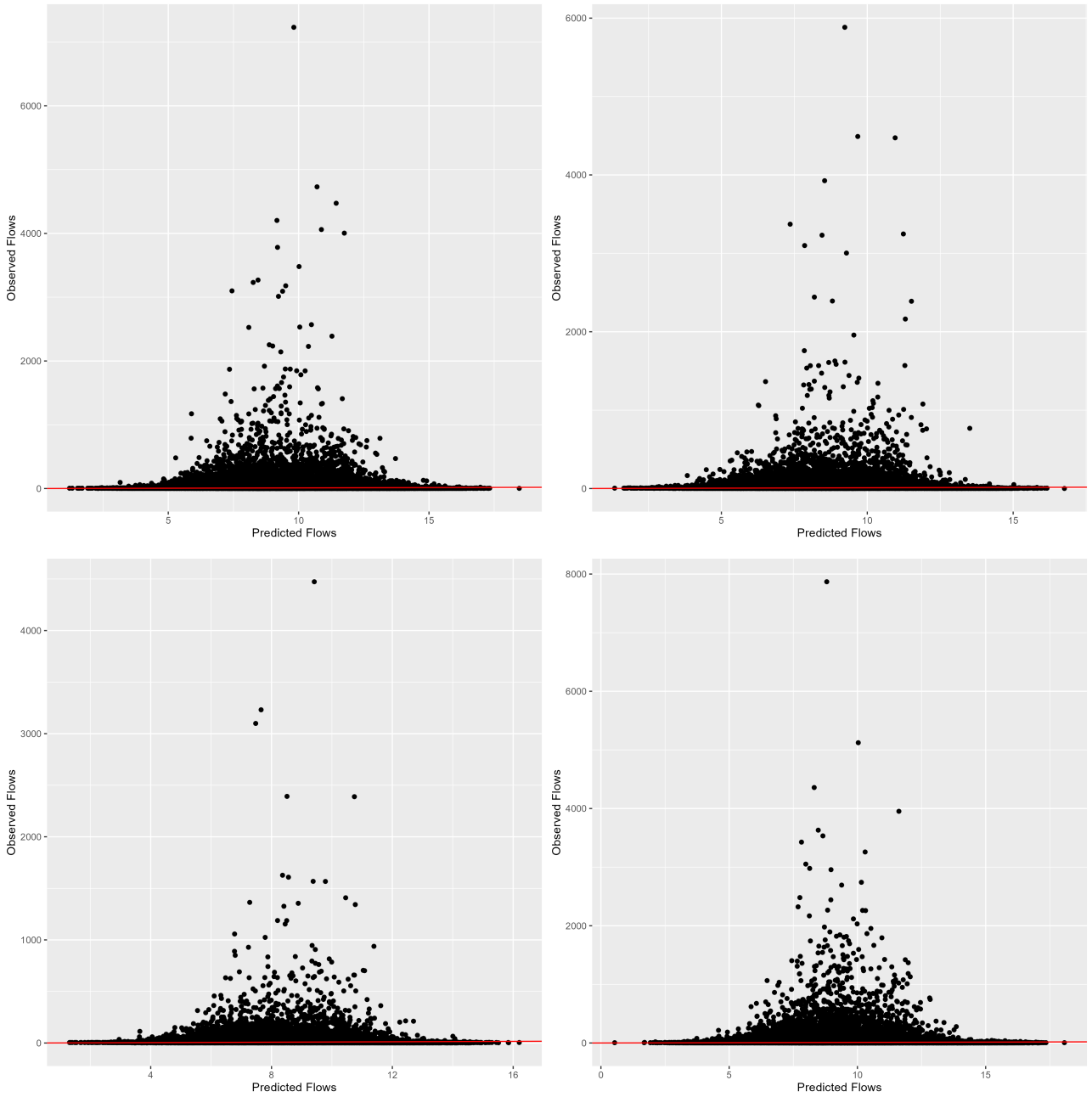

Figure 4.6: Observed (points) and predicted flows (red line) (Belgium, Germany, Luxembourg, Switzerland)

Chapter 5

Cross-border commuting distance from France: individual and geographical determinants

Abstract: The everyday movement of people, especially commuting, has significant social and environmental consequences. It is crucial to comprehend these mobility patterns for effective urban and transportation planning. The growing acceptance of teleworking in recent years has altered the perception of distance, enabling commuters to consider residential options farther away from their workplaces to reap various advantages. In border regions, where disparities in income and social benefits exist between countries, these changes may lead to even more notable transformations in commuting behaviors and patterns. Given the current lack of robust post-COVID data, we explore cross-border commuting distance before the pandemic. More precisely, in this paper we study the determinants of cross-border commuting distance at an individual level. The aim of the chapter is to quantify the factors that affect the cross-border commuting distance chosen or accepted. To that end, we employ regression analyses in a global and a local scale.

5.1 Introduction

Commuting addresses spatial disparities in job opportunities and housing quality between the place of residence and work. Transportation improvements have made commuting more accessible, allowing individuals to seek more attractive employment opportunities (in terms of working conditions, wages, benefits or employment sector) (Clark and Davies Withers, 1999; Van Ommeren and Rietveld, 2005; Gottholmseder and Theurl, 2007; Sandow and Westin, 2010; Vincent-Geslin and Ravalet, 2016) within varying distances. The acceptable commuting distance is influenced by a range of factors, including individual and geographical characteristics. In the European Union, approximately 20% of commuters travel an average distance of 29km to reach their workplaces (Giménez-Nadal et al., 2022). Longer commutes can have individual (time, expenses and health (Hansson et al., 2011)) and societal costs (congestion and environmental cost (Abrahamse et al., 2009)), which sustainability-focused policies aim to reduce, mainly by promoting public transport use (Chowdhury et al., 2018; Liu et al., 2016). However, residential choice parameters come into play, making the decision more complex.

However, there exists a significant number of more intricate cases, primarily concentrated in Europe, where individuals choose to reside in one country while working in another, primarily in border regions. In the European Union, approximately 1.4 million individuals, accounting for around 0.6% of all employed individuals, are cross-border commuters (European Commission, 2017). Approximately 40% of the EU28 population lives in a border region (Medeiros, 2019), which is typically defined at an aggregate administrative level (NUTS2). Notably, France is the country with the highest number of out-cross-border commuters (438,000) (EUROSTAT, 2015, Labour Force Survey), most of whom reside within a maximum distance of 50km from a border.

The recent COVID-19 pandemic has had a significant impact on commuting behaviors (Rüger et al., 2021), with the implementation of teleworking and hybrid work, serving as alternatives to regular on-site presence. This shift has allowed many individuals to decrease their weekly commuting time. As commuting becomes less frequent, the distance between workplaces and residences may become less of a burden, potentially leading to an overall increase in commuting distance while maintaining a similar total amount of time spent commuting (Rüger et al., 2021).

The changing commuting trends highlight a shift in the role of distance. With commuting becoming less frequent on a daily basis, it is anticipated that long-distance and cross-border commuting flows may witness an increase in the future. In this chapter, given the lack of stable data on commuting flows after the start of the pandemic, we aim to establish a benchmark and investigate the determinants that affect cross-border commuting distance, at an individual level. Specifically, we examine the determinants that lead individuals to commute closer to or further away from their residential location. In order to accomplish this, we employ an Ordinary Least Square Regression (OLS) approach at first and then a Geographically Weighted Regression (GWR) approach which enable us to identify the determinants of commuting distance at a global and local level respectively. We then examine the connection between commuting distance and being a cross-border commuter.

The chapter is structured as follows. First, we explore the relevant literature (Section 5.2), then, in Section 5.3, we describe our data and the methodologies we implemented. In Section 5.4, we present the results of our analyses using the different methodologies. In Section 5.5, we present our conclusions and extend the discussion. Finally, we include supplementary material in the Appendix.

5.2 Background Literature

In this section, we aim to stress the current state of the art in terms of cross-border commuting and its determinants, as well as about the studied role of distance.

5.2.1 Determinants of cross-border commuting

Chapters 2 and 3 of this dissertation delve into the investigation of the factors influencing cross-border commuting. In Chapter 2, we extensively review the existing literature to identify key determinants of cross-border commuting. Building upon this foundation, Chapter 3 presents the findings from our own data analysis, which shed light on the intricate interplay of individual and geographical factors that shape cross-border commuting flows.

As far as individual factors are concerned men in the age group 30-50, with a higher level of education consist the majority of cross-border commuters. Furthermore, working in the industrial sector and being a home and car owner increase the possibility to become a cross-border commuter. Moreover, living alone or without immediate family members requiring care, such as children or elderly relatives, increases the likelihood of becoming a cross-border commuter, as well.

When examining the geographical determinants of cross-border commuting, several notable patterns emerge. Firstly, residing in an isolated municipality, which is situated far from a business center, increases cross-border commuting. Similarly, the availability of job opportunities within the vicinity of the individual's residence plays a crucial role. A lower number of job opportunities in the immediate vicinity encourages individuals to look beyond their local area, potentially leading to cross-border commuting.Additionally, the distance to the border emerges as a significant determinant of cross-border commuting. Closer proximity to the border facilitates the flow of cross-border commuters, as it reduces travel time and potentially lowers transportation costs (see also Chapter 4).

5.2.2 Commuting distance

The commuting distance and time that people are willing to accept is essential in the decision to become a cross-border commuter. Research indicates that approximately 20% of commuters within the European Union travel an average distance of around 29km to reach their workplaces (Giménez-Nadal et al., 2022). Looking at specific countries, in Belgium, the average commuting distance is around 20km (Boussauw et al., 2012; Persyn and Torfs, 2016) while in Northern Sweden, it stands at approximately 27km (Sandow, 2008). Based on our findings presented in Chapter 4, we have confirmed that the average commuting distance in France is approximately 23km, regardless of the destination. However, when specifically considering cross-border commuters, we have identified a visible increase in the average commuting distance, ranging from 32km to 58km, depending on the specific border region.

Considering time, according to Eurostat (2020), more than 60% of European commuters had an average one-way commuting time of less than 30 minutes in 2019. This statistic highlights the prevalence of relatively short commuting durations among a significant majority of commuters across Europe. In contrast, 26.3% of individuals reported commuting times ranging from 30 minutes to one hour, indicating a substantial portion of the population that endures a longer commute. Only 8.1% of commuters had a commuting time of 60 minutes or more, suggesting that extended commuting durations are less common. Additionally, a small proportion of workers (4.3%) did not have to travel at all to reach their primary workplace, hinting at self-employment or

teleworking. Interestingly, the commuting times of cross-border commuters tend to align more closely with inter-city commuting times (Möller et al., 2018).

Transport mode and congestion levels play a crucial role in shaping commuting trips, either by facilitating them or by making them more difficult. This influence is particularly significant in the context of cross-border commuting, where the connectivity between neighboring countries becomes a crucial factor to consider. The availability and efficiency of cross-border public transport systems, as well as the quality and capacity of road infrastructure, greatly impact the feasibility and attractiveness of cross-border commuting options (Medeiros, 2018). Efficient cross-border transportation networks not only enhance the accessibility and mobility of cross-border commuters but also contribute to the overall integration and cooperation between neighboring regions or countries (Decoville and Durand, 2016).

5.2.3 GWR for studying commuting

Given this background, our study aims to make a valuable contribution to the field of cross-border commuting literature by filling a notable research gap. Specifically, we seek to examine the determinants of distance between residence and workplace (origin and destination). To this end, we employ two complementary approaches: an OLS analysis to capture the overall relationships, followed by a GWR approach that incorporates the geographical context of the data.

Geographically Weighted Regressions have been used for a variety of different applications. Such applications include the study of the factors influencing COVID-19 deaths (Grekousis et al., 2022), haze pollution (Zhou et al., 2019), fertility (Tsimpanos et al., 2018), carbon footprint (Wang et al., 2014) and landslide susceptibility (Chalkias et al., 2011), among others.

Close to our approach, Lloyd and Shuttleworth (2005) conducted a study in Northern Ireland, investigating the relationship between commuting distance and socio-economic factors. However, their study focused solely on commuting within Northern Ireland and did not consider the element of crossing national borders, which is an important aspect of our research. Additionally, their study utilized aggregated data, while our study utilizes individual-level data, allowing for a more detailed analysis. Furthermore, the independent variables used in their study differ from ours. Nevertheless, their findings indicate that employment accessibility and deprivation are significant factors influencing commuting distance (negative and positive effect respectively).

In the same framework, GWR has been employed in different applications exploring a variety of scenarios, regarding commuting, but not cross-border commuting. For instance, Bai et al. (2020) explore extreme commuting in Puget Sound, USA and identified urban land-use planning as a significant factor in explaining extreme commuting patterns. Jang et al. (2021) examine the effect of socio-economic characteristics on the selected transport modes in an urban setting, revealing a correlation between sustainable commuting patterns and lower income levels. In a different context, Cheng and Fotheringham (2013) explored the determinants of educational level on both sides of the international border between Northern Ireland and the Republic of Ireland, but their study did not take into account commuting.

5.3 Data and Methods

5.3.1 Data

To conduct our study, we utilized data from the year 2016 obtained from the French National Institute of Statistics and Economic Studies (INSEE). The dataset focused on individuals who were employed and resided in the

border regions of France (it is the same dataset used in Chapter 3 - Mobilités Professionnelles, 2016). We defined the border facade by identifying municipalities where the Euclidean distance between the commune's centroid and the nearest national border line was less than 50km. This 50km threshold was chosen as, according to previous research, the majority of cross-border commuters live within that zone (Pigeron-Piroth et al., 2018). Within this framework, our analysis specifically focused on cross-border commuters as they constituted the target group for our study. We found that, on average, 14.8% of the commuters residing in the border facade were cross-border commuters. Interestingly, as we moved closer to the border, the proportion of cross-border commuters increased.

In our study, the dependent variable we focus on is the distance in km between individuals' residences and their workplaces. To explore the factors influencing commuting distance, we categorize the explanatory variables into two main groups: Individual and household variables and urban geography variables.

Within the individual and household variables category, we consider a range of factors, including gender, age group, education level, types of jobs, employment sectors, household composition, car availability (at least one car available per household), and housing status. These variables help capture individual characteristics and household dynamics that may impact commuting distance.

In addition, we incorporate urban geography variables to account for the spatial context. These variables include the typology of the residential area, simplified as isolated municipality or not (which includes urban areas and multi-polarized municipalities). Furthermore, we assess the availability of jobs within a 25km radius around the individual's place of residence. These urban geography variables offer insights into the local job market and the proximity of employment opportunities to residential areas. The third independent variable we add is the distance to the nearest border, in km. Finally, we also include the border zone variable, indicating the zone to which each municipality belongs. However, in the final model, we choose to remove this variable to avoid imposing constraints on the zones. Lastly, we examine the relationship between commuting distance and cross-border commuting.

By incorporating these comprehensive sets of variables gradually, we aim to provide a thorough analysis of the factors influencing commuting distance and gain a deeper understanding of the dynamics at play in the study area.

5.3.2 Methods

In this study, we use two different regression types in order to study the determinants of commuting distance. In order to gain a better understanding into the effects in the border facade of France, we use global and local regression methods.

Global methods - OLS

The Ordinary Least Square (OLS) regression method is widely recognized as one of the most commonly utilized models for analyzing multiple variables (Zuo et al., 2020; Zhu et al., 2020). Its primary advantage lies in its ability to explore the degree and significance of statistical relationships between one dependent variable and one or more independent variables, employing a single equation. This is expressed by the following multiple regression formula:

$$y_i = \beta_0 + \beta_1 x_{1i} + ... + \beta_k x_{ki} + \epsilon_i \tag{5.1}$$

where y is the dependent variable, β_0 is the intercept of the model, $x_{1i}...x_{ki}$ are the k independent explanatory variables, $\beta_1...\beta_k$ are the coefficients of the variables x and ϵ_i is the random error with expectation 0 and variance σ^2 (Tsimpanos et al., 2018).

The OLS models are global models, which means that the estimated coefficients are assumed to homogenous across the study area. However, spatial data often exhibit significant local variations in the relationships between the variables under investigation (Wang et al., 2014; Zuo et al., 2020). This implies that the data may display spatial autocorrelation, whereby the values of a variable at nearby locations are correlated. The presence of spatial autocorrelation violates the null hypothesis of the OLS model (Zuo et al., 2020). To address this issue and avoid obtaining unsatisfactory results due to spatial dependence and heterogeneity in the data, it is recommended to employ models that account for spatial factors rather than relying solely on global models (Wang et al., 2014; Zuo et al., 2020).

In this study, we employ a two-stage approach to analyze our data. In the first stage, we conduct an OLS regression analysis, gradually introducing additional variables to explore their relationship with the dependent variable. Building upon this, in the second stage, we repeat the OLS regression analysis, but this time, we utilize the logarithm of the dependent variable. By taking the logarithm, we aim to linearize the relationship between the dependent and independent variables. This transformation enables us to make the results more generalizable and simplifies the analysis process.

Local methods - GWR

As mentioned previously, spatial data may require the utilization of local regression models, in order to address spatial autocorrelation. Local models are particularly valuable in capturing spatial variations by acknowledging that the relationships between variables vary across different regions. The Geographically Weighted Regression (GWR) model was specifically designed to accommodate this variability by estimating the relationship between the dependent and the independent variables for each distinct geographical point (Tsimpanos et al., 2018). Building upon Equation 5.1, the formula for the GWR model is:

$$y_i = \beta_0(u_i, v_i) + \beta_1(u_i, v_i)x_{1i} + ... + \beta_k(u_i, v_i)x_{ki} + \epsilon_i \tag{5.2}$$

where (u_i, v_i) are the coordinates in space of point i (Tsimpanos et al., 2018).

Drawing upon Tobler's First Law of Geography, which indicates that proximity creates notably stronger correlations, the local model incorporates weights to account for this proximity effect (Tsimpanos et al., 2018; Li and Niu, 2022). Consequently, observations are assigned weights, with those closer to point i exerting a stronger influence on the estimation compared to those in a greater distance (Lloyd and Shuttleworth, 2005; Tsimpanos et al., 2018). The weights are derived using a kernel function, which can be either fixed (with the same bandwidth regardless of neighbouring point density) or adaptive (taking into account the k nearest neighbours). The latter adjusts the bandwidth based on the number of neighbours, resulting in larger kernels in sparser data regions and smaller kernels in denser ones (Tsimpanos et al., 2018; Zuo et al., 2020). In our model we employ the b-square weight function, to ensure more efficient computations, using the following equation:

$$w_{ij} = \{_0^{[1-(d_{ij}/h_i)^2]^2},\ if\ d_{ij} \leq h_i \tag{5.3}$$

where w_{ij} is the weight of the observation j at the point i, d_{ij} is the distance between points i and j and h_i is the bandwidth (the distance from point i to the Nth nearest neighbor of i) (Wang et al., 2014; Tsimpanos et al., 2018).

The optimal bandwidth size can be determined by minimizing the corrected Akaike Information Criterion (Li and Niu, 2022), using the formula:

$$AIC_c = 2nln(\hat{\sigma}) + nln(2\pi) + n[(n + tr(S))/(n - 2 - tr(S))] \tag{5.4}$$

where n is the number of observations, $\hat{\sigma}$ is the estimated standard deviation of the residuals and $tr(S)$ is the trace of the GWR hat matrix (the sum of the diagonal of the weight matrix) (Tsimpanos et al., 2018).

Following the OLS approach, our investigation delves into GWR analysis, by incorporating the selected geographical independent variables. However, in this case, the dependent variable that we use consists of the residuals derived from the logarithmic OLS model (we chose the logarithmic model due to its higher explanatory power). The decision to use the residuals of the OLS model stems from the fact that the explanatory power of the OLS model is limited. Thus, our goal is to explore the factors that contribute to the unexplained variation in the dependent variable. By using the residuals as the dependent variable, we are essentially focusing on what remains unaccounted for by the OLS model. Due to the fact that our dataset consists of a significant number of records, the calibration of the GWR model appeared to be exceptionally time consuming. To that end, we created multiple random samples of a smaller number of records. Specifically, we modeled 100 random samples of 100,000 observations, following the Monte Carlo simulation approach. We used these samples to calibrate the GWR, we calculated the average of the global coefficients and the minimum and maximum of all the results. The multiple random samples were merged into one single data frame, in order to be analyzed and visualized.

5.4 Results

5.4.1 OLS for Individual effects

The first step in the analysis involves implementing OLS models using only individual and household characteristics. [1] The results reveal that the model incorporating the logarithm of the dependent variable exhibits higher explanatory power. The R^2 increases from 1.4% in the non-log model to 4% in the log model.

According to the findings, and as hypothesized, being female has a more pronounced negative effect on commuting distance compared to being male. Additionally, belonging to either a very low or very high age group has a stronger negative impact, as well. Being employed in a managerial position or an intermediate profession potentially increases commuting distance in comparison to being a worker. Employment in the Construction and Industry sectors also contributes to an increase in commuting distance. This suggests that certain sectors may concentrate employment opportunities in locations that require longer travel for workers. Notably, possessing any type of diploma has a positive effect on commuting distance. Furthermore, having access to a car increases the likelihood of a longer commute. This aligns with the notion that individuals with access to personal transportation are more likely to consider commuting over longer distances, as they have the means to do so.

As was expected, being in a household with more than three individuals (potentially indicating the presence of children) decreases commuting distance. However, surprisingly, being in a single-person household, also, leads to a decrease in distance compared to a household with only two individuals. This could be attributed to factors such as lifestyle preferences or proximity to work. Individuals living alone may prefer living closer to their workplaces, and not seek for amenities (i.e. housing or environmental) that larger households may require.

[1] For a more comprehensive analysis with all variables, including geographical factors, refer to the Appendix.

Table 5.1: Results of OLS models of Individual variables

	Model 1	Model 2 (Log of Dependent variable)
(Intercept)	28.708 (***)	2.548 (***)
	(0.343)	(0.005)
Female	-8.584 (***)	-0.209 (***)
	(0.153)	(0.002)
15-19 (ref=20-29)	-2.482 (***)	-0.123 (***)
	(0.586)	(0.009)
30-39	-2.728 (***)	-0.037 (***)
	(0.213)	(0.003)
40-49	-1.763 (***)	-0.055 (***)
	(0.215)	(0.003)
50-59	-1.334 (***)	-0.099 (***)
	(0.228)	(0.004)
60-69	3.386 (***)	-0.068 (***)
	(0.402)	(0.006)
Farmers (ref=workers)	-0.541	-0.140 (***)
	(1.728)	(0.028)
Artisans	0.998 (**)	-0.157 (***)
	(0.382)	(0.006)
Management employees	12.415 (***)	0.200 (***)
	(0.266)	(0.004)
Self-employed managers	7.544 (***)	-0.096 (***)
	(0.631)	(0.010)
Intermediate professions	4.660 (***)	0.075 (***)
	(0.220)	(0.004)
Employees	2.378 (***)	-0.007 (*)
	(0.220)	(0.004)
Prof. Diploma (ref=No Diploma)	-0.283	0.039 (***)
	(0.234)	(0.004)
Secondary Education	1.736 (***)	0.088 (***)
	(0.251)	(0.004)
High Degree	3.656 (***)	0.143 (***)
	(0.254)	(0.004)
1 pers (ref=2 in the household)	-0.129	-0.054 (***)
	(0.228)	(0.004)
3 and +	-0.266	-0.012 (***)
	(0.166)	(0.003)
Tenants (ref=Owners)	0.019	-0.059 (***)
	(0.179)	(0.003)
Low-cost tenants	-3.096 (***)	-0.234 (***)
	(0.245)	(0.004)
At least one car/employee (ref=FALSE)	-3.860 (***)	0.054 (***)
	(0.174)	(0.003)
Agriculture (ref=Trade, Transport, Serv.)	-3.135 (***)	-0.099 (***)
	(0.948)	(0.015)
Industry	-2.512 (***)	0.001
	(0.198)	(0.003)
Construction	-0.345	0.062 (***)
	(0.291)	(0.005)
Public Admin, Educ., Health	-4.903 (***)	-0.123 (***)
	(0.167)	(0.003)
R^2	1.434%	4.017%

Note: *p<0.1; **p<0.05; ***p<0.01

As anticipated, being a tenant negatively affects commuting distance, as opposed to being a homeowner. Especially being a low-cost tenant has the strongest negative effect in the model, indicating either the greater flexibility of low-cost tenants, or their preference for seeking employment opportunities in close proximity to their residence, possibly to minimize the financial burden associated with longer commutes. Homeowners may be more reluctant to relocate due to homeownership commitments, leading them to accept longer commutes for the sake of stability. On the other hand, renters may have more flexibility in choosing their place of residence, allowing them to live closer to their workplaces.

5.4.2 GWR for Geographical effects

The analysis of the previous model reveals that the selected independent variables account for only a small portion, 4%, of the variability in commuting distance. This suggests that there are other influential factors at play that are not captured by the chosen variables. To explore this remaining effect and gain further insights, we turn our attention to the residuals of the OLS model. By extracting the residuals, we can examine the unexplained variation of commuting distance and investigate whether geographic factors play a role in shaping this residual variability. Specifically, we focus on the previously used variables job availability within a 25km zone of the municipality of residence, distance to the nearest border and whether the municipality of residence is Isolated or not. These geographic variables are expected to provide additional explanatory power and shed light on the factors that go beyond individual and household characteristics. The motivation behind employing GWR is to account for the spatial heterogeneity in the relationship between the geographical variables and the residuals. This approach recognizes that the impact of these variables may differ across different locations within the study area.

Prior to implementing GWR, we observed that one out of the three independent variables exhibited a notably low variance of unique observations, since it is a categorical variable. Consequently, we conducted an assessment for multicollinearity by calculating the Pearson Correlation Coefficients. The results indicated no significant correlation among the independent variables, affirming their suitability for inclusion in the GWR model.

Table 5.2: Results of Pearson's Correlation Coefficients

	Job availability	Distance to the nearest border	Isolated Municipality
Job availability	1.000	0.116	-0.203
Distance to the nearest border	0.116	1.000	-0.083
Isolated Municipality	-0.203	-0.083	1.000

Table 5.3 presents the global results of the GWR analysis [2]. The model exhibits a notably low overall explanatory power, as indicated by an R^2 value of approximately 2.807%. While the decrease in the R^2 value suggests that the GWR model explains a slightly smaller proportion of the variability in the residuals, it is important to note that GWR focuses on capturing the local spatial variations in the relationship between the geographical variables and the residuals.

The results of the analysis reveal that the presence of available job opportunities within a 25km radius of the municipality of residence has a significant negative effect on commuting distance. This finding aligns with the dynamics of labor markets surrounding individuals' residential locations. When there are multiple job

[2]The residuals of the OLS model with logarithmic dependent variable. For the results of the analysis using residuals of OLS model with the non logarithmic dependent variable, refer to Appendix.

Table 5.3: Global results of GWR model of Residuals for Geographical variables

(Intercept)	-0.196
	(0.096)
Job availability	-0.686 (***)
	(0.060)
Distance to the nearest border	0.064 (***)
	(0.009)
Isolated Municipality	0.494 (***)
	(0.055)
R^2	2.807%
$AICc$	$26,873.514$
	Note: *p<0.1; **p<0.05; ***p<0.01
	∗Log of Dependent variable

prospects nearby, individuals are less inclined to seek employment at greater distances. Residing in an Isolated municipality has a significant positive effect on the commuting distance. This finding was expected, since individuals residing in isolated municipalities, are located at a greater distance from major employment poles and are, thus, compelled to travel longer distances to reach their workplaces. Furthermore, the analysis reveals a positive relationship between commuting distance and the distance to the nearest border. As the distance to the nearest border increases, commuting distance also tends to increase. This finding suggests the presence of a significant number of cross-border commuters within the study area.

Table 5.4: Results of the local estimates of the GWR model

	Minimum	Maximum	Median
Job availability	-1.502	0.011	-0.794
Distance to the nearest border	-0.046	0.236	0.059
Isolated Municipality	0.063	1.169	0.515
$AICc$			$26,469.701$

Upon examining the local effects of the independent variables, we observe significant variations across different locations for job availability. The global effect of job availability, which is negative, aligns with the median effect observed in the local variations. However, it is worth noting that the variable can also have positive (but notably weak) effects on commuting distances in certain locations. This implies that there are cases where individuals are willing to accept longer commutes in pursuit of attractive job opportunities located further away. These situations may arise due to personal preferences, the desire for career advancement, or the unavailability of suitable job options within a closer proximity.

As far as residing in an Isolated municipality is concerned, the median of the local variation aligns with the global estimate, indicating a significant positive impact on commuting distance. In this case, the variable doesn't exhibit any negative local effects, as even the minimum effect remains positive, albeit relatively weaker. This implies that across all scenarios, living in an Isolated municipality consistently elevates commuting distance, with variations spanning from modest to substantial increases.

Finally, the median effect of the distance to the nearest border aligns with the global estimate, indicating a positive, albeit weak, influence on commuting distance. This suggests that, on average, individuals residing at greater distances from the border tend to experience longer commuting distances. However, it is important to acknowledge that the local effects of the distance to the nearest border can also result in a decrease in commuting

distance in certain locations. This can be an indication of the presence of urban areas further from the borders, which provide significant employment opportunities in close proximity. Thus, individuals residing in such locations can benefit from easy access to nearby labor markets, resulting in shorter commuting distances.

These findings highlight the importance of considering the spatial context and local variations when studying the effects of different variables on commuting distances. Despite the marginal decrease in the overall explanatory power, the GWR approach offers a more refined understanding of the local dynamics influencing commuting distances. The high AICc values of the model could be attributed to the units of some variables (inconsistency and wide range) or to the high spatial heterogeneity.

Local Coefficients per municipality

In order to visualize the local coefficients of the independent variables within the context of individual-level data, we computed the average coefficient value for each municipality. The resulting maps unveil interesting insights. Notably, the average local coefficients associated with job availability appear predominantly negative across all municipalities. This negativity exhibits a stronger influence along the Italian border and a comparatively milder effect around the Swiss border. This phenomenon could be attributed to the predominant employment sectors in the different border regions. Job availability near the Swiss border seems to decrease commuting distance the least, likely because Switzerland serves as a more appealing cross-border destination. As a result, individuals might willingly endure longer commutes to reach Switzerland. However, job availability close to Italy decreases commuting distance significantly, indicating that crossing the border into Italy might not be as attractive.

On the other hand, the average local coefficients depicting the impact of residing in an Isolated municipality exhibit a consistent positive trend across the entire study region. The influence is more subtle in certain areas, particularly near the German border, while it becomes more pronounced adjacent to the Spanish border. This observation signifies that living in an Isolated municipality in close proximity to the Spanish border leads to a notable increase in commuting distance. This phenomenon can be comprehended through the lens of local geography, where the specific topographical features might contribute to extended commutes. However, the situation differs near the German border, as well as neighboring countries like Switzerland, Luxembourg, Belgium, and Italy. In these instances, the effect of residing in an Isolated municipality on commuting distance is comparatively subdued. This contrast could be attributed to the smoother terrain and enhanced transportation connectivity between France and these neighboring countries.

Finally, the average local coefficients for the distance to the nearest border appear to be mainly positive, with the exception of the first category. The lowest (even negative) effects of the variable can be found near Belgium and Spain. This suggests that greater distance from the border doesn't necessarily equate to an increase in commuting distance within these areas, possibly implying a reduced level of cross-border interaction. However, a different pattern emerges in proximity to the borders of Italy and Switzerland. Here, the distance to the border exhibits its most pronounced effect (albeit not significantly high). This might imply the presence of geographic obstacles or other factors that subtly shape commuting dynamics in these specific zones.

The border zones that emerge from the visual representation of the average local coefficients, closely align with the geographical regions we defined in Chapter 3. This correlation acts as significant confirmation, strengthening the idea that how close individuals are to different countries has complex and diverse effects on their choices for both internal and cross-border commuting. This agreement also highlights the complex geographical factors involved and provides empirical support for the unique influences of neighboring countries on people's commuting choices.

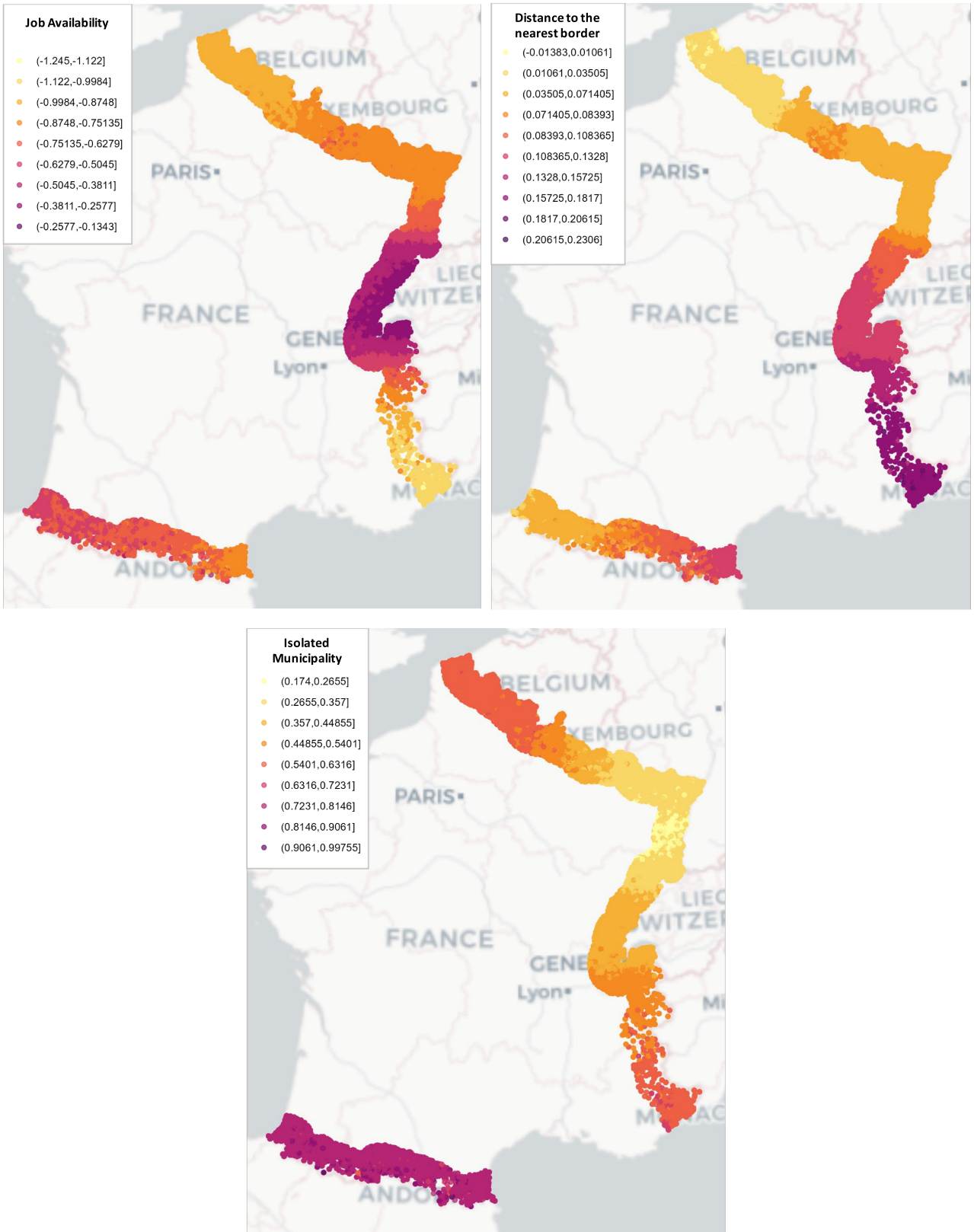

Figure 5.1: Local coefficients of independent variables (Average per municipality)

Residuals

To assess whether the GWR model tends to overestimate or underestimate commuting distances, we visualize the model residuals. Residuals represent the disparities between observed data and the model's predictions. Within the framework of GWR, these residuals are computed at the local level for various spatial locations. Since our GWR model employs sampling techniques, we collect residuals from each sample model and calculate the individual-level averages.

Analyzing the residuals map reveals some key insights. The majority of residuals indicate a slight underestimation of predicted values (manifesting as negative values). Conversely, many values exhibit a slight overestimation (tending towards positive values, albeit close to zero and one). Notably, only a handful of values display more substantial over-estimations. This suggests that the model's fit closely aligns with actual commuting distances for the sampled individuals.

In order to delve into the cross-border commuting dynamics, we scrutinize the residuals in relation to individuals' cross-border commuting status. Specifically, we explore overestimation or underestimation based on whether individuals engage in cross-border commuting or not. We then calculate the average residuals separately for these two commuting categories. This classification allows us to examine whether there are significant differences in the model's performance for these two distinct commuting groups. By doing this, we gain insights into how well our model performs for these two distinct groups of commuters. It helps us understand whether the model tends to overestimate or underestimate commuting distances differently for cross-border and non-cross-border commuters. This level of granularity in our analysis allows us to tailor our interpretations and recommendations to better suit the specific needs and behaviors of these commuting subgroups. Notably, the map reveals that commuting distances are slightly underestimated for cross-border commuters, while internal commuters experience significant overestimation.

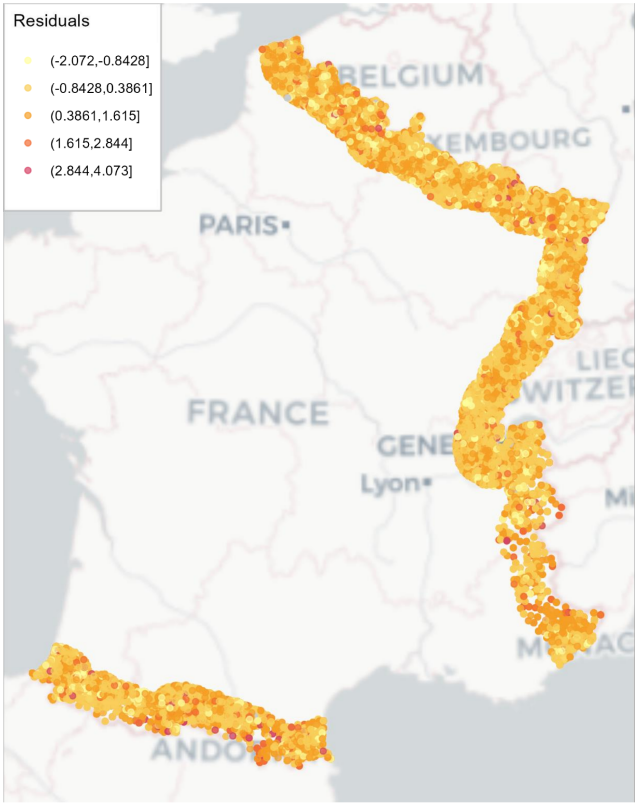

Figure 5.2: Residuals of GWR model

Figure 5.3: Over- or under-estimation of being a cross-border commuter (red: CDC, blue: Non-CBC)

5.5 Conclusions & Discussion

In this chapter, our objective is to delve into the factors that shape commuting distance in the border facade of France. To that end, we employ OLS regressions, to explore the individual and geographical determinants involved. Building upon this initial investigation, we further investigate the geographical determinants at a local level using Geographically Weighted Regression (GWR). The rationale behind incorporating GWR into our analysis is to acknowledge and account for the spatial heterogeneity inherent in the relationship between the geographical variables and the residuals. Traditional regression models assume a constant relationship between variables throughout the study area. However, in the context of commuting distance, it is reasonable to expect that the influence of geographical factors can vary across different locations within the study area. By embracing GWR, we can gain a deeper understanding of the local dynamics that shape commuting distance and uncover spatially varying relationships.

The findings highlight the importance of considering the spatial context and local variations when studying the effects of different variables on commuting distances. The analysis underscores the importance of considering not only the proximity to job opportunities but also the proximity to the border, as well as the unique characteristics of different types of municipalities in understanding commuting behavior. Our results suggest that the presence of available jobs within a 25km radius from one's residence, as well as the proximity to the border have the effect of reducing commuting distances. On the other hand, residing in an isolated municipality tends to increase commuting distance.

Understanding these localized effects can provide valuable guidance to policymakers and transportation planners when formulating targeted strategies to optimize cross-border commuting and minimize any adverse effects on overall commuting distances. Recognizing the distinct dynamics and challenges faced by internal and cross-border commuters is crucial to ensure the provision of efficient transportation systems and support mechanisms for both.

Additionally, this chapter identifies border zones that closely correspond to the geographical regions defined in Chapter 3, solidifying the concept that proximity to different countries and regions has diverse effects on commuting choices, both within and across borders. This provides strong evidence that neighboring countries have a unique impact on how people choose to commute.

The limited explanatory power of our models suggests the existence of unexplored factors influencing commuting distances. To enhance our understanding, it would be valuable to consider variables related to the existing transportation infrastructure, such as road connectivity, as well as the quality and availability of public transportation options. Additionally, accounting for cultural and linguistic similarities or disparities can provide further insights. Furthermore, considering the influence of housing markets on commuting distances may offer additional explanatory power to our analysis.

5.6 Appendix

Table 5.5: Results of OLS models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Intercept)	28.706 (***)	30.622 (***)	23.363 (***)	29.152 (***)	20.348 (***)	13.807 (***)
	(0.343)	(0.544)	(0.604)	(0.687)	(0.733)	(0.678)
Female	-8.587 (***)	-8.678 (***)	-8.657 (***)	-8.671 (***)	-8.543 (***)	-8.560 (***)
	(0.153)	(0.153)	(0.153)	(0.153)	(0.153)	(0.153)
15-19 (ref=20-29)	-2.479 (***)	-2.524 (***)	-2.744 (***)	-2.888 (***)	-2.324 (***)	-2.296 (***)
	(0.586)	(0.585)	(0.585)	(0.585)	(0.584)	(0.585)
30-39	-2.726 (***)	-2.743 (***)	-2.701 (***)	-2.765 (***)	-2.987 (***)	-2.907 (***)
	(0.213)	(0.213)	(0.213)	(0.213)	(0.213)	(0.213)
40-49	-1.758 (***)	-1.739 (***)	-1.727 (***)	-1.876 (***)	-2.090 (***)	-1.940 (***)
	(0.215)	(0.215)	(0.215)	(0.215)	(0.215)	(0.215)
50-59	-1.335 (***)	-1.184 (***)	-1.194 (***)	-1.407 (***)	-1.504 (***)	-1.303 (***)
	(0.228)	(0.228)	(0.227)	(0.227)	(0.227)	(0.227)
60-69	3.387 (***)	3.581 (***)	3.612 (***)	3.321 (***)	3.205 (***)	3.463 (***)
	(0.402)	(0.402)	(0.401)	(0.401)	(0.401)	(0.401)
Farmers (ref=workers)	-0.542	-0.858	-1.083	-1.262	-0.637	-0.585
	(1.728)	(1.726)	(1.725)	(1.723)	(1.722)	(1.724)
Artisans	1.000 (**)	1.433 (***)	1.263 (***)	1.128 (***)	1.827 (***)	1.802 (***)
	(0.382)	(0.382)	(0.382)	(0.382)	(0.383)	(0.382)
Management employees	12.414 (***)	13.044 (***)	13.140 (***)	13.394 (***)	13.476 (***)	13.153 (***)
	(0.266)	(0.266)	(0.266)	(0.266)	(0.266)	(0.266)
Self-employed managers	7.544 (***)	8.337 (***)	8.334 (***)	8.315 (***)	8.838 (***)	8.716 (***)
	(0.631)	(0.631)	(0.630)	(0.630)	(0.630)	(0.630)
Intermediate professions	4.657 (***)	4.992 (***)	4.969 (***)	5.039 (***)	5.235 (***)	5.100 (***)
	(0.220)	(0.220)	(0.220)	(0.220)	(0.220)	(0.220)
Employees	2.380 (***)	2.616 (***)	2.634 (***)	2.575 (***)	2.756 (***)	2.750 (***)
	(0.220)	(0.220)	(0.220)	(0.220)	(0.220)	(0.220)
Prof. Diploma (ref=No Diploma)	-0.276	-0.406	-0.536 (*)	-0.726 (**)	-0.793 (***)	-0.587 (*)
	(0.234)	(0.234)	(0.234)	(0.234)	(0.234)	(0.234)
Secondary Education	1.740 (***)	1.650 (***)	1.504 (***)	1.228 (***)	1.321 (***)	1.645 (***)
	(0.251)	(0.251)	(0.251)	(0.251)	(0.251)	(0.251)
High Degree	3.659 (***)	3.723 (***)	3.662 (***)	3.447 (***)	3.408 (***)	3.669 (***)
	(0.254)	(0.254)	(0.254)	(0.254)	(0.254)	(0.254)
1 pers (ref=2 in the household)	-0.134	0.010	0.106	0.129	0.087	0.037
	(0.228)	(0.228)	(0.228)	(0.227)	(0.227)	(0.227)
3 and +	-0.269	-0.218	-0.226	-0.204	-0.173	-0.189
	(0.166)	(0.166)	(0.166)	(0.166)	(0.166)	(0.166)
Tenants (ref=Owners)	0.015	0.387 (*)	0.448 (*)	0.373 (*)	0.373 (*)	0.403 (*)
	(0.179)	(0.179)	(0.179)	(0.179)	(0.179)	(0.179)
Low-cost tenants	-3.100 (***)	-1.971 (***)	-1.826 (***)	-1.450 (***)	-0.994 (***)	-1.392 (***)
	(0.245)	(0.246)	(0.246)	(0.247)	(0.247)	(0.246)
At least one car/employee (ref=FALSE)	-3.862 (***)	-4.238 (***)	-4.458 (***)	-4.663 (***)	-4.743 (***)	-4.531 (***)
	(0.174)	(0.174)	(0.174)	(0.175)	(0.174)	(0.174)
Agriculture (ref=Trade, Transport, Serv.)	-3.130 (***)	-3.713 (***)	-4.154 (***)	-4.757 (***)	-4.361 (***)	-3.732 (***)
	(0.948)	(0.947)	(0.947)	(0.946)	(0.946)	(0.946)
Industry	-2.511 (***)	-3.072 (***)	-3.062 (***)	-3.006 (***)	-3.150 (***)	-3.162 (***)
	(0.198)	(0.199)	(0.198)	(0.199)	(0.199)	(0.198)
Construction	-0.346	-0.523	-0.701 (*)	-0.790 (**)	-0.825 (**)	-0.734 (*)
	(0.291)	(0.291)	(0.291)	(0.291)	(0.291)	(0.291)
Public Admin, Educ., Health	-4.898 (***)	-4.953 (***)	-5.160 (***)	-5.320 (***)	-4.837 (***)	-4.669 (***)
	(0.167)	(0.166)	(0.167)	(0.167)	(0.167)	(0.167)
Job availability		-3.375 (***)	-4.703 (***)	-9.674 (***)	-5.313 (***)	0.731
		(0.445)	(0.448)	(0.526)	(0.540)	(0.481)
Isolated Municipality (ref=Urban Area)		14.063 (***)	14.665 (***)	13.339 (***)	12.664 (***)	14.190 (***)
		(0.407)	(0.407)	(0.412)	(0.412)	(0.407)
Multipolarized Municipality		5.493 (***)	5.102 (***)	4.512 (***)	4.664 (***)	5.270 (***)
		(0.210)	(0.210)	(0.214)	(0.214)	(0.210)
Distance to the nearest border			1.803 (***)	1.513 (***)	2.368 (***)	2.528 (***)
			(0.066)	(0.068)	(0.072)	(0.070)

Table 5.5: Results of OLS models (continued)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
IT (ref=BE)				4.905 (***)	4.860 (***)	
				(0.664)	(0.664)	
ITMO				-0.777 (**)	-1.907 (***)	
				(0.281)	(0.283)	
SPA				6.650 (***)	6.211 (***)	
				(0.253)	(0.253)	
ANDSPA				8.529 (***)	8.157 (***)	
				(0.884)	(0.884)	
BEGERLUX				-1.070 (**)	-3.110 (***)	
				(0.332)	(0.337)	
GERLUX				4.585 (***)	3.870 (***)	
				(0.388)	(0.388)	
GER				2.550 (***)	2.411 (***)	
				(0.217)	(0.217)	
GERSWI				-0.316	-1.442 (***)	
				(0.298)	(0.300)	
SWI				-2.196 (***)	-3.520 (***)	
				(0.230)	(0.233)	
SWIIT				-1.768 (***)	-2.467 (***)	
				(0.431)	(0.432)	
Cross-border commuter (ref=Not CBC)					8.434 (***)	7.345 (***)
					(0.244)	(0.238)
R^2	1.434%	1.696%	1.792%	1.962%	2.113%	1.913%

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5.6: Results of OLS models (with logged dependent variable)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Intercept)	2.548 (***)	2.961 (***)	2.723 (***)	2.633 (***)	1.957 (***)	1.945 (***)
	(0.005)	(0.009)	(0.009)	(0.011)	(0.011)	(0.010)
Female	-0.209 (***)	-0.215 (***)	-0.214 (***)	-0.216 (***)	-0.206 (***)	-0.206 (***)
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
15-19 (ref=20-29)	-0.123 (***)	-0.126 (***)	-0.133 (***)	-0.135 (***)	-0.092 (***)	-0.097 (***)
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
30-39	-0.036 (***)	-0.038 (***)	-0.037 (***)	-0.034 (***)	-0.051 (***)	-0.054 (***)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
40-49	-0.055 (***)	-0.054 (***)	-0.054 (***)	-0.050 (***)	-0.066 (***)	-0.071 (***)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
50-59	-0.099 (***)	-0.088 (***)	-0.088 (***)	-0.086 (***)	-0.093 (***)	-0.097 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)
60-69	-0.068 (***)	-0.054 (***)	-0.053 (***)	-0.044 (***)	-0.053 (***)	-0.065 (***)
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Farmers (ref=workers)	-0.140 (***)	-0.155 (***)	-0.163 (***)	-0.151 (***)	-0.102 (***)	-0.122 (***)
	(0.028)	(0.027)	(0.027)	(0.027)	(0.026)	(0.027)
Artisans	-0.156 (***)	-0.123 (***)	-0.129 (***)	-0.112 (***)	-0.058 (***)	-0.085 (***)
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Management employees	0.200 (***)	0.244 (***)	0.247 (***)	0.256 (***)	0.262 (***)	0.249 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Self-employed managers	-0.096 (***)	-0.038 (***)	-0.038 (***)	-0.027 (**)	0.013	-0.007
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Intermediate professions	0.075 (***)	0.097 (***)	0.096 (***)	0.101 (***)	0.116 (***)	0.107 (***)
	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Employees	-0.007 (*)	0.006	0.007 (*)	0.012 (***)	0.026 (***)	0.016 (***)
	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Prof. Diploma (ref=No Diploma)	0.040 (***)	0.031 (***)	0.026 (***)	0.018 (***)	0.013 (***)	0.022 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Secondary Education	0.089 (***)	0.075 (***)	0.070 (***)	0.067 (***)	0.074 (***)	0.082 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
High Degree	0.144 (***)	0.141 (***)	0.139 (***)	0.136 (***)	0.133 (***)	0.139 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
1 pers (ref=2 in the household)	-0.054 (***)	-0.044 (***)	-0.041 (***)	-0.038 (***)	-0.041 (***)	-0.046 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)
3 and +	-0.012 (***)	-0.009 (***)	-0.009 (***)	-0.009 (***)	-0.007 (**)	-0.006 (*)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Tenants (ref=Owners)	-0.059 (***)	-0.035 (***)	-0.033 (***)	-0.029 (***)	-0.029 (***)	-0.037 (***)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Low-cost tenants	-0.234 (***)	-0.157 (***)	-0.153 (***)	-0.150 (***)	-0.115 (***)	-0.117 (***)
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
At least one car/employee (ref=FALSE)	0.054 (***)	0.025 (***)	0.018 (***)	0.011 (***)	0.005	0.012 (***)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Agriculture (ref=Trade, Transport, Serv.)	-0.098 (***)	-0.127 (***)	-0.142 (***)	-0.148 (***)	-0.118 (***)	-0.107 (***)
	(0.015)	(0.015)	(0.015)	(0.015)	(0.014)	(0.015)
Industry	0.001	-0.036 (***)	-0.035 (***)	-0.046 (***)	-0.057 (***)	-0.043 (***)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Construction	0.062 (***)	0.048 (***)	0.043 (***)	0.042 (***)	0.039 (***)	0.040 (***)
	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)
Public Admin, Educ., Health	-0.123 (***)	-0.123 (***)	-0.130 (***)	-0.132 (***)	-0.095 (***)	-0.090 (***)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Job availability		-0.520 (***)	-0.563 (***)	-0.526 (***)	-0.191 (***)	-0.121
		(0.007)	(0.007)	(0.008)	(0.007)	(0.007)
Isolated Municipality (ref=Urban Area)		0.554 (***)	0.574 (***)	0.566 (***)	0.514 (***)	0.535 (***)
		(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Multipolarized Municipality		0.383 (***)	0.370 (***)	0.333 (***)	0.345 (***)	0.384 (***)
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Distance to the nearest border			0.059 (***)	0.069 (***)	0.135 (***)	0.118 (***)
			(0.001)	(0.001)	(0.001)	(0.001)

Table 5.6: Results of OLS models (with logged dependent variable) (continued)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
IT (ref=BE)				-0.010	-0.013	
				(0.010)	(0.010)	
ITMO				-0.198 (***)	-0.285 (***)	
				(0.004)	(0.004)	
SPA				-0.015 (***)	-0.049 (***)	
				(0.004)	(0.004)	
ANDSPA				-0.018	-0.047 (***)	
				(0.014)	(0.014)	
BEGERLUX				0.106 (***)	-0.051 (***)	
				(0.005)	(0.005)	
GERLUX				0.106 (***)	0.052 (***)	
				(0.006)	(0.006)	
GER				0.144 (***)	0.134 (***)	
				(0.003)	(0.003)	
GERSWI				0.022 (***)	-0.064 (***)	
				(0.005)	(0.005)	
SWI				-0.016 (***)	-0.118 (***)	
				(0.004)	(0.004)	
SWIIT				0.037 (***)	-0.016	
				(0.007)	(0.007)	
Cross-border commuter (ref=Not CBC)					0.648 (***)	0.598 (***)
					(0.004)	(0.004)
R^2	4.018%	7.854%	8.248%	8.916%	12.330%	11.320%

Note: *p<0.1; **p<0.05; ***p<0.01

Chapter 6

Conclusions

This dissertation is dedicated to the in-depth exploration of cross-border commuting patterns, effects, and drivers. Through four distinct and comprehensive chapters, it delves into the complexities of this phenomenon, offering valuable insights for policymakers, transportation planners, and researchers in the realm of urban development and transport policies. By unveiling the distinct dynamics and challenges experienced by cross-border commuters, this research significantly advances our understanding of cross-border commuting behavior. Its findings pave the way for informed decision-making and the formulation of targeted strategies to optimize cross-border commuting experiences and enhance regional development.

Chapter 2 of this thesis highlights the importance and challenges of cross-border commuting in urban development and transportation policies, through a systematic literature review. The findings underscore the need for integrated and sustainable approaches to address the complexities of cross-border commuting, while also encouraging further research to explore the connections between different subtopics and the impacts of CBC on various aspects of society and the environment. It can be concluded that the field requires consolidation and more integration with urban and transport studies in non-cross-border areas. This thesis proposes directions for future research, including addressing sustainability and social challenges, standardizing data and approaches, and understanding the impact of flexible work patterns. By offering the first extensive literature review on cross-border commuting, this dissertation consolidates knowledge, identifies gaps, and contributes valuable insights for advancing the field, making it an essential resource for policymakers, transportation planners, and researchers in urban development and transport policies.

Chapter 3 offers a comprehensive analysis of cross-border commuting patterns in France, shedding light on the determinants that influence these patterns in comparison to internal commuting. The research emphasizes the significance of geographical factors, including urban geography and proximity to the border, in shaping cross-border commuting decisions. Job availability within France plays a central role, driving individuals to seek opportunities across the border and expand their labor market options. The study also reveals the diverse impact of residing in proximity to different borders, with varying effects on cross-border commuting. To further enrich the model, it is suggested to incorporate measurements of the pull factor from foreign employment destinations and consider the influence of the current energy crisis on commuter mobility. Demographic changes and their effects on job availability should also be taken into account to gain a more comprehensive understanding of

cross-border commuting dynamics.

Chapter 4 presents compelling findings that deepen our understanding of commuting flows and the influence of distance and borders. While confirming the negative relationship between distance and commuting flows, the analysis reveals intriguing distinctions between internal and cross-border commutes within France. The slightly stronger distance effect observed for internal commutes highlights the subtleties involved in commuting patterns. Moreover, the study demonstrates the undeniable negative border effect, demonstrating how borders act as significant barriers for cross-border commuters. These insights offer valuable guidance for policymakers and planners seeking to design transportation systems that accommodate the intricacies of commuting dynamics in both national and cross-border contexts. The research contributes significantly to the field by enriching our knowledge of commuting patterns, border impacts, and the importance of integrating regional characteristics into spatial interaction models.

Chapter 5 of this thesis delves into the factors that influence commuting distance in the border facade of France. The analysis indicates that being a cross-border commuter increases commuting distance, but the local effects analysis reveals spatial heterogeneity in this relationship, with both positive and negative impacts observed in different areas. Similarly, the impact of other geographical variables on commuting distance also varies across locations. Our analysis reveals the emergence of certain border zones of similar characteristics, which highly resemble the border zones defined in Chapter 3. The findings emphasize the significance of considering the spatial context and local variations when studying the effects of different variables on commuting distances. Understanding these localized effects is crucial for policymakers and transportation planners to formulate targeted strategies that optimize cross-border commuting and minimize adverse effects on overall commuting distances.

The research findings consistently underscore Luxembourg's prominence as a highly sought-after destination for employees residing in France. Notably, Luxembourg stands out as the easiest border to cross among France's neighboring countries. This distinction is attributed to the comparatively weaker border obstacles present when commuting between France and Luxembourg, as opposed to other border crossings. The ease of interactions between the two countries contributes to the perception of Luxembourg as an attractive employment destination for cross-border commuters. The magnetic pull of employment opportunities in Luxembourg diminishes the usual influence of distance and local job availability on commuting decisions, prompting a larger proportion of cross-border commuters to willingly undertake longer commutes for the sake of working in Luxembourg. Examining flow patterns further emphasizes Luxembourg's significance as an integral component of the larger French urban network, attracting significant commuting flows and showcasing strong integration and connectivity with surrounding areas. This collective evidence solidifies Luxembourg's appeal and highlights its pivotal role in shaping cross-border commuting dynamics in the region.

While this research offers valuable insights into cross-border commuting patterns, drivers, and effects, it is essential to acknowledge its limitations. The study was conducted during a period marked by the COVID-19 pandemic, which had a significant impact on commuting flows. In the initial months, commuting, particularly cross-border commuting, came to a halt. As time progressed, flows gradually resumed, but within the context of a changed reality. To this day, the widespread adoption of teleworking and hybrid work arrangements has become a prominent feature of the new normal, altering commuting dynamics. This shift in work patterns has the potential to influence commuting distance, as daily commuting is no longer the norm. Furthermore, it could potentially impact cross-border commuting. To gain a more comprehensive understanding of these evolving trends, future research should explore more recent data from the post-COVID-19 era, providing insights into the "new normal" of commuting behaviors.

Finally, this study focused on specific variables that are commonly associated with commuting and cross-border commuting patterns. Future research could broaden this scope and explore additional variables, which may enhance the explanatory power of the models. Taking into account factors such as the influence of transportation infrastructure, road connectivity, and the availability and quality of public transportation options could provide additional explanatory power in understanding commuting patterns. Exploring the impact of cultural and linguistic similarities or disparities between regions on commuting behaviors could, also, offer valuable insights, especially in cross-border contexts. Investigating how housing market conditions, such as housing affordability and availability, influence commuting distances and choices could be a valuable addition to future research, as well. Additionally, conducting comparative studies across different regions or countries with varying border characteristics could help identify commonalities and differences in cross-border commuting dynamics. Lastly, assessing the effectiveness of policies aimed at promoting sustainable and efficient cross-border commuting could be an important area of future research. This could include evaluating the impact of cross-border cooperation agreements and transportation investments.

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