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Interdependence Between the Tourist Regions of Sergipe, Brazil

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Abstract. We constructed an interregional input-output system for the tourist regions of Sergipe and identified the contribution of Tourism Characteristic Activities (TCAs) to the state's economy. It is the first system built for tourist regions in Brazil that disaggregates tourism activities by sector and region, representing a novel approach in Brazilian literature. By measuring the weight of tourist activities, we avoid overestimating tourism in the regional economy. Researchers can use this method for countries and regions that do not have a Tourism Satellite Account. The main results estimate that TCAs in Sergipe accounted for 1.53% of the state's gross value added (GVA) in 2015, 3.7 times lower when we do not properly disaggregate the tourism activities. The Polo Costa dos Coqueirais stands out among the tourist regions, particularly regarding the distribution of TCAs' GVA within the state. Tourist road transportation is considered a key sector in all tourist regions.

Key words: tourist activities, input-output, regional planning, Sergipe

JEL classification: C67; R15; Z32

1 Introduction

Recent years have begun to show a scenario of world recovery in tourist activity, which had been severely affected by the COVID-19 pandemic. In 2019, according to the World Travel & Tourism Council's annual Economic Impact Report (EIR) data, tourism accounted for 10.3% of the world's Gross Domestic Product (GDP). In 2021 and 2022, however, this share dropped to 6.1% and 7.6%, respectively, which is still below the pre-pandemic levels. Brazil, an important tourist destination in South America, was also severely impacted by the pandemic. Ribeiro et al. (2021) estimated a 31% drop in the GDP of Brazilian tourist activities in 2020.

In this present scenario of recovery in the sector, the existence of based on concrete planning instruments is fundamental. Tourism is an important development alternative for poorer countries or regions. In Brazil, tourism has already been used explicitly as a regional development policy through PRODETUR Nacional, specifically in the Northeast region - PRODETUR NE I and II. Studies by Haddad et al. (2013) and Ribeiro et al. (2017, 2022) show that tourism reduces regional inequalities in the country.

The scarcity of resources in poorer states, often located in peripheral regions, contributes to the fact that tourism policy is not a priority in state public management, as is the case of Sergipe, located in the Brazilian Northeast. Sergipe is the smallest state in the country in territorial terms and accounts for 4% of the Northeast GDP and 0.6% of the national GDP, respectively. Although the state has tourism potential in several segments (sun and beach, adventure, and historical-cultural), they are not fully exploited.

Constructing tools that can aid tourism planning is fundamental for tourism development. Thus, this paper aims to build an inter-regional input-output (IO) system for Sergipe's tourist regions and identify the contribution of Tourism Characteristic Activities (TCAs) to the state economy. TCAs brings together tourism-related sectors, such as transportation, accommodation and food services, travel agencies and entertainment and leisure services.

Although many studies have used the IO model to estimate the intra and inter-regional economic effects of activities associated with tourism (Polo, Valle 2008, Lee et al. 2020, Lee, Hlee 2021, Kumara et al. 2021), the evaluation of the productive and regional interdependence of TCAs has been little explored in the literature. For the Brazilian case, some studies measure the economic contribution of tourism in specific regions, but they do not consider the inter-regional interdependence of TCAs.

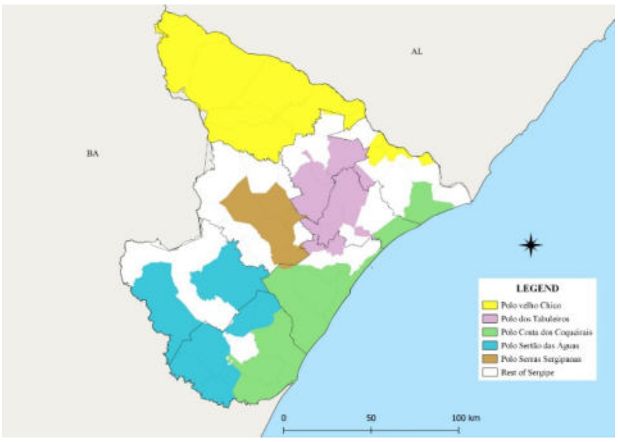
Casimiro Filho, Guilhoto (2003) built an IO model for the tourist economy in Brazil in 1999 and measured intersectoral linkages and the ability to induce investments in economic growth. Takasago, Mollo (2011) examined the potential for stimulating production growth, income generation, and employment in the Federal District. To do so, they use the IO matrix to calculate the linkage effects and the potential generators of production, employment, and tourism income, enabling a more accurate sectorial view.

Souza (2015) use an interregional IO matrix for Brazil to analyze the economic contribution of tourism in the Northeast region. Based on this, the authors seek to measure the influence of tourism on job and income generation, as well as its impact on reducing labor income inequality. Gonçalves et al. (2020) propose a method to measure the size of TCAs and their evolution in the Brazilian economy and its states between 2010 and 2015. The method consists of measuring TCAs on the supply side, using the same techniques employed to measure activities within the scope of the System of National and Regional Accounts of Brazil. They estimate a structure of weights applied to the value-added of economic activity groups.

The input-output method has been employed in various contexts in Europe. Mikulić et al. (2023), for instance, estimate the regional economic impact of tourism in Croatia. According to these authors, the reduction in economic activity due to the pandemic had a significant negative effect on GDP in all regions of Croatia. The direct effects are more pronounced in the Adriatic region, while the indirect effects are higher in the continental region. Rokicki et al. (2021) analyze different approaches to the construction of multi-regional IO tables for Austria and Pérez et al. (2009) use an inter-regional IO model to estimate the economic impact of European Union structural funds on the regions of Spain from 1995 to 1999. Ivanova et al. (2019) and Araújo Junior et al. (2020) also adopt the IO model to assess specific issues in European countries.

By employing an inter-regional IO system, the study avoids potential overestimation of the economic contribution of tourism by disaggregating TCAs. The absence of a Tourism Satellite Account (TSA) implies a failure to differentiate between expenditures by residents and non-residents within tourism-related sectors. For instance, expenditures such as meals consumed by residents while away from their usual residence are amalgamated within the accounting framework of the food sector. Consequently, this amalgamation leads to an overestimation effect on the perceived impact of tourism within the given locale.

This methodological insight not only enhances the precision of the findings for Sergipe but also provides a valuable approach for regions and countries globally facing similar challenges in accurately assessing the economic impact of tourism. The study's focus on trade flow dynamics, value-added concentration, and employment multipliers within



Source: Author's own.

Figure 1: Touristic regions of Sergipe

different tourist regions of Sergipe adds depth to the understanding of the economic intricacies of the tourism industry at a regional level.

Moreover, identifying key sectors provides tangible insights for policymakers and researchers promoting sustainable tourism development. While the research refrains from making explicit cross-regional or cross-national comparisons, its emphasis on precise regional data offers a rich foundation for future comparative studies. Additionally, the research highlights the need for tailored policies in Sergipe, leveraging regional production chains. This focus on practical applications adds depth to the broader international discourse on effective tourism planning and development, making it pertinent to a global audience of researchers, policymakers, and practitioners navigating the complexities of regional economic recovery and growth.

Despite efforts in the national literature to assess the productive interdependence of TCAs in Brazil, no study simultaneously deals with the regional and sectoral specification of tourist activities. Our main contribution, therefore, is: i) to regionally disaggregate the weight of trade flows from tourist activities and ii) to provide a tourism planning tool for Sergipe to encourage tourism development. In other words, this paper offers an unprecedented database for Brazil and Sergipe by sectorally and regionally disaggregating tourist activities. The method for estimating tourism can be replicated in countries and regions without a TSA, such as Brazil. The disaggregation of the TCAs avoids overestimating the effects of tourism on the state economy.

By building this system, regional heterogeneity is addressed. Thus, issues such as productive linkages, employment and income multipliers and spillovers can be discussed by tourist regions.

The remainder of this paper is organized as follows. Next section (Section 2) describes the tourist regions of Sergipe, based on socioeconomic data. Section 3 presents the step-by-step construction of the inter-regional IO system by tourist region and describes the databases used. Section 4 contains the results and discussion, followed by the main conclusions and policy recommendations.

2 Tourist Regions of Sergipe

Sergipe possesses considerable untapped potential in tourism. The state is subdivided into five distinct regions, each contributing to a diverse landscape encompassing sun-lit beaches, rugged mountains, and historically rich towns, as we can see in Figure 1. However, realizing this potential is contingent upon addressing existing challenges.

The city of Aracaju, the dynamic capital, anchors the bustling Polo Costa dos Coqueirais. This region represents Sergipe's economic and tourism epicenter, characterized by pristine beaches. It serves as the primary gateway to the various wonders scattered

Table 1: Tourist regions of Sergipe, 2022

Name	ID	Name	ID
Polo Costa dos Coqueirais (10)		*Polo Sertão das Águas (8)*	
Aracaju	A	Boquim	D
Barra dos Coqueiros	C	Cristinápolis	D
Estância	C	Itabaianinha	D
Indiaroba	E	Lagarto	C
Itaporanga d'Ajuda	D	Salgado	D
Nossa Senhora do Socorro	C	Tobias Barreto	C
Pacatuba	D	Tomar do Geru	D
Pirambu	D	Umbaúba	D
Santa Luzia do Itanhy	E	*Polo Velho Chico (11)*	
São Cristóvão	D	Canindé de São Francisco	D
Polo dos Tabuleiros (11)		Cedro de São João	D
Aquidabã	D	Gararu	D
Capela	D	Monte Alegre de Sergipe	D
Carmópolis	D	Nossa Senhora da Glória	D
Cumbe	E	Nossa Senhora de Lourdes	D
Divina Pastora	E	Poço Redondo	D
Maruim	E	Porto da Folha	D
Muribeca	E	Propriá	C
Nossa Senhora das Dores	D	Santana do São Francisco	E
Riachuelo	E	Telha	D
Santa Rosa de Lima	E		
Siriri	D		
Polo Serras Sergipanas (5)			
Areia Branca	E		
Frei Paulo	D		
Itabaiana	C		
Moita Bonita	E		
Ribeirópolis	E		

Source: Brasil Ministério do Turismo (2022), author's own.

throughout Sergipe. Beyond the coastal allure, Polo dos Tabuleiros and Polo Serras Sergipanas unfold a narrative of rolling hills and charming towns while the canyons of Polo Sertão das Águas, particularly the iconic Xingó Canyons, beckon adventure enthusiasts.

The Brazilian Tourism Map defined the tourist regions of Sergipe (Brasil Ministério do Turismo 2022). In general, this document guides the preparation and implementation of public policies by the Ministry of Tourism. In Brazil 2021, 338 tourist regions were defined, of which five belong to the state of Sergipe, as shown in Table 1. Only some municipalities are part of a tourist region since they must meet criteria jointly established by state agencies and the Ministry of Tourism. Municipalities are categorized (A, B, C, D, or E) due to the performance of their tourism economy, with A being the best classification and E being the worst.

Of the 75 Sergipe municipalities, 45 were included in the Tourism Map and constituted the formation of five tourist regions in the state, as we mentioned: Polo Costa dos Coqueirais, Polo dos Tabuleiros, Polo Serras Sergipanas, Polo Sertão das Águas, and Polo Velho Chico. Most municipalities in Sergipe were classified in Categories "D" and "E", which indicates that tourist activity is incipient in most of Sergipe. This is not a particularity of Sergipe since, according to Santos et al. (2018), the supply structure of labor in the tourism sector is incipient in 90.6% of Brazilian municipalities. Only the capital, Aracaju, was classified as Category "A". Table 2 shows some indicators of Sergipe's tourist regions for 2020 to understand this regionalization better.

Polo Costa dos Coqueirais is home to almost 50% of the state population and accounts for approximately 55% of Sergipe's GDP. This tourist region aggregates all the municipalities that form the Metropolitan Region of Aracaju (Aracaju, Barra dos Coqueiros, Nossa Senhora do Socorro and São Cristóvão). On the other hand, Polo dos Tabuleiros accounts for 5.19% of the state's GDP. Although Polo Velho Chico has one of the main tourist destinations in the state, the Xingó Canyons, its GDP per capita, the highest among tourist regions, is justified by the presence of the São Francisco Hydroelectric Company, as pointed out by Ribeiro, Jorge (2019).

Table 2: Indicators of the Sergipe's tourist regions, 2020[1]

Tourist regions	Population[2] (%)	GDP[3] (%)	GDP per capita (R$)
Polo Costa dos Coqueirais	48.86	54.88	21,995
Polo dos Tabuleiros	6.78	5.19	15,000
Polos Serras Sergipanas	6.92	6.59	18,654
Polo Sertão das Águas	13.11	8.64	12,908
Polo Velho Chico	9.12	12.46	26,750
Rest of Sergipe	15.20	12.23	15,755

Source: (1)Most recent year available for GDP data. (2)Population estimates for 2020, IBGE. (3)System of Nacional Accounts, IBGE. Author's own.

Despite these unique offerings, several municipalities in Sergipe remain relatively unnoticed, categorized as "developing" or "emerging" concerning tourism infrastructure. This pattern reflects a broader nationwide trend, emphasizing the necessity for strategic investments to unlock the latent potential of these inland regions. An additional impediment lies in accessibility challenges. While Aracaju boasts an international airport, venturing into the interior entails navigating winding roads and limiting public transportation options. Notwithstanding these obstacles, Sergipe finds itself at a pivotal juncture. Its landscapes, culture, and authentic experiences hold substantial allure for discerning travelers. Prioritizing accessibility, endorsing responsible development practices, and adeptly showcasing its hidden treasures could herald a transformative chapter in Sergipe's tourism narrative.

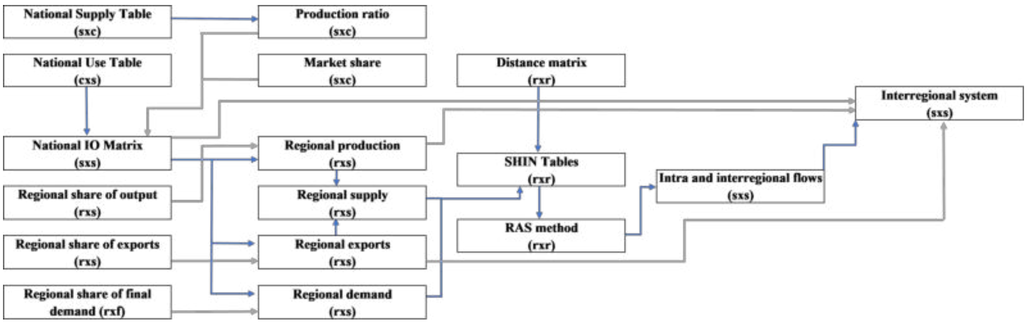
3 Inter-Regional Input-Output System for Tourist Regions, Databases, and Indicators

The construction of the interregional system used the *Interregional Input-Output Adjustment System* – IIOAS method, widely employed in the international literature for several countries worldwide, such as Brazil (Haddad et al. 2017), Egypt (Haddad et al. 2016), Greece (Haddad et al. 2020a), Indonesia (Hulu, Hewings 1993), and Mexico (Haddad et al. 2020b). The IIOAS is a hybrid method that blends data provided by official agencies, such as the Brazilian Institute of Geography and Statistics (IBGE, Portuguese acronym), with non-census techniques for estimating unavailable information. The key advantages of IIOAS lie in its alignment with the national IO matrix data and the flexibility of its regionalization process, which can be applied to any country that publishes its national Supply and Use Tables (SUTs) and provides a system of sectoral regionalized information (Haddad et al. 2015).

The IIOAS method is recommended in contexts where statistical information is limited. Nonetheless, the method demonstrates adherence, consistency, and robust results. In the absence of an official IO matrix for the state of Sergipe, we use the latest official Brazilian IO matrix for the base year 2015, which comprises 67 sectors (or industries) and 127 commodities (IBGE 2018), to generate an interregional system that includes the Sergipe's tourist regions.

The Brazilian IO matrix is disaggregated according to sectoral production in Sergipe and the rest of Brazil. In other words, input usage, consumption of final goods, and value-added payments in Sergipe are generated as components parts of the national economy. This approach allows the construction of a Sergipe-specific matrix with unique characteristics regarding technical coefficients and production multipliers. Furthermore, due to the scarcity of regional information for all activities, it was necessary to reduce the number of sectors to 59, as shown in Appendix, Table A.1. Figure 2 summarizes the stages of the IIOAS method.

The first column presents the data required for constructing the interregional system, i.e., the SUTs of Brazil and the regional shares of production and final demand vectors. From the second column onward, the estimation process stages are depicted. After constructing the regional vectors, the regional trade matrices are estimated based on the following steps:



Source: Author's own.

Note: The subscripts s, c, r, and f mean sectors, commodities, regions, and final demand components, respectively.

Figure 2: Steps of the IIOAS method

Step 1 Organizing regional shares of production and final demand components using municipal data from the state of Sergipe and the rest of Brazil (see Appendix, Tables A.2 and A.3).

Step 2 Estimating the domestic sales of each industry by region (DOM_Sales), which can be done by excluding respective exports ($\mathbf{x}$) and stock variation ($\mathbf{sv}$) from the corresponding gross production vector ($\mathbf{go}$), that is:

$$DOM\_Sales^R_{ix1} = \mathbf{go}^R_{ix1} - \mathbf{x}^R_{ix1} - \mathbf{sv}^R_{ix1} \quad \forall R = 1, \ldots, 7; \quad \forall i = 1, \cdots, 59 \tag{1}$$

where i refers to a given industry, and R represents a certain region of the state of Sergipe or the rest of the country.

Step 3 Estimating the total demand for each domestic (**dom_dem**) and imported goods (**imp_dem**) in each region if the demand structure of respective users follows the preference patterns of national demand.

$$\mathbf{dom\_dem}^R_{ix1} = \sum_{j=1}^{59} \mathbf{IC}^{R,DOM}_{ixj} + \mathbf{gfcf}^{R,DOM}_{ix1} + \mathbf{hc}^{R,DOM}_{ix1} + \mathbf{ge}^{R,DOM}_{ix1} \quad \forall i = 1, \cdots, 59; \quad \forall R = 1, \cdots, 7 \tag{2}$$

$$\mathbf{imp\_dem}^R_{ix1} = \sum_{j=1}^{59} \mathbf{IC}^{R,IMP}_{ixj} + \mathbf{gfcf}^{R,IMP}_{ix1} + \mathbf{hc}^{R,IMP}_{ix1} + \mathbf{ge}^{R,IMP}_{ix1} \quad \forall i = 1, \cdots, 59; \quad \forall R = 1, \cdots, 7 \tag{3}$$

Here j refers to a given input, **IC** refers to intermediate consumption flows, **gfcf** refers to gross fixed capital formation, **hc** household (consumption expenditure), and **ge** refers to government expenditure.

Step 4 Estimation of trade matrices representing the transactions of each commodity between origin and destination for each industry (intrasectoral flows), the so-called SHIN matrices.

The first step in obtaining the SHIN (share) tables, based on Haddad et al. (2020b), is the generation of diagonal cells (intraregional submatrices) corresponding to commodity flows using the following equation:

Table 3: Value of the term $F(i)$ for the sectors of the IO matrix, 2015

Type	Criterion	$F(i)$	Sectors (No.)
Tradable	$\frac{DOM\_Sales_c}{\mathbf{go}_c} \leq 0.99$	0.5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 33, 35, 36, 37, 38, 39, 40, 41, 43, 44, 46, 47, 48, 49, 50, 57
Non-tradable	$\frac{DOM\_Sales_c}{\mathbf{go}_c} > 0.99$	0.9	14, 30, 31, 32, 34, 42, 45, 51, 52, 53, 54, 55, 56, 58, 59

Source: Author's own, based on Haddad et al. (2020b).

Table 4: Distance matrix (in km) between the regions of the interregional system, 2015

			Region code						
Code	Region name	Reference point (city)	R1	R2	R3	R4	R5	R6	R7
R1	Polo Costa dos Coqueirais	Aracaju	0.0	48.6	55.8	79.3	196	38.8	2,161
R2	Polo dos Tabuleiros	Carmópolis	49.6	0.0	73.6	110	160	12.7	2,191
R3	Polo Serras Sergipanas	Itabaiana	56.3	73.4	0.0	40	140	62.3	2,164
R4	Polo Sertão das Águas	Lagarto	79.9	111	41.1	0.0	179	101	2,124
R5	Polo Velho Chico	Canindé São Francisco	195	160	141.0	179	0.0	158	2,237
R6	Rest of Sergipe	Rosário do Catete	39	12.4	61.7	99.4	158	0.0	2,181
R7	Rest of Brasil	São Paulo	2,156	2,187	2,159	2,120	2,232	2,177	0.0

Source: Author's own based on information from Google Maps.

$$SHIN^1_{(i,d,d)} = \min\left\{\frac{DOM\_Sales_{(i,d)}}{DOM\_Dem_{(i,d)}}, 1\right\} * F(i) \tag{4}$$

In equation (4), d represents any of the 6 regions of the state of Sergipe or the rest of the country, where sales and consumption of each good occur. The term $F(i)$ defines the pattern of international trade for goods (sectors), with values closest to 1 indicating non-tradable sectors or "local goods". Table 3 shows the values used. As expected, most non-tradable sectors are service activities.

In equation (5), $o = 1, \ldots, 7$ and $d = 1, \ldots, 7$ represent, respectively, origin and destination regions, but for the case where $o \neq d$. With this step we obtain the interregional submatrices (interregional flows). the interregional submatrices (interregional flows).

$$\mathbf{SHIN^2}_{(c,o,d)} = \left\{\frac{1}{\left(dist_{(i,d)}\right)^2} \cdot \frac{DOM\_Sales_{(i,o)}}{\sum_{k=1}^{7} DOM\_Sales_{(i,k)}}\right\} \times \left\{\frac{1 - SHIN_{(i,d,d)}}{\sum_{j=1,j\neq 1}^{7}\left[\frac{1}{\left(dist_{(j,d)}\right)^2} \cdot \frac{DOM\_Sales_{(i,j)}}{\sum_{k=1}^{7} DOM\_Sales_{(i,k)}}\right]}\right\} \tag{5}$$

This means that for each sector there is a proportional matrix (SHIN table) to distribute the total value of trade (sales and purchases) among all regions. Table 4 shows the distance matrix ($dist_{j,d}$), which refers to the road distance in kilometers between origin and destination, where the reference point for each region is the municipality with the highest GDP in 2015.

Step 5 The calculation of intraregional and interregional flow matrices ("initial values") between any combination of o and d is expressed in equations (6) and (7):

$$\mathbf{TRADE_1} = \mathbf{SHIN}^1_{(i,d,d)} * \mathbf{dom\_dem}_{(i,d)} \tag{6}$$

$$\mathbf{TRADE}_2 = \mathbf{SHIN}^2_{(i,o,d)} * \mathbf{dom\_dem}_{(i,d)} \tag{7}$$

Step 6 Balancing the trade matrices to equate the supply and demand of each commodity using the bi-proportional adjustment method.

Given that the construction of the inter-regional system requires data from different statistical sources, a system balancing procedure is performed, which was carried out using the bi-proportional adjustment method (RAS[1]), ensuring consistency and balance between supply and demand.

Step 7 Finally, the combination of transactions within and between the different regions of the sample enables the generation of an inter-regional system related to the trade of intermediate goods.

3.1 Databases

We obtained information on sectoral production from different municipal data sources. For the agriculture sector, the value of production from temporary and permanent crops is aggregated directly from the Municipal Agricultural Production Survey (PAM, Portuguese acronym) (IBGE 2015a) for the year 2015. For the livestock sector, the value of animal production is considered from the Municipal Livestock Survey (PPM, Portuguese acronym) of 2015 (IBGE 2015c). For the forestry production sector, the values of production in silviculture and plant extraction are combined from the Plant Extraction Production Survey in 2015 (IBGE 2015b). For the remaining 56 productive sectors, regional shares are measured using the following proxy variables: (i) wages paid to formal workers and (ii) wages paid to formal and informal workers. The choice of proxy variable is made based on the characteristic of each sector, with information from the Annual Employment Information Report (RAIS, Portuguese acronym) for industrial activities and microdata from the 2010 Demographic Census (IBGE 2011) for the service sectors (see Appendix, Table A.2).

A new regional distribution is organized to represent workforce employment in each sector. This new approach allows sectoral employment per production unit to be flexible and not bound to a fixed rate, as established in the 2015 Brazilian IO matrix. In other words, a given sector employs proportionally depending on the peculiarities of each region. Due to the scarcity of municipal data in primary sector surveys, the employment distribution follows the regional share of production in corresponding activities. We use the number of active employment contracts as of December 31, 2015, available in RAIS (MTE 2023) for industrial activities. For service sectors, the total number of employees, both with and without formal contracts, is estimated using microdata from the 2010 Demographic Census.

For government consumption expenditures, we use the participation of each tourist region in the value-added of the public administration in Sergipe. To do this, we aggregate the municipal values provided at the municipality level by IBGE (2017) (see Appendix, Table A.3).

Given the unavailability of other proxy variables at the municipal level, the regional share of the remaining macroeconomic aggregates follows the regional distribution of sectoral production. To do this, we adopted new assumptions that gross capital formation, household consumption, and consumption of nonprofit institutions serving households (NPISH) are proportional to regional production in monetary terms.

The data on foreign trade for tourist regions is obtained from the Federal Government's Comex Stat. In this case, it is necessary to reconcile the commodities classified under the Harmonized System Code (HS4) with the 127 commodities in the 2015 IO matrix. The sectoral regionalization is prepared by applying the proportions of each commodity's exports to the weighted values of exports in the matrix. For commodities in the IO matrix for which data is not available in Comex Stat, the total export value of each commodity is multiplied by the share of each region in total output.

However, the values provided in Comex Stat consider the municipality of the exporting company rather than the municipality of origin of the commodities. For the state of Sergipe, where commodity distribution varies among regions, the use of such data leads

[1]Please see Miller, Blair (2022), chapters 9 and 10.

Table 5: Weight for the disaggregation of TCAs in Sergipe, December 2015

TCAs	Sergipe	Brazil
Food services	0.22	0.27
Water transportation	0.00	0.10
Air transportation	0.95	0.83
Travel agencies	0.83	0.78
Culture and leisure	0.15	0.04
Accommodation	0.86	0.78
Non-metropolitan land transportation	0.21	0.26

Source: IPEA.

to significant distortions in the interregional system. For example, the Polo Costa dos Coqueirais accounted for 89.3% of agricultural exports in 2015 while being responsible for only 15.5% of the state's total output. Considering these issues, Haddad et al. (2016, 2017, 2020a,b) suggest relying on the regional distribution of sectoral production.

For the identification of tourism-related activities (TCAs) in Brazil, we use the study "Economia do Turismo - Uma Perspectiva Macroeconômica 2003–2009" (IBGE 2012). According to this study, TCAs accounted for 3.6% of the country's gross value added in 2003. Moreover, tourism comprises the following activities: i) restaurants and accommodation services, ii) passenger transportation, iii) travel agencies and tour operators, and iv) recreational and entertainment services. Matching this information with the IO matrix, we identify six TCAs: S34 - Land transportation; S35 - Water transportation; S36 - Air transportation; S38 - Accommodation; S39 - Food services; S57 - Artistic, creative, and entertainment activities; and S50 - Other administrative and support services. The last activity includes Travel Agencies.

However, given the absence of a TSA in Brazil and Sergipe, using these sectors directly without any statistical treatment would overestimate the weight of tourism activities in the economy. Thus, it is necessary to disaggregate these sectors' TCAs. Based on information from the wage mass of RAIS, Gonçalves et al. (2020) constructed weights for the disaggregation of TCAs in Brazil. According to these authors, the weights had low variability between 2010 and 2015. For the state of Sergipe, the Institute of Applied Economic Research (IPEA, Portuguese acronym) provided monthly sectoral weights for 2015, as shown in Table 5. In other words, these weights represent the size of tourism in each TCA.

Due to minor weight variations throughout 2015, we consider the weight for December. It can be observed that Air transportation, Accommodation, and Travel agencies have the highest weights, with 95%, 86%, and 83%, respectively, of these sectors corresponding to tourism activities. On the other hand, sectors such as Culture and leisure, Food Services, and Non-metropolitan land transportation have the lowest weights. The Water transportation sector will not be considered as its weight in Sergipe was zero. Based on these weights, the trade flows of the corresponding sectors in the IO matrix were disaggregated. Thus, the matrix now recognizes six additional tourism sectors: Tourist land transportation, Tourist air transportation, Tourist accommodation, Tourist food services, Professional tourist services (travel agencies), and Artistic, creative, and entertainment tourist activities (culture and leisure). The analyzes in the results section (Section 4) will refer to these activities.

3.2 Indicators

To structurally evaluate the TCAs in the tourist regions of Sergipe, we calculate the simple production and employment multipliers and the backward-forward indexes. To define these indices, the starting point is the solution of the IO model, formally expressed as:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y} \tag{8}$$

where x is the output vector, $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief Inverse matrix, in which $\mathbf{I}$ is an Identity matrix, $\mathbf{A}$ is the Technological matrix and $\mathbf{y}$ is the final demand vector.

Table 6: GVA regional distribution of TCAs in Sergipe, 2015

Tourist activities	Polo Costa dos Coqueirais	Polo dos Tabuleiros	Polo Serras Sergipanas	Polo Sertão das Águas	Polo Velho Chico	Rest of Sergipe
Tourist land transportation	69.1%	6.5%	7.1%	6.7%	4.6%	6%
Tourist air transportation	100%	0%	0%	0%	0%	0%
Tourist accommodation	83.6%	1.1%	0.9%	2.8%	7.9%	3.7%
Tourist food services	76.9%	1.7%	6.4%	6.9%	3.3%	4.7%
Professional tourist services	91.3%	0.2%	4.2%	0.9%	2.7%	0.7%
Artistic, creative, and tourist entertainment activities	78.1%	0.8%	4.6%	7.5%	2.7%	6.3%

Source: Author's own based on IO matrix.

The simple production and employment multiplier of sector j can be defined, respectively, as $\mathbf{m(o)_j} = \sum_{i=1}^{n} l_{ij}$ and $\mathbf{m(h)_j} = \sum_{i=1}^{n} a_{n+1,i} l_{ij}$, in which l_{ij} is the Leontief inverse elements, and $a_{n+1,i}$ is the employment coefficient, that is, the ratio between employment and the output in sector i.

The indices of Rasmussen (1958) and Hirschman (1958) measure the degree of backward and forward linkages of a given productive structure. The indices are expressed by a ratio between the average of the impacts of the sector and the total average of the economy, that is:

$$U_{oj} = \frac{\frac{1}{n} L_{oj}}{\frac{1}{n^2} \sum_{i=1}^{n} L_{oj}} \tag{9}$$

$$U_{io} = \frac{\frac{1}{n} L_{io}}{\frac{1}{n^2} \sum_{j=1}^{m} L_{io}} \tag{10}$$

where U_{oj} is the backward linkage (BL), and U_{io} is the forward linkage (FL), n is the number of sectors. The sector is considered a key sector when it presents both indices above one and, therefore, when it has intermediate purchases and sales above the economy average.

4 Results and Discussion

The first three tables (Tables 6, 7, 8) provide an exploratory analysis of the inter-regional system to assess the generation of value-added and the regional composition of trade flows between the tourist regions of Sergipe. We estimated that tourist activities accounted for only 1.53% of the state GVA in 2015. IPEA estimated the weight of tourism in the Northeast region and Brazil at 2.1% and 2.2%, respectively, considering occupation data in December 2014. When considering wages in the formal labor market, Gonçalves et al. (2020) estimated at 3.02% the weight of TCAs in the total GVA of Sergipe in 2015. Without the disaggregation of TCAs from the coefficients shown in Table 5, the weight of the "tourism sector" in the total GVA of Sergipe would be overestimated by 3.7 times, that is, 5.6%.

Table 6 presents the GVA distribution of the TCAs in Sergipe's tourist regions. We can see an intense concentration in the Polo Costa dos Coqueirais, which accounts, on average, for 83.2% of the value-added generation of TCAs within the state of Sergipe. Except for the Polo Costa dos Coqueirais, the GVA for Tourist land transportation has a more homogeneous distribution among the other tourist regions. The only airport in Sergipe is in the capital, Aracaju, which explains the generation of 100% of GVA for Tourist air transportation in the Polo Costa dos Coqueirais.

Tables 7 and 8 show the share of trade flows among the tourist regions of Sergipe, the rest of Sergipe, and the rest of Brazil based on the origin of purchases and destination of intermediary sales, respectively. We highlighted the intra-regional flows on the main diagonal: purchases and sales made within the region.

The Polo dos Tabuleiros and the Polo Costa dos Coqueirais have the highest degree of self-sufficiency among the tourist regions of Sergipe since 14.7% and 12.7% of their

Table 7: Share of the origin of trade flows by tourist region of Sergipe, 2015

	Regions	R1	R2	R3	R4	R5	R6	R7
R1	Polo Costa dos Coqueirais	12.7%	6.8%	7.0%	3.5%	0.8%	12.2%	0.4%
R2	Polo dos Tabuleiros	0.3%	14.7%	0.1%	0.0%	0.0%	3.4%	0.0%
R3	Polo Serras Sergipanas	0.2%	0.1%	9.4%	0.6%	0.1%	0.2%	0.0%
R4	Polo Sertão das Águas	0.2%	0.1%	0.7%	5.6%	0.1%	0.1%	0.0%
R5	Polo Velho Chico	0.0%	0.1%	0.1%	0.1%	6.4%	0.0%	0.0%
R6	Rest of Sergipe	4.1%	6.2%	0.5%	0.3%	0.1%	7.6%	0.1%
R7	Rest of Brazil	82.5%	72.0%	82.2%	90.0%	92.5%	76.5%	99.4%

Source: Author's own based on IO matrix.

Table 8: Share of the trade flows' destination by tourist region of Sergipe, 2015

	Regions	R1	R2	R3	R4	R5	R6	R7	Total
R1	Polo Costa dos Coqueirais	12.3%	0.3%	0.3%	0.3%	0.1%	1.9%	84.9%	100%
R2	Polo dos Tabuleiros	8.0%	17.0%	0.1%	0.1%	0.1%	15.2%	59.6%	100%
R3	Polo Serras Sergipanas	5.0%	0.1%	9.5%	1.0%	0.1%	0.6%	83.8%	100%
R4	Polo Sertão das Águas	2.4%	0.1%	0.5%	6.6%	0.1%	0.3%	90.1%	100%
R5	Polo Velho Chico	0.5%	0.0%	0.1%	0.1%	6.3%	0.1%	92.9%	100%
R6	Rest of Sergipe	20.4%	1.3%	0.1%	0.1%	0.0%	6.1%	71.9%	100%
R7	Rest of Brazil	0.4%	0.0%	0.0%	0.0%	0.0%	0.1%	99.4%	100%

Source: Author's own based on IO matrix.

purchases and 17% and 12.3% of their sales, respectively, have region itself as origin and destination (see Table 7). Sergipe is the smallest state in Brazil, so we can see the substantial importance that the rest of Brazil has in the composition of trade flows for all the tourist regions in the state.

The origin of purchases from the other tourist regions (R2 to R5), except for those originating in the region itself, is greater in the Polo Costa dos Coqueirais than the sum of purchases originating in the other regions of Sergipe. The Polo Velho Chico (92.5%) and the Polo Sertão das Águas (90%) have the greatest dependence on the rest of Brazil about the origin of their purchases.

The relative importance within the state of Sergipe of the Polo Costa dos Coqueirais also appears in the sales' destination, as shown in Table 8. The Polo Tabuleiros is the tourist region that proportionally sells fewer inputs and goods to the rest of Brazil, whose region accounts for 59.6% of the destination of its intermediary sales.

Table 9 presents the simple production multipliers by TCA and tourist regions in Sergipe. As it is an inter-regional system, these multipliers are broken down into intra (region itself), inter (spillover effect), and total (sum of the two previous ones). The last row of the table shows the regional multipliers, which consider all economic sectors per region. A significant advantage of these multipliers is the possibility of explicitly measuring the spillover effect to other regions, which can help in elaborating and implementing tourism policies in Sergipe with a focus on regional production chains. Moreover, Fleischer, Freeman (1997) warn about the importance of considering the interactions of multiregional models not to underestimate the multiplier effects of tourism.

The highest regional production multipliers are from the Polo dos Tabuleiros and the Polo Costa dos Coqueirais. For the first one, for every variation of $1 in its final

Table 9: Production multiplier by tourist activity and tourist region of Sergipe, 2015

Tourist activities	Polo Costa dos Coqueirais			Polo dos Tabuleiros			Polo Serras Sergipanas			Polo Sertão das Águas			Polo Velho Chico			Rest of Sergipe		
	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total
Tourist land transportation	1,07	0,88	1,95	1,09	0,90	1,98	1,08	0,91	1,99	1,04	0,94	1,99	1,02	0,97	1,99	1,04	0,91	1,94
Tourist air transportation	1,03	1,06	2,09	1,03	1,09	2,12	1,02	1,12	2,13	1,01	1,12	2,14	1,01	1,14	2,15	1,02	1,05	2,07
Tourist accommodation	1,06	0,64	1,70	1,05	0,66	1,71	1,04	0,67	1,70	1,02	0,68	1,70	1,04	0,67	1,70	1,03	0,67	1,70
Tourist food services	1,03	0,83	1,85	1,03	0,83	1,87	1,03	0,83	1,86	1,02	0,84	1,86	1,01	0,86	1,87	1,02	0,84	1,86
Professional tourist services	1,02	0,96	1,98	1,03	0,93	1,96	1,02	0,96	1,98	1,01	0,94	1,95	1,01	0,99	2,00	1,03	0,95	1,97
Artistic, creative, and tourist entertainment activities	1,04	0,55	1,60	1,02	0,58	1,60	1,02	0,58	1,60	1,01	0,59	1,60	1,02	0,58	1,60	1,01	0,58	1,60
Regional multipliers	**1,06**	**0,63**	**1,68**	**1,06**	**0,62**	**1,69**	**1,04**	**0,57**	**1,61**	**1,02**	**0,64**	**1,67**	**1,02**	**0,58**	**1,60**	**1,03**	**0,65**	**1,68**

Source: Author's own based on IO matrix.

Table 10: Employment multiplier by tourist activity and tourist region of Sergipe, 2015

Tourist activities	Polo Costa dos Coqueirais			Polo dos Tabuleiros			Polo Serras Sergipanas			Polo Sertão das Águas			Polo Velho Chico			Rest of Sergipe		
	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter	Total
Tourist land transportation	16	5	21	16	5	21	22	5	27	27	5	32	26	5	31	26	5	31
Tourist air transportation	3	6	9	0	6	6	0	6	6	0	6	6	0	7	7	0	6	6
Tourist accommodation	17	6	23	22	6	28	40	6	46	32	6	38	22	6	28	28	6	34
Tourist food services	24	7	31	45	7	52	28	7	35	38	7	45	50	8	58	54	7	61
Professional tourist services	7	7	14	11	7	18	9	7	16	24	7	31	8	7	15	29	7	36
Artistic, creative, and tourist entertainment activities	36	4	40	64	4	68	60	4	64	80	4	84	84	4	88	87	4	91
Regional multipliers	**9**	**6**	**16**	**13**	**6**	**19**	**15**	**6**	**21**	**13**	**6**	**20**	**18**	**6**	**23**	**9**	**6**	**15**

Source: Author's own based on IO matrix.

demand, the entire economy would generate $1.68, with $1.06 in the region itself, and $0.63 would leak to other regions. The lowest regional leakage effect is from the Polo Serras Sergipanas (0.57) and the highest from the Polo Sertão das Águas (0.64).

From the sectoral point of view, the interregional multipliers differ more among Sergipe's tourist regions when compared to the total multipliers, which are more similar across regions. For instance, the simple production multiplier of Tourist land transportation varies between 1.94 and 1.99 between tourist regions. It means that for each variation of $ 1 in its final demand, the economy would produce between $ 1.94 and $ 1.99 depending on the region considered. However, the spillover effect (inter multiplier) varies between 0.88 and 0.97. For each variation of $ 1 in the final demand of Tourist land transportation in Polo dos Tabuleiros, for instance, the entire economy would have to produce $ 1.98 to meet this variation, with $ 1.09 being produced in the region itself and $ 0.90 would be leaked to other regions.

The highest total production multiplier in all tourist regions, including the above regional multiplier, is the Tourist air transportation, with values ranging between 2.07 and 2.15. However, in all tourist regions, this sector has a strong spillover effect (inter). For Polo Velho Chico, for example, for every $ 1 variation in the final demand of this sector, the entire economy would need to produce $ 2.15, but only $ 1.01 would be in the locality itself, and $ 1.14 would leak to other regions. According to Souza (2015), the tourism sector had a production multiplier 1.31 in the Brazilian Northeast.

Table 10 presents the simple employment multipliers by TCA and tourist region in Sergipe. The last row of the table shows the regional multipliers, which consider all economic sectors. Generally, there is greater regional variability in the total multiplier and a smaller one in the inter-regional employment multiplier. Furthermore, the spillover effect (inter) is low in all ACTs in all tourist regions since the activity is developed locally. Ribeiro et al. (2017) pointed out a similar result when estimating the impact of tourist spending in the Brazilian Northeast. These authors observed a low effect of job leakage outside the region. These results highlight the comparative advantage of tourism in the Brazilian Northeast, driven by the region's natural resources and development potential, as corroborated by Ribeiro et al. (2022).

The highest employment multiplier among the TCAs is that of Artistic, creative, and touristic entertainment activities, varying between 40 and 89 among the tourist regions, even well above the regional multipliers. This means that, for every $ 1 million variation in the final demand of this sector, between 40 and 89 jobs would be created directly and indirectly depending on the region. For each variation of R$ 1 million in the final demand of this sector in Polo Velho Chico, for instance, 89 jobs would be created throughout the economy, 84 of which would be in the region itself, and 4 jobs would spillover to other regions.

Except for the Polo Costa dos Coqueirais, the employment multiplier of Tourist air transportation is zero in all tourist regions. This means that all jobs generated due to variations in the final demand of this sector would be generated outside the respective regions. This result is consistent with what has already been shown in Table 6. The employment multiplier of Tourist food services is also relevant across regions. Its spillover effect of Polo Velho Chico is slightly higher than the economy average. According to Souza (2015), the main activities that contributed to the generation of employment in the Brazilian Northeast were Accommodation, road transportation of passengers, and

Table 11: HR indexes of tourist activity by tourist region of Sergipe, 2015

Tourist activities	Polo Costa dos Coqueirais		Polo dos Tabuleiros		Polo Serras Sergipanas		Polo Sertão das Águas		Polo Velho Chico		Rest of Sergipe	
	BL	FL	BL	FL	BL	FL	BL	FL	BL	FL	BL	FL
Tourist land transportation	**1,023**	**1,136**	**1,035**	**1,209**	**1,040**	**1,202**	**1,022**	**1,116**	**1,003**	**1,044**	**1,010**	**1,044**
Tourist air transportation	0,982	0,956	0,978	0,951	0,981	0,965	0,990	0,978	0,986	0,980	0,993	0,972
Tourist accommodation	**1,012**	0,958	0,995	0,953	**1,000**	0,966	**1,003**	0,980	**1,016**	0,982	0,997	0,975
Tourist food services	0,983	0,957	0,982	0,952	0,989	0,968	0,996	0,980	0,992	0,981	0,989	0,973
Professional tourist services	0,975	0,958	0,978	0,951	0,988	0,966	0,991	0,978	0,987	0,981	0,999	0,972
Artistic, creative, and tourist entertainment activities	0,997	0,956	0,974	0,951	0,983	0,965	0,992	0,979	**1,000**	0,980	0,985	0,972

Source: Author's own based on IO matrix.

food services.

Only Tourist air transportation and Professional tourist services have shown employment multipliers smaller than the regional multiplier (considering all economic sectors) in all the tourist regions, except for the last sector in Polo Sertão das Águas.

Table 11 presents the results of the Hirschman-Rasmussen (HR) indices by TCA and Sergipe's tourist regions. We have highlighted in red and blue, respectively, the above-average forward and backward linkages. Tourist land transportation is the only TCA ranked as a key sector across all tourist regions, i.e., both indices above one. Prado (1981) a nd Guilhoto et al. (2005) state that key sectors should be considered strategic to stimulate economic growth. A similar result for the Brazilian capital (Federal District) was found by Takasago, Mollo (2011). They identified that the road transportation and intercity tourism sector was also considered a key sector along with the recreational and cultural activities sector.

In general, backward linkages are greater than forward linkages, which means that tourism activities buy more inputs from other sectors than they sell. This result is expected and consistent with previous studies carried out for Bermuda (Archer 1995), Seychelles (Archer, Fletcher 1996), China (Oosterhaven, Fan 2006), East Asia (Blake 2008), Brazil (Takasago et al. 2010), South Korea (Lee, Hlee 2021) and Indonesia (Kumara et al. 2021). This occurs because tourist activities mostly meet final demand.

The Tourist accommodation sector, according to Miller, Blair (2022) can be classified as dependent on inter-industry supply as it only presents purchases above the average for the economy ($BL > 1$) in all tourist regions, except Polo dos Tabuleiros. Most tourist activities are not strongly connected with other sectors since their intermediate purchases and sales are below average (BL and $FL < 1$). Gabriel et al. (2020) state that industrial segments are more expected to be classified as key sectors since they purchase and sell a greater diversity of activities. An example of this for the state of Sergipe is that the four key sectors, according to Ribeiro, Leite (2012), are industrial: Food and beverages, Textiles, Paper and cellulose, and Rubber and plastic.

For Brazil, Casimiro Filho, Guilhoto (2003) identified six key sectors of the tourism segment: air transportation, travel agencies, auxiliary activities to air transportation, Accommodation, restaurants, and other food service establishments. It is noteworthy, however, that these authors did not perform any statistical treatment regarding the weight of the TCAs.

Our findings offer significant socioeconomic insights for Sergipe, and it can serve as a case study for all Brazilian states and similar regions worldwide. Identifying key sectors within the tourism industry, characterized by high economic multipliers, presents an opportunity to bolster economic development. In addition, we highlight the regional dynamics of tourism activities. By acknowledging and leveraging the distinct economic contributions of different regions, regional policies can work towards reducing disparities and promoting more inclusive development.

Understanding employment multipliers across various tourism activities provides a valuable tool for crafting labor market policies. Policymakers can prioritize sectors with higher job creation potential, contributing to local and regional employment opportunities. Furthermore, the study's insights into income generation and inequality highlight the potential of tourism to play a role in addressing socioeconomic disparities. Crafting targeted policies that harness the economic benefits of tourism can contribute to reducing income inequality and enhancing overall economic well-being across the state.

5 Conclusions

This research advances the estimation of an inter-regional IO system specified for tourist regions in Sergipe and disaggregates the tourism activities. By building this system, regional heterogeneity is addressed. Thus, issues such as productive linkages, employment and income multipliers and spillovers can be discussed by tourist regions. However, the ideal scenario is the Brazilian statistical officers' availability of the Tourism Satellite Accounts. Thus, the impacts of these activities can be estimated more precisely since, in tourist activities, only what is consumed by tourists will be considered.

The exploratory analysis revealed that TCAs accounted for only 1.53% of Sergipe's state GVA in 2015. Comparatively, the weight of tourism in the Northeast and Brazil was estimated at 2.1% and 2.2%, respectively. Furthermore, without disaggregating the TCAs from the presented coefficients, the weight of the tourism sector would be overestimated 3.7 times.

The Polo Costa dos Coqueirais was identified as the region concentrating the largest generation of GVA from the TCAs in Sergipe, corresponding to 83.2% of the state's total. Furthermore, Tourist air transportation had the highest production multiplier, varying between 2.07 and 2.15 in all regions. However, tourist regions also showed a strong spillover effect, indicating that part of the generated production is destined for other regions. As for employment multipliers, artistic and creative activities and tourist shows had the highest values. The spillover effect of jobs to other regions was low in all TCAs and tourist regions, indicating that the activity is predominantly developed locally.

Tourist land transportation was a key sector in all tourist regions of Sergipe. In general, backward linkage indices were higher than forward linkage indices, indicating that TCAs purchase more inputs from other sectors than they sell. Tourist activities would mainly meet the final demand. The Tourist accommodation sector depended on inter-industry supply, with purchases above the average in all regions except for the Polo dos Tabuleiros. Most tourist activities are not strongly connected to other sectors, as their intermediate purchases and sales are below average for the economy.

We used an unprecedented method in the Brazilian literature that disaggregates tourist activities by sector and region. In addition, with the identification of TCAs in Sergipe, it was possible to measure the spillover effect to other regions explicitly. It can be useful for elaborating and implementing tourism policies focused on regional production chains. Furthermore, researchers can replicate this method for countries and regions that, like Brazil, do not have a Tourism Satellite Account.

The main limitation of the research, however, is that the technical coefficients of disaggregated tourist activities, for example, tourist accommodation and non-tourist Accommodation, are the same. Ideally, we would have specific coefficients for each tourism sub-activity, which is only possible with the Satellite Account.

The utilization of disaggregated data from this study offers a concrete foundation for crafting targeted policies and interventions in Sergipe's tourism sector. With a detailed understanding of various TCAs' specific contributions and regional distribution, stakeholders can tailor strategies to each tourist region's unique needs and potential. This granularity in data analysis becomes instrumental for optimizing resource allocation, fostering economic growth, and a practical approach to tourism planning.

Addressing regional development disparities is imperative, as the study reveals the concentration of tourism-related economic activities. Actionable measures such as strategic infrastructure improvements, direct support for local entrepreneurial ventures, and targeted promotion of distinctive attractions must be implemented to stimulate economic growth in less-developed tourism regions. These interventions should spur economic development, reduce regional inequalities, and cultivate a more diversified and equitable tourism landscape in Sergipe. Moreover, it is essential to recognize the significance of place identity in shaping residents' perceptions and aspirations for their region's future. Residents' deep-rooted connections to Sergipe's cultural heritage and economic potential can inform decision-making processes and foster inclusive, community-driven approaches to development and planning. Sustainable practices and specific measures should involve implementing stringent environmental regulations, fostering community engagement initiatives, and promoting eco-friendly tourism practices that resonate with residents' sense of place identity.

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A Appendix

Table A.1: Sectoral aggregation

Code	Sector's name	Number	New name
1800	Printing and reproduction of recordings	18	Manufacture of furniture and various industries
3180	Manufacture of furniture and products from various industries		
2091	Manufacture of organic and inorganic chemicals, resins, and elastomers	21	Chemical manufacturing
2092	Manufacture of pesticides, disinfectants, paints, and various chemicals		
2093	Manufacture of cleaning products, cosmetics/perfumes, and personal hygiene items		
2100	Manufacture of pharmochemical and pharmaceutical products		
2500	Manufacture of metal products, excluding machinery and equipment	26	Manufacture of metal products, machinery, and equipment
2600	Manufacture of computer equipment, electronic products, and optical devices		
2700	Manufacture of electrical machinery and equipment		
2800	Manufacture of mechanical machinery and equipment		
3300	Maintenance, repair, and installation of machinery and equipment		

Source: Own elaboration based on information from IBGE (2011), **IBGE, 2016 / MISSING REFERENCE**.

Table A.2: Regional share in the sectoral production of Sergipe, 2015

No.	Sector name	R1	R2	R3	R4	R5	R6	R7
1	Agriculture, incl. support for agriculture & post-harvest activities	0.001	0.000	0.000	0.001	0.001	0.001	0.996
2	Livestock farming, incl. support for livestock farming	0.001	0.001	0.001	0.001	0.005	0.002	0.990
3	Forestry production; fishing & aquaculture	0.000	0.000	0.000	0.000	0.000	0.000	1.000
4	Extr. of coal & non-metallic minerals	0.003	0.001	0.001	0.001	0.000	0.019	0.975
5	Extr. of oil & gas, incl. support activities	0.021	0.001	0.000	0.000	0.000	0.018	0.961
6	Extr. of iron ore, incl. beneficiation & agglomeration	0.000	0.000	0.000	0.000	0.000	0.000	1.000
7	Extr. of non-ferrous metallic minerals, incl. beneficiation	0.000	0.000	0.000	0.000	0.000	0.000	1.000
8	Slaughtering & meat products, incl. dairy & fish products	0.000	0.000	0.000	0.000	0.001	0.000	0.999
9	Sugar manufacturing & refining	0.006	0.000	0.000	0.000	0.000	0.000	0.994
10	Other food products	0.006	0.000	0.000	0.002	0.000	0.000	0.992
11	Beverage manufacturing	0.005	0.000	0.000	0.000	0.000	0.000	0.994
12	Tobacco product manufacturing	0.001	0.000	0.000	0.009	0.000	0.000	0.990
13	Textile manufacturing	0.007	0.000	0.001	0.000	0.001	0.003	0.988
14	Apparel & accessory manufacturing	0.002	0.000	0.000	0.000	0.000	0.000	0.997
15	Footwear & leather goods manufacturing	0.000	0.000	0.000	0.005	0.000	0.005	0.990
16	Wood product manufacturing	0.001	0.000	0.001	0.000	0.000	0.000	0.998
17	Pulp, paper, & paper product manufacturing	0.001	0.000	0.000	0.000	0.000	0.000	0.999
18	Manufacture of furniture & various industries	0.002	0.000	0.001	0.000	0.000	0.000	0.996
19	Petroleum refining & coke ovens	0.015	0.000	0.000	0.000	0.000	0.000	0.985
20	Biofuel manufacturing	0.000	0.002	0.000	0.000	0.000	0.012	0.986
21	Chemical manufacturing	0.005	0.000	0.000	0.000	0.000	0.000	0.994
22	Rubber & plastic product manufacturing	0.001	0.000	0.000	0.001	0.000	0.000	0.999
23	Non-metallic mineral product manufacturing	0.006	0.000	0.002	0.002	0.000	0.000	0.989
24	Pig iron/ferroalloy production, steelmaking, & seamless steel tubes	0.000	0.000	0.000	0.000	0.000	0.000	1.000
25	Non-ferrous metal metallurgy & metal casting	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Continued on the next page.

Table A.2: Regional share in the sectoral production of Sergipe, 2015

No.	Sector name	R1	R2	R3	R4	R5	R6	R7
26	Manufacture of metal products, machinery, & equipment	0.001	0.000	0.000	0.000	0.000	0.000	0.999
27	Manufacture of automobiles, trucks, & buses, except parts	0.000	0.000	0.000	0.000	0.000	0.000	1.000
28	Manufacture of parts & accessories for motor vehicles	0.004	0.000	0.000	0.000	0.000	0.000	0.996
29	Manufacture of other transport equipment, except motor vehicles	0.000	0.000	0.000	0.000	0.000	0.000	1.000
30	Electricity, natural gas, & other utilities	0.006	0.000	0.000	0.000	0.001	0.000	0.993
31	Water, sewage, & waste management	0.010	0.000	0.000	0.001	0.001	0.001	0.987
32	Construction	0.007	0.001	0.000	0.000	0.000	0.000	0.992
33	Wholesale & retail trade	0.004	0.000	0.001	0.001	0.000	0.001	0.993
34	Land transport	0.005	0.000	0.000	0.000	0.000	0.000	0.993
35	Water transport	0.005	0.000	0.000	0.000	0.000	0.000	0.994
36	Air transport	0.002	0.000	0.000	0.000	0.000	0.000	0.998
37	Storage, support activities for transportation, & postal services	0.003	0.000	0.000	0.000	0.000	0.000	0.996
38	Accommodation	0.007	0.000	0.000	0.000	0.001	0.000	0.992
39	Food services	0.005	0.000	0.000	0.000	0.000	0.000	0.993
40	Publishing & integrated printing	0.003	0.000	0.000	0.000	0.000	0.000	0.997
41	Television, radio, film, sound & image recording/editing activities	0.004	0.000	0.000	0.000	0.000	0.000	0.996
42	Telecommunications	0.002	0.000	0.000	0.000	0.000	0.000	0.997
43	Systems development & other information services	0.002	0.000	0.000	0.000	0.000	0.000	0.998
44	Financial intermediation, insurance, & pension funds	0.004	0.000	0.000	0.000	0.000	0.000	0.994
45	Real estate activities	0.004	0.000	0.000	0.000	0.000	0.000	0.996
46	Legal, accounting, consulting, & corporate head offices	0.004	0.000	0.000	0.000	0.000	0.000	0.995
47	Architecture, engineering, technical testing/analysis, R&D services	0.002	0.000	0.000	0.000	0.000	0.000	0.997
48	Other professional, scientific, & technical activities	0.002	0.000	0.000	0.000	0.000	0.000	0.997
49	Non-real estate rentals & management of intellectual property assets	0.009	0.001	0.000	0.000	0.000	0.000	0.989
50	Other administrative & support services	0.004	0.000	0.000	0.000	0.000	0.000	0.995
51	Surveillance, security, & investigation activities	0.006	0.000	0.000	0.000	0.000	0.000	0.993
52	Public administration, defense, & social security	0.009	0.000	0.000	0.001	0.001	0.001	0.988
53	Public Education	0.006	0.000	0.001	0.001	0.001	0.001	0.990
54	Private education	0.006	0.000	0.000	0.000	0.001	0.001	0.992
55	Public healthcare	0.005	0.000	0.000	0.000	0.001	0.000	0.994
56	Private healthcare	0.005	0.000	0.000	0.000	0.000	0.000	0.994
57	Artistic, creative, & entertainment activities	0.004	0.000	0.000	0.000	0.000	0.000	0.995
58	Associations & other personal services	0.004	0.000	0.000	0.000	0.000	0.000	0.994
59	Domestic services	0.005	0.000	0.000	0.000	0.000	0.000	0.993

Source: Own elaboration based on information from IBGE (2011, 2015a,b,c) and MTE (2023).
Note: As industrial sectors have a high formal rate, we use RAIS data, which considers only formal jobs. For services sectors we use data from Census, which take into account formal and informal jobs.

Table A.3: Regional share in the sectoral production of Sergipe, 2015

Code	Region name	Household consumption (HC)	Gross fixed capital formation (GFCF)	Government Expenditure (GE)	NPISH demand
R1	Polo Costa dos Coqueirais	0.0040	0.0040	0.0051	0.0040
R2	Polo dos Tabuleiros	0.0003	0.0003	0.0006	0.0003
R3	Polo Serras Sergipanas	0.0004	0.0004	0.0007	0.0004
R4	Polo Sertão das Águas	0.0006	0.0006	0.0014	0.0006
R5	Polo Velho Chico	0.0006	0.0006	0.0013	0.0006
R6	Rest of Sergipe	0.0008	0.0008	0.0017	0.0008
R7	Rest of Brazil	0.9933	0.9933	0.9892	0.9933
	Total	0.0040	0.0040	0.0051	0.0040

Source: Own elaboration, based on information from IBGE (2017).

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China's Impact on Sustainable Economic Growth in Central Asian Countries in the Context of the Silk Road Economic Belt

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Abstract. This paper examines how the economic relations between China and the Central Asian countries affect the economic development of the Central Asian countries in the context of the Belt and Road economy. China has come up with the global economic strategy initiative known as "One Belt, One Road" as a way of incorporating and expanding its economic activities around the world into this initiative. The article argues that China's economic activities in Central Asia are part of its global economic strategy. China's global "Belt and Road Initiative" is aimed at realizing its political aspirations through economic dominance, which then leads to a virtuous cycle. Of course, we all know that every country in the world needs to develop its economy, and Central Asian countries are no exception. Central Asian countries have the need and desire to cooperate with China to develop their own economies, which is the basis of this article. The method of argumentation in the article is to analyze the development needs and relations of cooperation between the two sides in terms of economic indicators, trade cooperation, economic dependence, infrastructure investment, geopolitical pattern of energy, and transportation of goods of Central Asian countries, respectively, and at the same time, data from World Energy Statistics Yearbook, World Bank, China Statistical Yearbook, and China's Outward Foreign Direct Investment Statistical Bulletin are used as the basis. This provides a clear understanding of the patterns of economic cooperation between China and Central Asian countries, and how they interact with each other. Despite the end of the Cold War and the collapse of the Soviet Union, Central Asia remains a central element of the People's Republic of China's (PRC) security strategy, a strategic location that creates a continuum between China's internal and external security. The guiding principle of China's policy towards Central Asia is primarily stability, which is the main theme of current Chinese politics, with the goal of ensuring continuity from domestic stability to the stabilization of border regions and surrounding areas. Throughout their independent existence, the Central Asian states have had different perceptions of Russia, the United States, China, and European countries, which is one of the prerequisites for the formation of multidirectional foreign policies in Central Asian countries. The balance of interests among Russia, the United States, China, and European countries in the region is of vital importance for Central Asian countries, which ensures the independent foreign policy and development paths of Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan, and Tajikistan, as well as contributes to the stability of the region.

Key words: Central Asia; China; GDP growth; economic dependence; trade; oil; gas

1 Introduction

After the collapse of the Soviet Union, five former Soviet republics in Central Asia declared their independence, namely Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, with a total current population of over 74.2 million. Although the definition of Central Asia is not universally recognized, the region has some distinctive features and geographically refers to a vast area stretching from the Caspian Sea in the west to Xinjiang in China in the east, to Afghanistan in the south, and to Russia in the north (Figure 1). Since the collapse of the Soviet Union in 1991, the political systems of the five Central Asian countries have not undergone a good democratic transition, and Turkmenistan, in particular, has been called the North Korea of Central Asia. According to the Economist Intelligence Unit's Democracy Index for the past 10 years, only Kyrgyzstan has a mixed regime, while the rest have authoritarian regimes. Similarly, according to the Freedom House Freedom Level of Freedom data for the last 10 years, only Kyrgyzstan among the five Central Asian countries is more than partially free. Naturally, the reform of the political system does have a great impact on the degree of openness and long-term development of the economy.

This paper focuses on the five countries mentioned above. The region occupies an important place in global geostrategy because of its abundant energy reserves. BP's Statistical Yearbook of World Energy 2022 states that Central Asia has approximately 4.1 billion tons of proven oil reserves, accounting for about 1.8% of the world's total proven oil reserves, and 22 trillion cubic meters of proven natural gas reserves, accounting for about 9% of the world's total proven natural gas reserves. These hydrocarbon reserves are primarily located in three countries: Kazakhstan, Turkmenistan, and Uzbekistan. Kazakhstan possesses the largest oil storage and development capacity in Central Asia, with proven oil reserves of about 4 billion tons in 2020, ranking 12th in the world (Chakeeva et al. 2023). Turkmenistan possesses the largest natural gas storage and development capacity in Central Asia, with 19.5 trillion cubic meters of natural gas reserves, the fourth largest in the world, and a reserve-to-production ratio of more than 300 years (Chungang 2022). Although Uzbekistan's oil and gas reserves are slightly lower than those of Kazakhstan, its gas production is second only to that of Turkmenistan, and the country has a relatively complete pipeline network. In addition to oil and gas, Central Asia is also rich in non-ferrous mineral resources and occupies an important position in the world market, which is mainly located in Kazakhstan and Uzbekistan.

Owing to its unique geographical location and abundant energy reserves, Central Asia has become increasingly important in recent years in the global supply and demand of hydrocarbon resources and in the geopolitics of energy. Nevertheless, there is still a generally low level of oil and gas refining capacity in Central Asian countries, and consumption in these countries remains relatively low compared to the abundant reserves and steadily growing production capacity, with most of the product being exported. Prior to the collapse of the Soviet Union in 1991, Central Asia's oil supply capacity stabilized at around 50 to 60 million tons; since 2000, however, production of oil and gas has continued to rise with the assistance of multinational companies. While Central Asian countries possess oil and gas reserves, they lack the capital and technology required to put them into production alone, which is a fact that gives Central Asian countries and foreign companies a share in the production and revenues. Thus, an important geopolitical consequence of the collapse of the Soviet Union was the intense political and commercial competition among the newly independent states of Central Asia for control of vast energy resources (Arvanitopoulos 1998, Zhou et al. 2020). With regard to economic cooperation between China and Central Asian countries, it is necessary to explain China's "One Belt, One Road" initiative. "One Belt" is the abbreviation for the "Silk Road Economic Belt," which refers to the land route of road and rail transportation through the interior of Central Asia along the historically famous East-West trade routes, and "One Road" is the abbreviation for the "Maritime Silk Road of the 21st Century," which refers to the Indo-Pacific maritime route through Southeast Asia to South Asia, the Middle East, and Africa. The Initiative has worked with more than 150 countries and international organizations (Gao 2020). China has also established

Notes: Figure drawn by the author

Figure 1: Schematic representation of countries in the traditional Central Asian region

the Asian Investment Bank and the Silk Road Fund to provide financial support for the Belt and Road Initiative. Infrastructure investments under the Belt and Road Initiative include ports, skyscrapers, railroads, highways, bridges, airports, dams, coal-fired power stations, and railway tunnels. Central Asia, where the Belt and Road Initiative was first proposed, is the core region, home to the world's largest landlocked and doubly landlocked countries, the first stop on China's westward journey, and one of the key targets for China's economic cooperation on the Silk Road Economic Belt, which connects Asia and Europe.

As a neighboring country to Central Asian countries and one of the first countries to establish diplomatic relations with them, China is also an important channel for Central Asian countries to access the sea, Southeast Asia, and Northeast Asia. The 30 years since the establishment of diplomatic relations between China and Central Asian countries have been a period of fluctuations in the world economy, during which Central Asian countries have become more and more deeply integrated into the world economic system, gradually synchronized with the development of the world economy, and have shown an upward momentum of development with ups and downs (Cieślik, Gurshev 2023).

2 Methodology and Data

In studying Chinese factors influencing the economic growth of Central Asian countries, the methodology used in the article is to measure the degree of economic dependence by utilizing the value of economic transactions between the two parties (foreign trade dependence = total foreign trade/GDP) and the value of investment (foreign investment dependence = investment flows/GDP). A greater economic dependence or a higher weight indicates a higher degree of dependence. In order to make the article more convincing, we supplement this method by separately analyzing the demand and dependence of both sides on some special resources and commodities, because the irreplaceability of these special resources and commodities can also affect the degree of economic dependence between the two sides. For example, a particular commodity imported from another country is a key input in the production process, and the lack of similar substitutes makes this part of the country's production highly dependent on imports of this particular commodity. The metrics are multifaceted since this measurement relates to specific transactional behaviors (Wang 2018).

According to the needs of the article, we performed several grouping and aggregation operations on the base data, which allowed us to specify the most relevant trends in the dynamics of economic growth indicators of Central Asian countries for the period from 2013 to 2022. We chose the indicators that characterize the economy's sustainable development as a basic parameter for comparative analysis, namely:

- Gross domestic product (GDP)

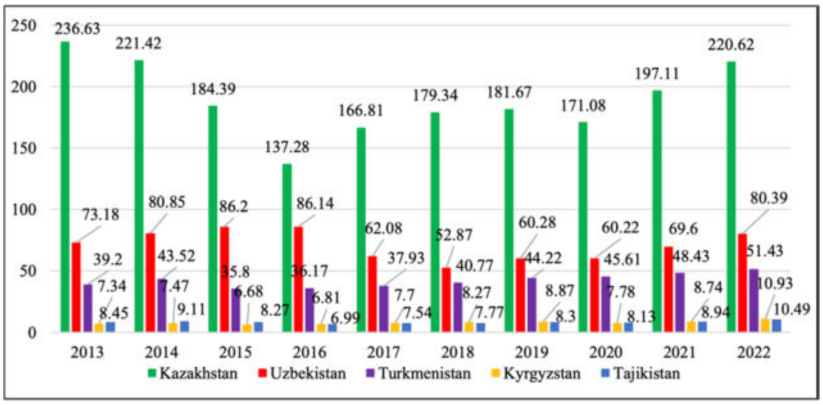
- GDP per capita and national income (GNI) per capita measures
- GDP growth rate
- Inflation
- Unemployment rate

According to World Bank data, the total economic volume of the five Central Asian countries in 2022 was 373.9 billion U.S. dollars. The main industries in Central Asian countries are energy and mineral extraction and processing, transit transportation, agriculture and livestock, textiles, and the two major religions, Islam and Christianity. Central Asia is rich in reserves of oil, natural gas, coal, uranium, and other mineral resources, and the distribution of energy resources is relatively concentrated, known as the strategic base for energy and resources in the 21st century. China borders the Central Asian region and territorially shares borders with Kazakhstan, Kyrgyzstan, and Tajikistan. Central Asian countries have shown strong growth in the trade sector and have made remarkable leaps in the last decade, with real GDP growing at an average annual rate of 6.2%. Export earnings, remittances from migrant workers, and foreign direct investment have contributed to rising incomes and declining poverty in Central Asia. Total foreign trade in goods of Central Asian countries in 2021 amounted to $165.5 billion, a six-fold increase over the past two decades; GDP per capita in purchasing power parity (PPP) terms tripled; and the stock of inward foreign direct investment (FDI) reached $211 billion (Vinokurov et al. 2022).

Although the five Central Asian countries are geographically close to each other and have similar patterns of economic development and institutions, there are marked differences in the degree of economic development in each country. In terms of population size, Kazakhstan is the second largest country after Uzbekistan. In addition, Kazakhstan is the largest of the five countries in terms of land area, and its economic development is the best of the five. According to the economic scale (GDP), the five Central Asian countries can be divided into three gradients: Kazakhstan can be listed as the first gradient, Uzbekistan and Turkmenistan as the second gradient, and Kyrgyzstan and Tajikistan as the third gradient. Kazakhstan's economic strength far exceeds that of the other four Central Asian countries, with Kazakhstan's GDP accounting for more than 60 percent of the GDP of the five Central Asian countries (combined) from 2013 to 2022 (Figure 2). In particular, Kazakhstan's GDP share among the five Central Asian countries was 64.9% in 2013. However, in 2014, international oil prices dived all the way from a high of $110 (bbl) in July, down nearly 60%, and by 2015, international commodities as well as oil prices continued to fall, with the average annual price of Brent crude oil dropping from $98.9/bbl to about $53 (bbl). In addition, in 2015, Kazakhstan's main trading partner, Russia, fell into a crisis as a result of the recession in the world economy due to low growth and shrinking external demand, and Kazakhstan's exports fell sharply in the same year (by 42.5% year-on-year). Subsequently, Kazakhstan adjusted its exchange rate policy, however, not very successfully, with a sharp depreciation of the tenge (Kazakhstan's currency) (88% for the year), which resulted in a slowdown in Kazakhstan's GDP growth and a year-on-year decline in its share among the five Central Asian countries. In 2016, Kazakhstan's GDP fell sharply to $137.28 billion, 20 times that of third-tier Kyrgyzstan and Tajikistan, and its share of the GDP among the five Central Asian countries dropped to 50.2%. From 2017 to 2022, Kazakhstan's economy was gradually getting back on track, accounting for more than 59% of the GDP of the five Central Asian countries each year (Sodiqova et al. 2023).

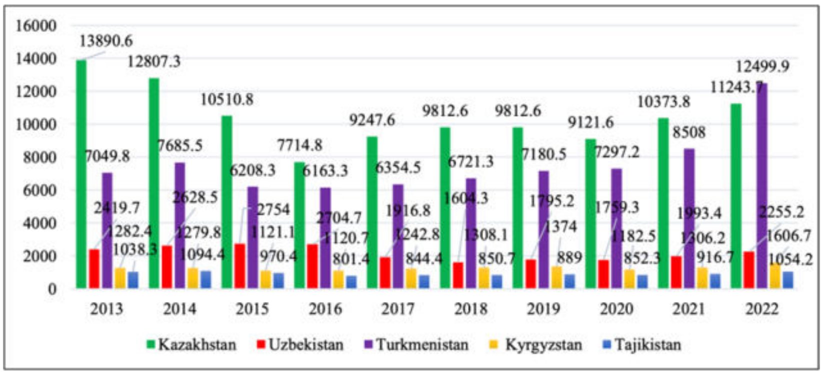
The five Central Asian countries exhibit notable variations in the extent of the wealth gap when assessed by GDP per capita and GNI per capita.

First, according to the comparison of GDP per capita, Kazakhstan and Turkmenistan are at the first level among the five Central Asian countries, and Kyrgyzstan, Tajikistan, and Uzbekistan are at the second level. In 2013-2015, Kazakhstan's GDP per capita was nearly equal to the combined GDP per capita of the remaining four Central Asian countries. Kazakhstan's GDP per capita was above $9,000 from 2013 to 2022, except for 2016, when it was only $7,714.8, which was primarily caused by the depreciation



Data source: World Bank. https://data.worldbank.org.cn/

Figure 2: Comparison of GDP of the five Central Asian countries (in billions of dollars)



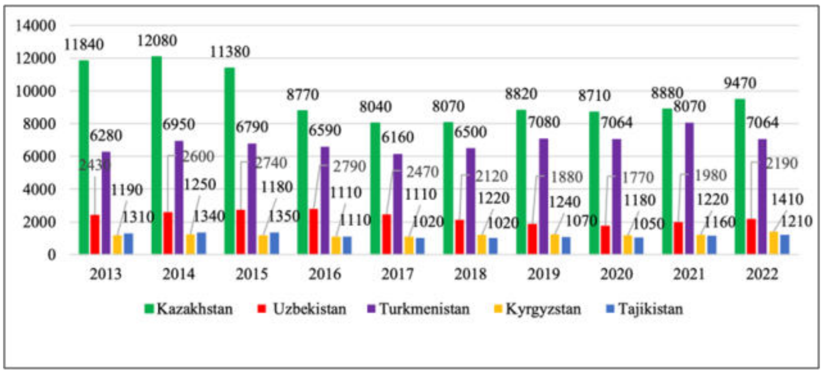
Data source: World Bank. https://data.worldbank.org.cn/

Figure 3: Comparison of GDP per capita in five Central Asian countries (US$)

of Kazakhstan's exchange rate and the decline in economic growth due to the fall in international commodity and oil prices in 2015 (Zhang et al. 2017). It is worth noting that the dynamics of GDP per capita in Turkmenistan in the period 2013-2022 show mainly positive changes, with an average annual growth of 6.2%. Over the course of the decade, Turkmenistan's GDP per capita saw two notable fluctuations, with the biggest increases occurring in 2022 (+46.9%, +$3,391.4) and the biggest declines occurring in 2015 (-19.2%, -$1,477.2); on the whole, however, Turkmenistan's GDP per capita has been increasing gradually. The GDP per capita of the other three countries in the second tier remained essentially unchanged (Figure 3).

Second, according to the latest World Bank GNI per capita classification, Kazakhstan and Turkmenistan were upper-middle-income countries from 2013 to 2022, with a significantly higher level of GNI per capita compared to the other four Central Asian countries, while Uzbekistan, Kyrgyzstan, and Tajikistan were lower-middle-income countries (Figure 4). Kazakhstan's GNI per capita reached $9,470 in 2022, which was 7.8 times higher than that of Tajikistan at the lowest level.

Due to a combination of factors such as downward pressure on the world economy, geopolitical tensions, and the cascading effect of the Russian recession, the economic growth rate of Central Asian countries slowed down from 2013 to 2016. As a result of the COVID-19 pandemic, each country's economic growth rate fell to its lowest points in a decade in 2020, with Kazakhstan, Turkmenistan, and Kyrgyzstan even experiencing negative growth rates of -2.5, -2.4, and -8.4, respectively (Figure 5). Oil production and the rise in global oil prices served as the main drivers of Kazakhstan's economic growth for a considerable amount of time. Due to several factors, including the decline in commodity prices, the cessation of oil production growth in the Kazakh economy, the country's

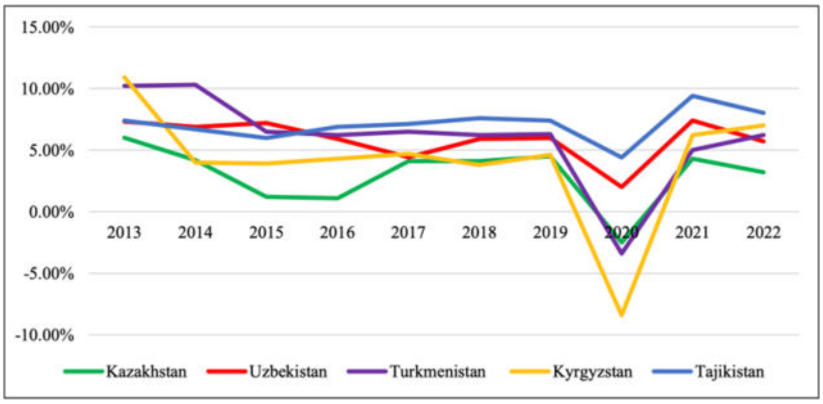


Data source: World Bank. https://data.worldbank.org.cn/

Figure 4: Comparison of GNI per capita in the five Central Asian countries (US$)

continued reliance on raw materials, and a lack of readiness for changes in both internal and external conditions, the GDP growth rate fell from 6.0% in 2013 to 1.1% in 2016 (Zhang et al. 2017). From 2013 to 2022, the economic situation in Uzbekistan remained generally stable, and even in the face of various crises during the COVID-19 pandemic, its economic growth rate remained positive, averaging 5.9%. According to economic experts in Uzbekistan, the country's economy has been able to maintain its high growth rate for three reasons: firstly, the economic situation of Uzbekistan's main neighboring economic partners has remained stable; secondly, Uzbekistan's inflation rate continues to decline; and thirdly, the growth rate of fixed investment has accelerated (Choriev 2022). Kyrgyzstan's GDP growth slowed significantly from 10.9% in 2013 to 4% in 2014, increased by 3.9% in 2015, and showed only modest growth of 4.3% in 2016. International financial institutions have ranked Kyrgyzstan as one of the poorest countries in the post-Soviet region. However, its relatively attractive investment climate and favorable business environment have contributed to the dynamic and, most importantly, effective development of the country's economy. The country's economic growth rate was also very impressive, coming in at 6.2% and 7.0% in 2021 and 2022, respectively. Industry was growing at a significant rate of 11.4%, construction at 8%, trade at 7.5%, and agriculture at 7.3% (Zheirenova et al. 2023). Despite the overall slowdown in global economic growth and three downward revisions of global growth expectations by the International Monetary Organization, Turkmenistan's economy was still able to buck the trend, with its GDP growth rate exceeding 10.2% for two consecutive years in 2013 and 2014, which was a leading position among the five Central Asian countries. However, in 2015, in the context of a complex international economic situation, the annual GDP growth rate decreased sharply to 6.5%. Over the next five years, Turkmenistan successfully implemented large-scale reforms to ensure continued socio-economic development, and its GDP growth rate remained above 6.0%. During the COVID-19 pandemic, various unfavorable factors led to a drop in Turkmenistan's GDP growth rate to -3.4% in 2020. However, over the next two years, against the backdrop of a decline in global economic growth from 6.0% in 2021 to 3.2% in 2022, Turkmenistan's economy showed very strong momentum, with its GDP growth rate remaining at 6.2% for the second consecutive year (Gogoberishvili, Bayar 2023, Trapeznikov 2023). Tajikistan's economic development trend is similar to that of Turkmenistan, with a slight decline in GDP growth from 2013 to 2015, to 6.0% in 2015. Tajikistan's economic growth rate was steady for a long time, remaining above 6.0% for seven consecutive years, and even during the COVID-19 pandemic, Tajikistan's GDP growth rate remained at 4.4%. With the end of the COVID-19 pandemic, Tajikistan's economy rebounded rapidly, becoming the fastest-growing country in Central Asia in the last two years, reaching 9.2% in 2021 and 8% in 2022. As in previous years, according to the authorities, the growth was mainly due to an increase in industrial and agricultural production (Chorshanbiyev 2023).

Higher inflation rates are one of the main challenges for Central Asian countries. The Asian Development Bank calculates the average inflation rate in Central Asian countries



Data sources: World Bank. https://data.worldbank.org.cn/

Figure 5: Comparison of economic growth rates of the five Central Asian countries (%)

based on data from the International Monetary Fund, which is a minimum of 7% in 2015, reaches 8.4% in 2020, increases to almost 13% in 2022, and predicts that it will decrease to 7.1% in 2023 (Khitakhunov 2022). Reasons for high inflation in Central Asia are (Chen 2021):

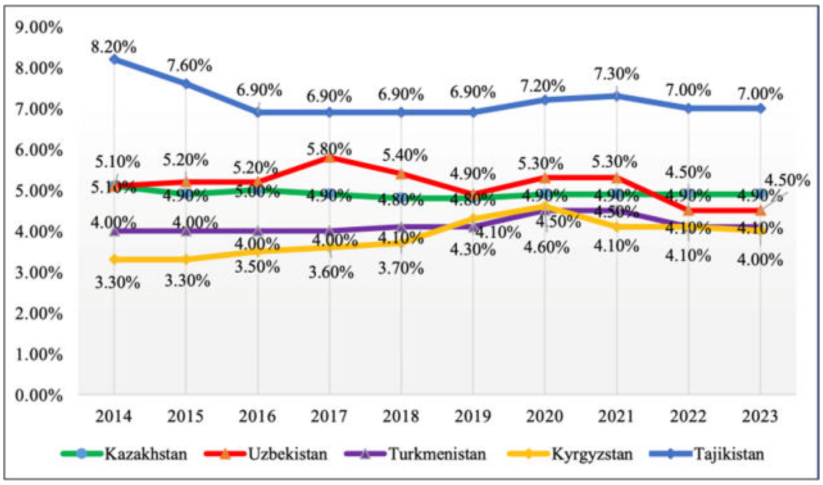
1. The impact of massive stimulus measures in developed economies ripples across the globe.
2. A mismatch between supply and demand pushes up inflation.
3. A continued rise in commodity prices.

Overall, Tajikistan's unemployment rate is the highest among the five countries, with a trend of decreasing and remaining flat from 2014 to 2023. In the other four countries, the trend is basically flat. It is noteworthy that the unemployment rate in Kyrgyzstan is essentially the lowest of the five countries (Figure 6). For more than a decade, Kazakhstan's unemployment rate has been in the range of 4.7-5.0%, remaining unchanged even as global unemployment rose sharply during the 2020 pandemic. The other four countries showed a slight upward trend during this period.

With regard to unemployment in the Central Asian countries, the reasons for this are as follows:

1. Shortage and uneven distribution of jobs.
2. Low competitiveness of the labor market.
3. Insufficient investment in the economy.
4. Lack of qualified specialists.
5. Rapid population growth, which puts additional pressure on the labor market.
6. Regional imbalances: market indices are much higher in economically developed regions than in other regions, leading to regional unemployment.
7. The shadow sector of the economy: informal work and lack of labor contracts create frictional unemployment and reduce tax revenues (Zhavmanov, Murodkulov 2023).

Khitakhunov (2022) suggests that in order to fight inflation, central banks need to normalize their balance sheets and raise the real discount rate above the neutral level fast enough and long enough to control inflation and inflationary expectations. Fiscal policy should also support monetary policy to moderate demand in countries with excess aggregate demand and overheated labor markets. Authorities should take into account



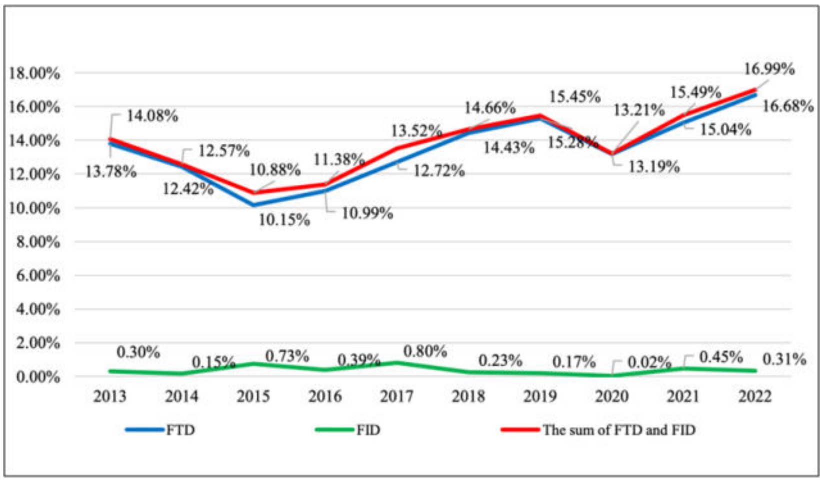
Source: World Bank: https://data.worldbank.org/indicator/SL.UEM.TOTL.ZS?end=2023&locations-=TM&start=2013

Figure 6: Comparison of Unemployment Rates in the Economies of the Five Central Asian Countries (%)

that efforts to stimulate supply can support monetary policy by reducing inflation. In a supply-constrained environment, increasing government spending or implementing tax cuts would only push up inflation further. Thus, price instability could jeopardize all government efforts to increase economic growth. In addition, rising costs of living can jeopardize the most vulnerable groups in society, as poor households tend to spend more than others on food, heating, and fuel, where price increases are particularly pronounced. When designing policies to protect vulnerable groups, policymakers should take care to avoid broad price caps or subsidies on food and energy, which can inadvertently increase demand by reducing or eliminating supply incentives. Almost all Central Asian countries have responded by raising interest rates, and fiscal authorities have also proposed and planned a variety of measures to counter inflation and mitigate its effects. Indeed, there is a need to first conduct a comprehensive study and assess the contribution of all factors and policy measures, including trade, monetary and fiscal measures, external shocks, and other relevant factors. Second, measures need to be coordinated between monetary and fiscal authorities and within fiscal policy. And third, policy implementation, including supply-side measures, should be based on analysis and empirical research (Khitakhunov 2022).

3 Results and discussion

Analysis of economic relations between China and Central Asian Countries. The article analyzes the trade and investment data between China and Central Asian countries from 2013 to 2022 based on data from World Bank, China Statistical Yearbook, and Statistical Bulletin on China's Outward Foreign Direct Investment. The trade and investment data between China and Central Asian countries from 2013 to 2022 have been statistically organized, and the trade dependence (total trade/GDP) and investment dependence (investment flow/GDP) of Central Asian countries on China during this decade have been calculated. Foreign trade dependence is an indicator of a country or region's economic dependence on import and export trade, and investment dependence is an indicator of a country or region's economic dependence on foreign investment.The sum of foreign trade dependence and foreign investment dependence can serve as an indicator to measure the degree of openness of a country or region to the outside world, which can reflect the degree of openness of a country or region and can also be used to measure the degree of dependence of a country or region's economy on the international market and foreign investment. Therefore, the degree of openness to the outside world has a great deal to



Data sources: World Bank (https://data.worldbank.org.cn/), China Statistical Yearbook (https://-www.stats.gov.cn/sj/ndsj/), and China's Outward Foreign Direct Investment Statistical Bulletin (http://images.mofcom.gov.cn/hzs/202310/20231007152406593.pdf)

Figure 7: Trends in economic dependence of the five Central Asian countries on China

do with a country's or region's stage of economic development, economic structure, level of economic outward orientation, and even its choice of exchange rate.

We focus on the relationship between the economic dependence of Central Asian countries on China (sum of foreign trade dependence and foreign investment dependence) and the economic growth of the Central Asian region. Since the trade volume between China and Central Asian countries is significantly larger than the investment volume, we take trade dependence as the focus of our study. The trend of trade dependence can be divided into three stages: from 2013 to 2015 as the first stage, Central Asian countries' trade with China decreases; from 2015 to 2019 as the second stage, bilateral trade activities continue to rebound, and trade dependence on China reaches 15.28% in 2019; and from 2020 to 2022 as the third stage, which is due to the impact of the COVID -19 pandemic, bilateral trade is severely hampered in 2020 and then picks up steadily in the following two years, reaching the highest level of 16.68% in the last decade in 2022. There is no uniform and precise standard or conclusion regarding what level of foreign trade dependence should be considered reasonable, and the degree of external dependence varies greatly depending on the structure of the industry (Nuhanović, Nurikić 2021). Since China's investment in Central Asian countries accounts for a relatively small proportion of their total GDP, the trend of investment dependence is relatively flat, with fewer ups and downs. In fact, the sum of trade dependence and investment dependence of Central Asian countries on China is more representative of the degree of dependence and openness of Central Asian countries on China, and the trend of this indicator is generally showing a slow increase from 2013 to 2022 (Figure 7). To some extent, increased openness to the outside world also means an increased contribution to national economic development. In terms of investment, the cooperative relationship between China and Central Asian countries is dominated by one-way investment from China into Central Asian countries, which to a certain extent improves the capacity and level of economic development of Central Asian countries. In addition to investments in the fields of energy and minerals, water conservancy, power engineering, petrochemicals, and finance, China has also been actively promoting infrastructure construction in the five Central Asian countries and has already built a comprehensive interconnection system of highways, railroads, air transportation, and networks. At present, the China-Kyrgyzstan-Uzbekistan highway, the China-Tajikistan highway, the China-Central Asia gas pipeline, the China-Kazakhstan crude oil pipeline, and other projects are in safe and stable operation (Wang 2023b).

Before we analyze the relationship between the dependence of Central Asian countries on China's economy and the economic growth rate of Central Asian countries (the average of the growth rates of the five countries), we calculate the correlation coefficient between

Table 1: Correlation coefficients between the economic dependence of the five Central Asian countries as a whole on China and the economic growth rates of the five countries from 2014 to 2022

Year	Change in economic dependence (in years)	Change in GDP growth rate (in years)	Correlation coefficient	Average correlation coefficient
2014	-1.51	-1.94	0.78	
2015	-1.69	-1.46	1.16	
2016	0.50	-0.08	-6.25	
2017	2.14	0.48	4.46	
2018	1.14	0.16	7.13	0.86
2019	0.79	0.24	3.29	
2020	-2.24	-7.34	0.31	
2021	2.28	8.04	0.28	
2022	1.50	-0.44	-3.41	

Data sources: World Bank (https://data.worldbank.org.cn/), China Statistical Yearbook (https://-www.stats.gov.cn/sj/ndsj/), and China's Outward Foreign Direct Investment Statistical Bulletin (http:-//images.mofcom.gov.cn/hzs/202310/20231007152406593.pdf)

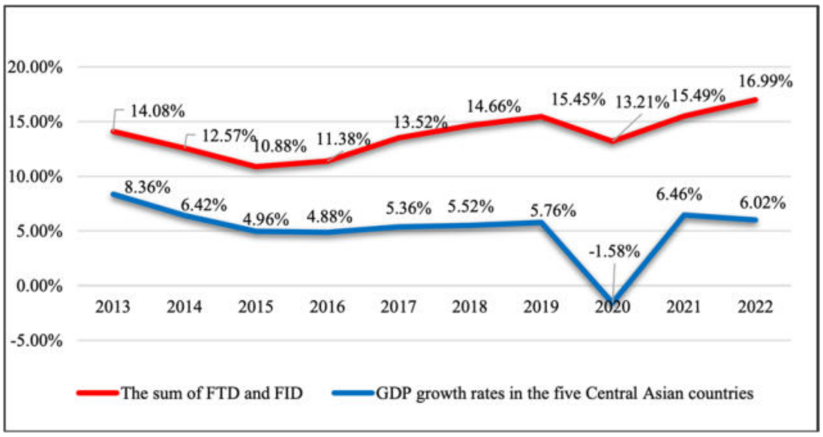


Figure 8: Comparison of trends in the economic dependence of the five Central Asian countries on China with trends in the GDP growth rates of the five Central Asian countries

them, which is the ratio of the change in the sum of trade dependence and investment dependence to the change in the GDP growth rate (in years). The economic dependence here refers to the degree of economic dependence of the five Central Asian countries as a whole on China, and similarly the economic growth rate refers to the economic growth rate of the five Central Asian countries as a whole. In other words, if the correlation coefficient between them is closer to 1, it indicates a higher degree of correlation, and a higher degree of correlation implies a greater influence of trade and investment on GDP growth. Consequently, we can conclude that the correlation coefficient generally represents China's economic influence on Central Asian nations.

The average correlation coefficient was calculated to be 0.86 for the period from 2013 to 2022. (Table 1). We could also find that the trend of economic dependence of Central Asian countries on China (the sum of trade dependence and investment dependence) is approximately similar to the trend of economic growth rate of Central Asian countries (Figure 8). By analyzing the two in combination, it can be shown to a certain extent that trade and investment from China have a great effect on the economic development of Central Asian countries; that is to say, when China's trade and investment with

Central Asian countries changes, the economic growth of Central Asian countries will also be changed accordingly. For example, if China increases or decreases the amount of investment and trade in the five Central Asian countries, then the GDP growth rate and total GDP of the five Central Asian countries will change accordingly, and this correlation can be expressed by the correlation coefficient. At the same time this expresses the degree of influence of the Chinese factor on the economic development of the Central Asian countries. In addition, we must also consider some special energy, resources, and other dependent commodities in bilateral trade, which are essential for both sides to rely on. For example, China's net exports to Central Asia are mainly manufactured goods in labor-intensive and capital-intensive commodities, including high-grade commodities and high-tech products, and people's consumption of ordinary goods, which forms a typical pattern of international trade in the division of labor exchange of primary commodities and manufactured goods. On the other hand, the commodities exported to China by the five Central Asian countries are mainly energy, mineral products, and primary processed products, which shows the obvious trade characteristics of the ladder division of labor (Rasoulinezhad et al. 2022).

With the establishment of the Shanghai Cooperation Organization (SCO) in 2001, China's cooperation with Central Asian countries expanded from bilateral to multilateral. With the opening of the crude oil pipeline between China and Kazakhstan and the China-Central Asia natural gas pipeline in 2006 and 2009, respectively, China imported large quantities of oil and gas from Kazakhstan, Uzbekistan, and Turkmenistan, which marked the beginning of the great development of oil and gas cooperation between China and Central Asian countries. Oil and gas and other bulk strategic resource commodities have become one of the most important trade commodities between China and Central Asian countries, and the dependence on each other's trade has been increasing (CCTV 2022). In 2013, China imported 11.98 million tons of crude oil from Kazakhstan, reaching the largest amount ever. It dropped directly to 6.27 million tons in 2014, and crude oil deliveries remained stable in the following years. The China-Kazakhstan crude oil pipeline delivered 10.88 million tons of crude oil to China in 2019, second only to 2013. In 2022, the main export destinations of Kazakhstan's crude oil were Italy (18.2 million tons), the Netherlands (6.1 million tons), South Korea (5.8 million tons), and China (5.3 million tons). By 2022, Central Asian countries have transported a cumulative total of 150 million tons of crude oil to China through the China-Kazakhstan crude oil pipeline. (Source: China General Administration of Customs and PetroChina West Pipeline Company)

In 2017, Central Asian countries transferred 38.7 billion cubic meters of gas to China through the China-Central Asia Gas Pipeline, with Turkmenistan being the largest importer of pipeline natural gas to China, with an import volume of 26.9 billion square meters, accounting for 84.6% of the total volume of pipeline natural gas imported by China. Natural gas exports from Central Asia to China totaled 47.49 billion cubic meters in 2018. In 2021, China's gas imports from Central Asia were 44.1 billion cubic meters, while gas from the Sino-Russian Eastern Route was about 10 billion cubic meters in the same year, which made Russia China's second-largest pipeline natural gas importer after Turkmenistan from 2021 onwards. In 2022, China imported 43.2 billion cubic meters of natural gas from Central Asia, accounting for about 30% of China's total natural gas imports. By 2022, Central Asian countries have transported a cumulative total of more than 400 billion cubic meters of natural gas to China through the China-Central Asia Gas Pipeline (PetroChina West Pipeline Company 2022). (Source: China General Administration of Customs, PetroChina West Pipeline Company)

Besides, small entrepreneurs in Central Asian countries are also more dependent on China due to the region's high demand for the Chinese market and the wide range of cooperation with China. These small entrepreneurships mainly operate in the fields of engineering, chemicals, building materials, green economy, artificial intelligence, e-commerce, water reservoirs, processing industry, automobiles, electricity, transport, medical care, education, daily necessities, food and oil, etc., which cover almost all the fields needed for people's daily life.

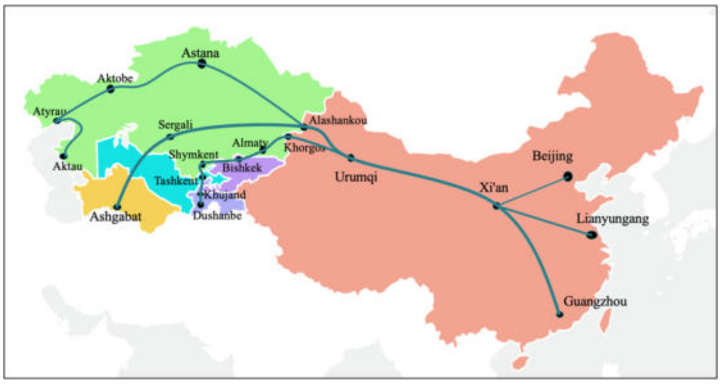
Although none of Central Asian countries has access to the world's oceans, the region's location at the intersection of trade routes between Asia, the Middle East, and Europe gives it the advantage of a geostrategic position, and like the Silk Road, which once connected the five major economic centers of Greater Eurasia (China, India, Persia, the Middle East, and Europe), the region's modern transportation routes not only play a transit role but also contribute to the development of industry, services, and trade in all the countries of the region (Vinokurov et al. 2022). So, among the many factors to promote the economic development of Central Asian countries, the China-Europe railway is also a factor worth mentioning because the China-Europe railway passes through the Central Asian region, and there is a branch that we call the China-Central Asia Railway Express. From the perspective of transportation economic characteristics, the transportation cost of the China-Europe railway is about one quarter to one fifth of that of air transportation, and the transportation time is about one quarter to one third of that of sea transportation. Considering the cost of in-transit time for high value-added goods, the China-Europe railway can save 8% - 20% of the overall logistics cost compared with traditional sea-railway transportation, and it has a significant comparative advantage for specific logistics needs such as high value-addedness and strong timeliness. For example, it can facilitate the transportation of bulk e-commerce products, light industry and high-tech electronic products, and foodstuffs such as wines that require refrigeration, all of which have requirements on delivery time (Wei, Wang 2023). Compared to freighters, the China-Europe railway is more environmentally friendly; for example, for every 40-foot (12-meter) container transported, the trains produce only 4% of the carbon dioxide emissions of freighters (Josephs 2017). With the advent of the China-Europe railway, shipping large volumes of goods is no longer the only option, while the central and western parts of China and the central and eastern inland parts of Europe have become frontline windows for opening up. In this way, products no longer need to be transported from the inland hinterland to the coastal ports. Instead, inland cities such as Chongqing, Chengdu, Wuhan, Almaty, Budapest, Łódź, Warsaw, and Prague have become new import and export distribution centers, which makes the development of China's central and western regions have new growth points, while Central Asia has gradually become an emerging market for transnational logistics (Zhao et al. 2020).

A rail freight service from China to Central Asia, known as the Central Asia Railway, gathers commodities from all over China for export to Kyrgyzstan, Kazakhstan, Uzbekistan, Tajikistan, and Turkmenistan. All routes now offer railroad freight services to meet the expanding commercial demands of the China-Central Asia economic belt. Three routes make up the China-Central Asia Railway (Lin 2023) (Figure 9). The first route goes from Alashankou (China) to Aktau (Kazakhstan) via Astana (Kazakhstan), Aktobe (Kazakhstan), and Atyrau (Kazakhstan). The second route goes to Ashgabat (Turkmenistan) from Khorgos (China) via Sergali (Kazakhstan). The third route goes through Almaty (Kazakhstan), Bishkek (Kyrgyzstan), Shymkent (Kazakhstan), Tashkent (Uzbekistan), and Khujand (Tajikistan) on its way from Khorgos (China) to Dushanbe (Tajikistan).

Based on the above factors regarding China's influence on the sustainable economic development of Central Asian countries, the article predicts that the dependence of Central Asian countries on China will continue to rise in the future for three reasons: first, geographically, China and Central Asian countries are neighbors to each other, so they are easily influenced by each other. Second, China has achieved great success in the economy, science, and technology, while Central Asian countries are still weak. Third, economic globalization is the trend of world development, and regional economic and economic integration is a prerequisite for economic globalization.

4 Conclusions

The economic role and prospects of Central Asia are still not fully recognized by the world, and due to inertia, the international community does not yet see the region as an important player on the world economic map. However, the region is changing, and over the past 30 years, Central Asian countries have made significant progress in their development. As a neighbor of Central Asia, China has developed into a world eco-



Notes: Figure drawn by the author

Figure 9: China-Central Asia railroad routes

nomic giant as a result of its large, advanced, and innovative economic policies. Overall, Central Asia has become the most important trade corridor and trade transit point for China along the Belt and Road, which is of strategic importance. For Central Asian countries, China, as the largest trading partner of Central Asian countries, has an important value and an increasingly irreplaceable role in the stable development of their economies. Therefore, both China and Central Asian countries have the common needs of expanding economic space, developing infrastructure, exploiting local potential, adjusting economic structure, and improving people's lives (Wang 2023a). The scale of trade cooperation between China and Central Asian countries is not exactly the same as the economic scale and development level of other countries, which depends on a variety of factors such as the degree of mutual strategic interface, geopolitics, economy, culture, development of international relations, and other factors. Central Asian countries are far more dependent on China's foreign trade than China is on Central Asian countries, particularly in recent past when the global political, security, and economic landscape is full of uncertainties. Since gaining independence, the Central Asian nations have peacefully settled their border conflicts with China, and traditional security concerns such as territorial disputes do not exist. Moreover, good relations have been maintained between successive Chinese leaders and the leaders of Central Asian countries, which has laid a good political foundation for mutual investment and cooperation in large-scale, long-term projects (People's Daily 2022). The WTO remains an important mechanism for international economic cooperation, and the accession of Central Asian countries to the WTO has established a more orderly environment and rules-based platform for regional cooperation. In the process of developing the world economy, regardless of the development of counter-globalization and trade protectionism, Central Asian countries, which are already fully enjoying the benefits of globalization of the world economy, have a clear attitude of opening up to the outside world, while at the same time actively integrating into the global economy. Economic and trade cooperation between Central Asian countries and China will appear more standardized, transparent, and predictable under the unified system of the WTO and other international rules.

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Positive Outcomes of Cross-Border Tourism Development Cooperation: A Case of Kazakhstan, Kyrgyzstan and Uzbekistan

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Abstract. The development of cross-border tourism between neighboring countries has become increasingly popular in recent decades. In European countries where the visa-free regime is established, this scheme is well developed and positively affects the development of the country's economy. Developing cross-border areas and establishing cross-border cooperation with neighboring countries is one of the priorities of Central Asian state policy. In the last ten years, several large-scale cross-border platforms aimed at developing tourism have been implemented among the more developed countries (Kazakhstan, Kyrgyzstan and Uzbekistan) in Central Asia, so our study was based on the border regions of the three countries mentioned above. The study aims to highlight the benefits of cooperation in cross-border tourism by examining the experiences and expectations of experts who are well-versed in the field of tourism. A qualitative research method was mainly used in semi-structured interviews focused on the positive results associated with the development of cross-border tourism among people familiar with the region's tourism. The analysis showed that according to the informants, the development of cross-border tourism has a moderate impact on the joint development of infrastructure projects by countries. The results also showed that all of the survey participants believed that cross-border tourism would provide an impetus to strengthen joint tourism marketing and the exchange of knowledge and innovation between countries. In short, it can be seen from the results of the research that the respondents generally highly appreciated the positive influence of the development of cross-border tourism on the growth of the country's economy.

Key words: cross-border tourism; cooperation; advantages; Kazakhstan; Kyrgyzstan; Uzbekistan; Central Asia

1 Introduction

Cross-border partnerships are a unique type of organizational cooperation that is geographically anchored in the borderlands of two or more countries. One of the main advantages of cross-border project cooperation is that the project partners can test technology and socio-economical techniques in various settings by cooperating across

Source: authors' own work

Figure 1: Popular tourist attractions along the borders of KZ, KG and UZ

national boundaries (Castanho et al. 2018). In cross-border areas, formal and informal, bilateral or networked cooperation of various actors in the cross-border market may develop, including non-governmental organizations such as local governments, associations, clubs, foundations, etc. (Kurowska-Pysz, Szczepańska-Woszczyna 2017). Cooperation across borders helps to lessen the negative effects of state borders and the areas around border areas, thereby enhancing the socioeconomic standing of the local community (Dunets et al. 2019). Tourism frequently serves as a strategic policy instrument in borderlands to enhance local perceptions, sculpt identity narratives, and promote cross-border contacts (Stoffelen, Vanneste 2017). According to Prokkola (2011), through functional (institutional-infrastructural) and imaginary (socio-cultural, identity-creating) consequences, tourism projects can promote cross-border regionalization processes, altering border landscapes and contextualizing chances for regional development.

1.1 Importance of the study

Although Central Asian countries have been active in developing the tourism industry, the percentages of the tourism industry to the GDP in the Central Asian countries are about 5% on average. The competitiveness of tourism is low compared to some developing Asian countries. In the Central Asian countries, the challenges in promoting the tourism sector are effective utilization of tourism resources, planning and implementation of marketing strategies, infrastructure development related to tourism, and securing employment opportunities through human resource development for the younger generation. Based on the above background, this survey will collect detailed information on the current status of the tourism sector in three countries in Central Asia and summarize the current situation and issues related to the sustainable development of tourism and related industries. Furthermore, taking into account the great role of tourism in the implementation of sustainable development, it is undeniable that the study of the impact of cross-border cooperation in the field of tourism on economic development is a relevant topic.

Let's briefly explain why the border regions of 3 states in Central Asia were chosen for our research topic: firstly, the political climate of the 3 mentioned countries is stable, as well as friendship and cooperation between countries are deep; secondly, the socioeconomic situation of countries is improving every year; the last and most important factor is that the 3 countries are very rich in cultural and natural tourism resources, and most of these resources are concentrated in the border regions between them and complement each other. For example, as you can see in Figure 1, most of the famous tourist destinations included in the world heritage list are located near the common borders of the three countries.

2 Literature Review and Research Hypotheses

One of the fastest growing industries in the world is tourism, which not only helps many developing countries, but also some industrialized countries to progress economically and socially. The benefits of tourism development are defined as creating jobs, strengthening the local economy, contributing to local infrastructure development, helping to conserve the natural environment, cultural assets, traditions and reduce poverty and inequality (Ridho, Alisa 2020). Furthermore, because of its substantial functions as a source of foreign exchange earnings, the generation of employment opportunities and an important source of public income in many countries, tourism has drawn a lot of attention in the literature on economic growth (Ertugrul, Mangir 2015). In addition, by fostering cultural and experiential exchanges between source and origin nations, tourism increases social capital. Finally, due to initiatives in green tourism, the travel and tourist industry may also play a significant role in promoting the preservation of the environment and species (Shahzad et al. 2017). The tourism-led growth (TLG) hypothesis has emerged as a result of the favourable and interdependent effects of tourism development on the economy (Balaguer, Cantavella-Jorda 2002). This hypothesis holds that one of the key factors influencing long-term economic growth is tourism. Therefore, it is essential for governments to determine the empirical viability of the TLG hypothesis in a nation in order to allocate resources to tourism development as efficiently as possible and so to reap the numerous benefits that follow (Shahzad et al. 2017). If tourism is indeed an important means of redistributing consumption potential between economies and thus plays a major role in determining local or regional GDP, then it is important to know in which direction this redistribution takes place by choosing a tourist destination (Tubadji, Nijkamp 2018).

Tourism, together with labour migration, was noted as a source for the B-S effect by Samuelson (1964). In addition to classifying tourism as a special category of location-specific services, Samuelson recognises that labour migration and tourism are the two main factors in the relocation of consumption potential. In our contemporary society, when individuals are more mobile, we see rising tourism and falling transportation costs, which helps to highlight the immense significance and potential of tourism for counter-balancing the B-S hypothesis (Tubadji, Nijkamp 2018). A sector such as tourism, which accounts for about 3% of the GDP of most economies, needs to be given a lot of attention (Aslan 2015, Kumar 2014, Kumar, Stauvermann 2016, Perez-Rodríguez et al. 2015). Outbound (or foreign) tourism can be seen as a method for shifting the capacity for consumption across nations. Additionally, recent research has demonstrated that tourism has a positive impact on international trade as well as economic expansion (Cortes-Jimenez et al. 2011, Fry et al. 2010). These facts serve as compelling evidence that the relationship between tourism, the trading sector, and socioeconomic development in a nation should not be disregarded. Since tourists make purchases in local markets, it is natural to assume that tourism has an impact on receiving countries.

2.1 Benefits of Cooperation in Cross-border Tourism

Tourism-related cross-border collaboration is a key driver of regional growth. Joint cross-border tourism cooperation has always many benefits and positive results. These include joint development of infrastructure, strengthening of regional identity and marketing, improving regional economies, and promoting innovation and knowledge transfer (Hartmann 2006, Park 2014, Timothy 2002, Timothy et al. 2014, Weidenfeld 2013). It is clear that there is a connection between borders and tourism, different levels of cross-border cooperation, and complex network destinations and attractions in border areas (Skäremo 2016).

The tourism industry can be attributed to certain parts of the improved relations in the world. Some people think it can be used as a means to develop local infrastructure (Timothy 2002). In particular, tourism between border areas has the potential to increase cooperation across political borders and preserve the surrounding natural landscape. These changes are due to the increased demand for additional border crossings, border demarcations, and border-related services provided by the tourism industry in an area

(Timothy et al. 2014). Effective and well-functioning infrastructure is very important to the tourism industry. With the internationalization of infrastructure construction in border areas, the quality of transportation can meet the needs of tourists. Cross-border cooperation and networking related to infrastructure development can reduce the expensive and possibly unnecessary duplication of facilities and services frequently used by tourists such as airports, hotels, and shopping centers (Timothy 2002). Therefore, through cross-border cooperation, it is possible to effectively use the infrastructure and services related to tourism.

Effective marketing and enhanced regional identity are one of the advantages of cross-border tourism development (Skäremo 2016). The Boundaries dividing countries sometimes turn into historical sites or natural attractions. Cooperation in the field of cross-border tourism can be understood as an important force in changing the function of borders. The appearance of transnational identities is the result of increased mobility in border areas and deeper cross-border partnerships (Prokkola et al. 2015). In order to enter a broad market, an international reputation is highly valued in the tourism industry. Therefore, the promotion and marketing work of multinational companies in border areas is particularly important (Skäremo 2016). Through cooperation in marketing, there will be greater opportunities to increase the tourism potential of the entire region and bring greater benefits to stakeholders (Timothy 2002).

Cooperation in the field of cross-border tourism can be a catalyst for innovation and knowledge exchange. Regions have become important for the creation and transfer of knowledge, which is due to the globalization of the economic order, as well as the growth of knowledge and a creativity-based economy (Skäremo 2016). The cluster of actors and organizations in the border areas is particularly important because they can facilitate the flow of knowledge across borders. The benefits of engaging in innovative clusters can lead to access to knowledge and learning processes that are difficult to obtain in the marketplace (Park 2014). Maintaining the competitiveness of the region is important in the world market (Hartmann 2006), and public regional participants involved in the development of tourism may benefit greatly from participating in a wide range of cooperation across national borders. Thus, they will gain new valuable knowledge and have great opportunities to increase the tourist potential of the region (Skäremo 2016).

Other results of the further development of cross-border tourism in border areas may include a general increase in cross-border travel and social changes (Skäremo 2016). Improving the regional economy and creating employment opportunities is another benefits of tourism in border areas (Skäremo 2016). Tourism is usually a method to get hard currency, and it may improve the balance of payments. Therefore, it has become an integral part of economic transformation (Timothy 2002). As a result of the development of tourism, socio-economic growth has become a powerful tool for changing the shape of nation-states by modifying borders and territorial exchanges (Timothy et al. 2014). Creating new jobs, improving living standards, increasing regional incomes and establishing efficient governance are additional benefits of cross-border tourism cooperation (Timothy 2002). Therefore, the development of cooperation in the field of cross-border tourism plays an important role in the social and regional development of border areas. Tourism is not the main driving force for changing border functions in some areas. However, subsequent changes in border procedures and the function of border tourism often become important users of border territories (Timothy et al. 2014). Sometimes tourism is seen as a symbol of freedom because it allows citizens to travel freely, and by allowing and encouraging closer interaction between tourists and host communities, it can also serve as a catalyst for social change (Timothy 2002). Consequently, the development of cross-border tourism can lead to the efficient use of border areas and to strengthen the interaction between tourists and the region as a means of allowing and encouraging citizens to travel across borders (Skäremo 2016).

Our study seeks to update and expand previous studies by Skäremo (2016), focusing on benefits of cross-border tourism development in the Öresund Region, evaluating the advantages and challenges associated with collaborations between neighboring countries with a perspective on visitors and private entrepreneurs in border regions. The above-mentioned research has been proven among countries with advanced management systems, developed economies and high education levels of the population, while our study area is a region with an imperfect management system, low level of economic development, and a relatively low average level of education of the population. Therefore, in order to increase the accuracy of the research results, we selected the survey participants in our research from among the qualified specialists who know the industry well.

Thus, the main purpose of this study is to evaluate the positive effects of the development of cross-border tourism between countries on the example of the border areas. In order to meet the objectives, a set of research hypotheses was formulated that relate the benefits of cross-border tourism development cooperation between neighboring countries with potential explanatory variables usually referred to in the empirical literature, and which we will now present:

Hypothesis 1 : Cooperation in the development of cross-border tourism has a positive impact on the joint development of infrastructures.

Hypothesis 2 : Cooperation in the development of cross-border tourism has a positive impact on the strengthening of joint tourism product marketing.

Hypothesis 3 : Cooperation in the development of cross-border tourism has a positive impact on the improvement of innovative and knowledge exchanges.

3 Study Area Overview

3.1 Study area description

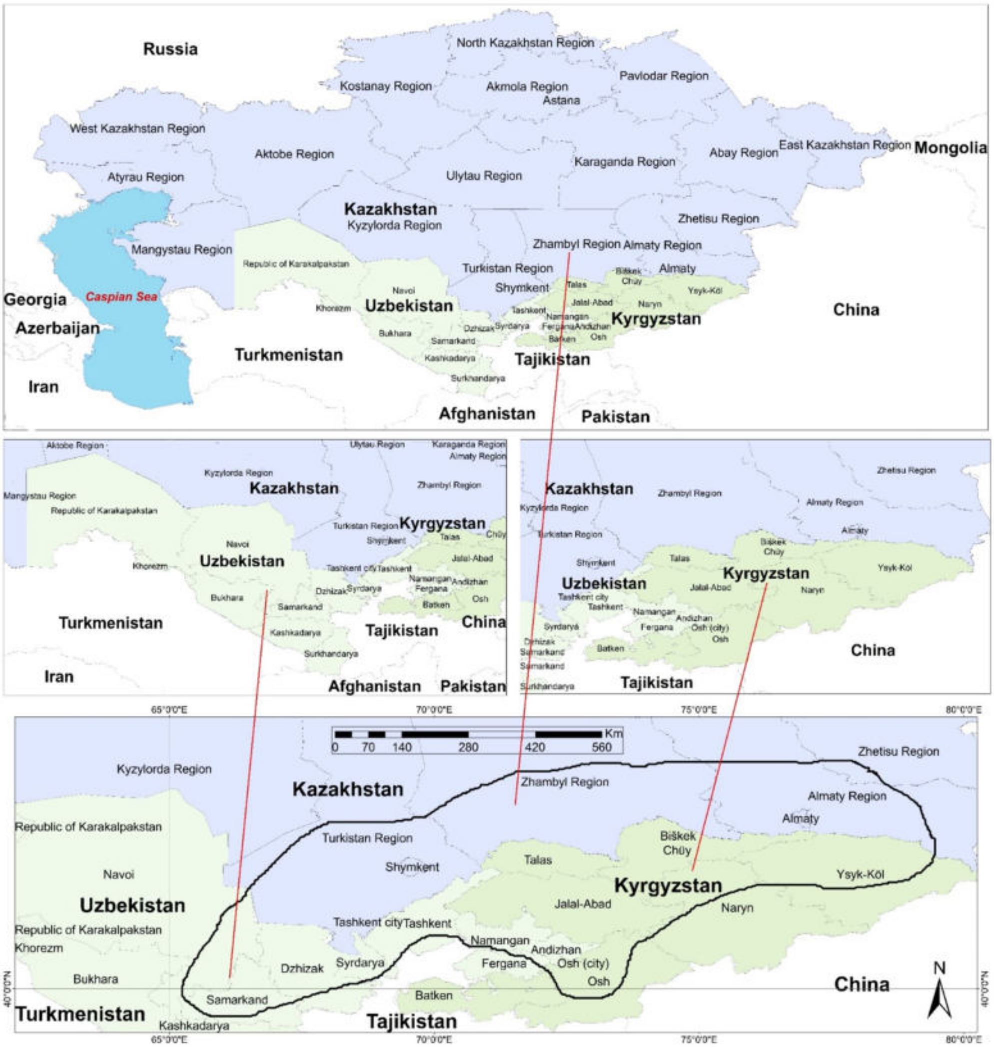
Kazakhstan, Kyrgyzstan and Uzbekistan are separated by the beautiful Tien-Shan mountain range, and these regions were the intersection of nomadism and ancient settlement. Therefore, these regions, often rich in recreational, cultural and natural resources, offer great potential for sustainable tourism development. Leading Central Asian nations Kazakhstan and Uzbekistan have collaborated in the area of cross-border tourism for both of their mutual benefits. (Sergeyeva et al. 2022).

Kazakhstan (KZ) is the largest country in Central Asia and the ninth largest in the world. It is bounded on the northwest and north by Russia, on the east by China, and on the south by Kyrgyzstan, Uzbekistan, the Aral Sea, and Turkmenistan; the Caspian Sea bounds KZ to the southwest. Law on Tourism in KZ was enacted in 2001 and has undergone multiple amendments. The most recent amendment was made in April 2020, and the law is shifting from a state-led tourism law for the management of tourists to one that stipulates the role of the state in guaranteeing and regulating the activities of private travel agencies.

Kyrgyzstan (KG) is one of the smallest countries of Central Asia. It is bounded by KZ on the northwest and north, by China on the east and south, and by Tajikistan and Uzbekistan on the south and west. Most of KG borders run along mountain crests. According to the National Development Strategy of the KG for 2018 - 2040, the tourism sector is one of the priority sectors, along with mining, agroindustry, and light industry. The tourism sector is positioned as a priority development sector with mining, agroindustry, and light industry.

Uzbekistan (UZ) lies mainly between two major rivers, the Syr Darya (ancient Jaxartes River) to the northeast and the Amu Darya (ancient Oxus River) to the southwest, though they only partly form its boundaries. UZ is bordered by KZ to the northwest and north, KG and Tajikistan to the east and southeast, Afghanistan to the south, and Turkmenistan to the southwest. In July 2019, a new Tourism Law was enacted, replacing the old Tourism Law enacted in 1999. While the old Tourism Law was state-centric, focusing on managing tourists with an emphasis on national security, the new Tourism Law sets rules for implementing tourism as an economic activity focusing on tourists and tourism businesses. In addition, the new Tourism Law refers to the terminology used abroad and in the UNWTO to ensure that it is in line with international standards.

The three above mentioned Central Asian countries (KZ, KG and UZ) have experienced economic growth of between 4% and 6% from 2010 to 2019. Despite high rates of economic growth in recent years, GDP per capita in Central Asia was higher than



Source: authors' own work

Figure 2: Border regions between KZ, KG and UZ

the average for developing countries only in KZ in 2013 (PPP$23,206). It dropped to PPP$5,167 for UZ, home to 45% of the region's population, and was even lower for KG (Mukhitdinova 2015). GDP per capita in 2019 is 7,830 US dollars for KZ, where oil and natural gas are exported, 1,323 US dollars for the KG, and 1,725 US dollars for UZ (JICA 2022). KZ leads the Central Asian region in terms of foreign direct investments. The Kazakh economy accounts for more than 70% of all the investment attracted in Central Asia. In terms of the economic influence of big powers, China is viewed as one of the key economic players in Central Asia, especially after Beijing launched its grand development strategy known as the Belt and Road Initiative (BRI) in 2013 (Cheung, Hong 2018).

3.2 The Basis for Developing Cross-border Tourism between KZ, KG and UZ

The history of traveling between KZ, KG and UZ has seen considerable variations. Until the 1990s, when it was part of the Soviet Union, people in present-day KZ, KG, and UZ did not have strict border restrictions, and moved freely between the republics. After the end of the Soviet era, border crossings were tightly controlled and population movements began to decline. However, with the end of the crisis in the countries and the rapid development of the market economy, the movement of the population between the three countries to trade, travel and visit for relatives and friends was revived.

After the end of the crisis in 2009, the three neighbouring countries began to diversify

Table 1: The visitor numbers between KZ, KG and UZ from 2014 to 2018

Kazakhstan	▲ **2018**	▲ **2017**	▲ **2016**	▲ **2015**	**2014**
(All foreign visitors)	(8,789,314)	(7,701,196)	(6,509,390)	(6,430,158)	(6,332,734)
Uzbekistan	▲ 4,351,413	▲ 3,344,577	▲ 2,459,757	▲ 2,297,180	2,107,177
Kyrgyzstan	▲1,327,877	▼ 1,273,378	▼ 1,348,709	▲ 1,359,625	1,308,139
Total	▲ *5,679,290*	▲ *4,617,955*	▲ *3,808,466*	▲ *3,656,805*	*3,415,316*
Kyrgyzstan	▲ **2018**	▲ **2017**	▼ **2016**	▲ **2015**	**2014**
(All foreign visitors)	(6,946,531)	(4,567,370)	(3,853,385)	(4,000,558)	(3,790,849)
Kazakhstan	▲ 2,675,523	▲ 2,759,415	▼ 2,578,320	▼ 2,841,487	2,854,972
Uzbekistan	▲ 3,295,804	▲ 694,131	▲ 348,792	▲ 244,802	179,926
Total	▲ *5,971,327*	▲ *3,453,546*	▼ *2,927,112*	▲ *3,086,289*	*3,034,898*
Uzbekistan	▲ **2018**	▲ **2017**	▲ **2016**	▲ **2015**	**2014**
(All foreign visitors)	(5,346,219)	(2,690,074)	(2,027,034)	(1,917,714)	(1,861,961)
Kazakhstan	▲ 2,293,077	▲ 1,752,238	▲ 1,384,220	▲ 1,250,812	1,142,865
Kyrgyzstan	▲ 1,055,688	▲ 366,053	▲ 168,128	▲ 139,790	114,296
Total	▲ 3,348,765	▲ 2,118,291	▲ 1,552,348	▲ 1,390,602	1,257,161

Data sources: Yearbook of Tourism Statistics 2020 Edition, UNWTO (WTO 2020).

their economies and attract foreign investment to prosper their motherlands. Due to the fact that all three countries are rich in tourist resources, the development of tourism has become one of the priorities of the economy during this period. However, due to the fact that UZ has been pursuing a closed policy until recently, compared to KZ and KG, UZ lags behind in the development of cross-border tourism. A new milestone was 2018 when the borders of UZ were reopened for travellers. Since then tourist flows between KZ, KG and UZ have been growing.

The statistics take into account the total number of visitors, including travellers for work and business purposes, for seeing friends and relatives, as well as for leisure. If we analyse the number of visitors to KZ for the recent 5 years (2014-2018) from neighbouring UZ and KG, the number of visitors from UZ accounts for the vast majority of visitors to KZ, about a third in 2014, growing every year. By 2018 it reached 4,351,413 people, accounting for about half of all foreign visitors, an increase of more than 2 million people compared to 2014. As for the number of visitors from KG, during these 5 years, the number of visitors was not changed much, fluctuating around 1,300,000 people. While the number of visitors increased slightly in the first two years, the number of visitors decreased in the following two years. The highest number was in 2015, with 1,359,625 people. The lowest number was in 2017, with 1,273,378 people (Table 1).

Table 1 showed that according to the number of visitors to the KG from KZ and UZ, the number of visitors from KZ accounts for about 70% of all foreign visitors in 2014, and about more than 2.5 million Kazakhstani visit KG every year. The highest number of visitors was observed in 2014, with 2,854,972 people and the number of visitors decreased in the following 2 years. The lowest number of visitors was seen in 2016, with 2,578,320 people. The number of visitors from UZ to KG was not very high between 2014 and 2017. It gradually grew up year by year during the beginning 3 years' period. However, in 2018 the number of visitors increased incredibly, reached to 3,295,804 people. The lowest number of visitors was seen in 2014, with 179,926 people.

Table 1 also indicated that the number of visitors to UZ from KZ and KG has been growing every year from 2014 to 2018. The number of visitors from KZ remain more than a million during the beginning 4 years' period, accounting for more than half of the total number of foreign visitors to UZ. In 2018 the number of Kazakhstani tourists was the highest, with 2,293,077 people. The number of visitors from KG has been growing steadily in the beginning 4 years' period. In 2018 it increased from 114,296 people in 2014 to 1,055,688 people. The proportion of visitors from KG to UZ in the beginning 3 years accounted for about less than 10% of the total number of foreign visitors to UZ, but in 2018 this proportion increased about 2 times more. Although the number of mutual travelers between KG and UZ is not significant, the number of people traveling from KZ to KG and UZ is more than half of the total number of overseas travelers to those countries.

South Kazakhstan Region - City Almaty	10 members of the Department of Recreational Geography and Tourism - Al-Farabi Kazakh National University
North Kyrgyzstan Region - City Bishkek	6 members of the Department of Tourism and Recreational Geography - Kyrgyz National University named after Jusup Balasagyn
East Uzbekistan Region - City Tashkent	7 members of the Department of Economic and Social Geography - National University of Uzbekistan named after Mirzo Ulugbek

Figure 3: Approach for targeting the respondents

4 Data and Methodology

4.1 Data collection and methodology

To demonstrate the relevance of the chosen topic, we issued our questionnaire survey questions to the citizens of the three neighbouring countries in Central Asia, which have great potential naturally and culturally in the development of cross-border tourism, in December 2022. Considering the research work focused on the study of cross-border tourism, the majority of respondents were from the tourism sector. Initially, three in-depth open structured interviews were conducted with 28 key informants in the tourism sector. They are mainly Tourism Researchers, Tourism and Event Coordinators, Destination Developers and Project Advisor. The questionnaire was sent to the e-mails of the respondents after getting their consent by contacting the participants through acquaintances. It took about 10 days to collect the survey questions, which were completed by all participants. The survey questions were conducted by the authors of the article in Kazakh, Kyrgyz, Uzbek and Russian languages. After receiving the answers, the authors immediately translated them into English and analysed them. After the fully completed versions of the research questions were received from the respondents, a debriefing meeting was held with all authors to select the qualified answers. As a result, 23 out of 28 answers were left. Other tourism studies have used a similar multi-stage interview structure (Fan et al. 2015, Hampton et al. 2018, McCamley, Gilmore 2017, Shircliff 2018). The quotations in the analysis and discussion section represent the respondents' views on the positive effects of cross-border tourism development. To ensure confidentiality, participants were identified using an internal numerical code.

4.2 Sampling strategy and targeted respondents

The sampling strategy was to find and contact independent researchers who are already contributing to tourism development. This means selecting researchers working in higher educational institutions with knowledge of tourism development in the Central Asian region. It would be best to select informants that are representative of all shared border areas of the entire region, as it would provide views from both small border towns and large cities. However, this would be an overwhelming task considering the magnitude of the region and limited resources such as funds and time. The initial plan was to contact each of the tourism researchers in higher education institutions in all major cities near the border crossings points between the three countries. This would provide different perspectives of the respondents partly working on the development of cross-border tourism in the region.

After beginning the process of contacting organization members in border cities, it became clear that adjustments needed to be made regarding the target respondents. Since the vast majority of people with higher education about tourism in other cities near the border are graduates of the three large educational institutions that we selected, it was necessary to select only participants with responsibility and extensive experience in tourism development. Not all members of the three selected organizations were interested

Table 2: Details of respondents interviewed ($n = 23$)

Characteristics	Frequency	Percentage
Gender:		
Male	15	65.2
Female	8	34.8
Citizenship:		
Kazakhstan citizen	10	43.5
Kyrgyzstan citizen	6	26.1
Uzbekistan citizen	7	30.4
Age category:		
Young (18–34)	12	52.2
Middle age (35–54)	7	30.4
Elder (≥ 55)	4	17.4
Education:		
Middle (school or college)	7	30.4
High (university or above)	16	69.6
Positions:		
Tourism Researcher	7	30.4
Tour and Event Coordinator	7	30.4
Destination Developer	6	26.1
Project Advisor	3	13.1
Average years at position	5	
Average total years in tourism	9	

in participating in the survey. However, as shown in Figure 3, a total of 28 members agreed to participate, and they were employees of higher educational institutions in Almaty (KZ), Bishkek (KG) and Tashkent (UZ). Figure 3 shows the details of the target survey participants used in this study.

4.3 Sample Characteristics

Table 2 shows that the majority of respondents were male (65.2%), and nearly half of the respondents were citizens of Kazakhstan (43.5%), while Kyrgyzstan citizens and Uzbekistan citizens were 26.1% and 30.4%, respectively. The highest proportion of respondents was aged 18–34 (52.2%), followed by 35–54 years old, accounting for 30.4% and the lowest proportion of informants was the elder group, aged above 55 (17.4%). The proportion of informants who have attended university or above educational institutions (considered as high-level education) accounts for the largest number (69.6%) and only 30.4% were those who have received middle education (including school or college).

As shown in Table 2, the number of Tourism Researchers and Tour and Event Coordinator from the survey participants is the same, with 30.4%. The next place is occupied by Destination Developer, who holds about a quarter of the participants (26.1%), followed by Project Advisor who ranked last place, accounting for 26.7%. As far as average years at position is concerned, the term of the informants in their current work is 5 years. Concerning the average total years in tourism, the average period of their work in the field of tourism is 9 years (Table 2).

5 Results and Discussion

The "geographical transboundary structures" are of particular importance for international cooperation (Dunets et al. 2019). The historical background of cross-border cooperation between neighbouring countries is related to the peculiarities of the natural and cultural conditions of each country, which affects the formation of cultural and economic activities in the region. Central Asian states have some important overall characteristics.

For one, Central Asia historically has been closely tied to its nomadic peoples and the Silk Road. As a result, it has functioned as a crossroads for the movement of people, goods, and ideas between Europe, West Asia, South Asia, and East Asia. It is also sometimes known as Middle Asia or Inner Asia, Falls with the scope of the wider Eurasian continent (Qi, Evered 2008). The authors will discuss the benefits of cross-border tourism cooperation between KZ, KG, and UZ, which are located in the middle of four large countries (Russia, China, India and Iran) with large populations and comparatively developed economies. And the region is the main part of Central Asian countries, which is also the most developed place for tourism.

There are often a number of positive outcomes associated with tourism collaborations in border regions. These are usually improved infrastructure and a way to handle expensive investments as the region can share facilities, strengthened regional identity, creation of jobs, effective marketing, and knowledge transfer and innovations (Park 2014, Timothy 2002, Timothy et al. 2014). Many of these advantages of cross-border tourism collaborations were recognized by the informants in the studied region. And next, to achieve our research objective, we will discuss the following three topics that show the positive effects of cross-border tourism based on the respondents' opinions.

5.1 Development of Infrastructure

In 2011, the Asian Development Bank (ADB) and the European Bank for Reconstruction and Development (EBRD) provided parallel co-financing for the Almaty-Bishkek road rehabilitation project to restore the 245 km area between Almaty and Bishkek highway (Asian Development Bank 2008). The regional road rehabilitation project between Almaty and Bishkek will give an additional impetus to the development of the economies, services sectors and tourism industries of the border territories and facilitate the development of these regions on the whole. Almaty–Bishkek Economic Corridor Tourism Master Plan was created by Asian Development Bank in December 2019. In Central West Asia, the area between Almaty in KZ and Bishkek in KG is home to exceptional heritage and a wealth of cultural and natural assets. The tourism potential is immense, but remains largely untapped. This tourism master plan provides a framework for developing the Almaty–Bishkek Economic Corridor (ABEC) into an international-quality destination. It identifies key investment priorities such as developing ski resorts along the mountain range between Almaty and Issyk-Kul and linking these winter sport facilities with summer tourism opportunities. It also proposes transport infrastructure improvements, including enhancing Almaty International Airport as the major gateway to the region (Asian Development Bank 2019). Bilateral cooperation in designing multi-destination travel in a whole may meet the needs of tourists and more efficient and effective travel needs, but such cooperation may also lead to the development and management of tourism in neighbouring countries in a more sustainable manner (Tosun et al. 2005). Upgrading the tourism infrastructure to accommodate the more demanding categories of tourists is something that the tourism departments of these countries can make money together. In order to assess the positive impact of cooperation in the development of cross-border tourism between the three selected countries on the development of infrastructures in-depth, we asked the survey participants the following question:

> *How to describe the positive impact of cooperation in the development of cross-border tourism between the three countries on the joint development of infrastructures? (The tourist infrastructures mainly include roads, railways, airports, water supply, sewage networks, electricity networks and broadband internet connection).*

A number of neighboring developed countries in the world are jointly developing the construction of border crossings and the infrastructure of cities and villages near the borders to ensure the comfort of guests coming to their countries (Deutschmann et al. 2023). For example, Chinavia is another large scale project focusing on the Chinese market and to attract Chinese tourists to visit Scandinavia. It is an important and interesting project for the region as it is very much driven by Wonderful Copenhagen

(Skäremo 2016). And if we look at the countries of Central Asia, according to the survey participants, the number of jointly developed infrastructure projects is not much. As they said states are often limited to joint development of customs infrastructures. They also mentioned that as we have seen, in the last ten years, in order to increase the relations between the three mentioned countries, many old infrastructures have been modernized and the number of border crossings has been increased to meet the growing demand. One participant from Uzbekistan said that, due to the increase in the number of border crossings, he does not have to wait in line for hours to cross the border when going to Kazakhstan now:

> **Informant UZ 5:** The border crossings between KZ and UZ have been rebuilt and modernized, these positive changes will facilitate the fast travel of passengers. ... I would say generally this is a reflection of the fact that the governments of KZ and UZ opened the way for the rapid development of cross-border tourism between the countries.

At the same time, one Kazakh survey participants expressed their feelings and views on infrastructure development under the influence of cross-border tourism development cooperation. He told us about the convenience of people' movement between the countries:

> **Informant KZ 2**: I was born in the border region of Kazakhstan with Uzbekistan, and what I saw in the past was that millions of Uzbek travelers used to come to Kazakhstan every summer for various purposes, and queued up for several days at the border crossings. ... Over the past 10 years, since the two countries agreed to renovate and rehabilitate several previously closed border crossings in order to make it more convenient for cross-border travelers, the time it takes travelers to cross the border has decreased.

If we take into account that tourism is one of the important sources of income of the countries of Central Asia, especially the people of Uzbekistan and Kyrgyzstan, the renewal of the road construction between the three countries is aimed at increasing the number of tourists between the countries. According to survey participants, the governments of these three countries have promised to improve the quality of highways and increase the number of bus stations between large cities near the border in order to reduce obstacles that slow down the flow of passengers. Two Uzbek survey participants spoke about the convenience of the modernization of the car roads between countries:

> **Informant UZ 2**: The 200-km road between Tashkent (UZ) and Shymkent (KZ) used to take four hours for passengers, but since the construction of the road was made at a modern level, the time it takes passengers to travel has been reduced by 2 times. ...
>
> **Informant UZ 4**: Thanks to the construction of high quality highways between countries, the number of tourists between the three neighboring countries has increased many times because they can travel by private vehicles, so they don't have to spend money on tickets for buses or airplanes, and they don't have to depend on anyone in terms of time.

Similar to the above, another two Kazakh participants stated the benefits of the West Europe-West China highway, which passes along the borders between KZ, KG and UZ through the Southern part of KZ, plays an important role in traveling by car between these countries. They say that the construction of this road is one of the good results of the cross-border tourism development project between the countries:

> **Informant KZ 6**: Due to the start of this Chinese project, the Central Asian countries have modernized the transport routes to their territories in order to increase the flow of tourists between the countries, it in turn increased the movement of people between Central Asian cities along the route. ... I believe that the construction of this expressway is not only a gateway to KG and UZ, but also a passage for Chinese, Russian and even Europe tourists to Central Asian countries.

Many participants agree that the infrastructure of important tourist destinations is improving due to the increase of foreign visitors to the countries, especially that each country is paying more attention to the development of tourist destinations near country borders. For example, two of Kyrgyz participants stated that along with the development of cross-border tourism, the infrastructure in Issyk-Kul, a popular tourist destination of Kyrgyzstan, has been developed:

> **Informant KG 1**: Due to the rapid development of cross-border tourism between countries, many infrastructures in the Issyk-Kul region of our country have been renewed and modernized. ... As the general public knows, the highway between the capital of Kyrgyzstan and the lakeside tourist town of Sholpan-ata was built with high quality.
>
> **Informant KG 4**: Because of the large number of vacationers coming from KZ, a charter flight from Almaty to Issyk-Kul was opened in the summer months of 2019, therefore the construction of the airport on the shore of Issyk-Kul was modernized and expanded. ... You know that on the one hand, expanding airport construction leads to a large number of foreign tourists to our place, on the other hand, it offers jobs to the local residents.

One Kazakh survey participant, adding to the above views, noted that one of the significant positive effects of cross-border tourism between the three countries on the development of infrastructure is the modernization of the city of Turkistan in Kazakhstan:

> **Informant KZ 5**: As you know, due to the development of cross-border tourism in Central Asia, the construction of Turkistan City, recognized as the spiritual capital of the Turk people, has been developed by combining the features of the medieval model with the modern model since 2019. ... The development of tourism in the city accelerated the implementation of many infrastructure projects for the benefit of the city population, for example, many public facilities were built in the city center, new parks were opened, and city roads were renewed.

Usually, with the increase in the flow of tourists between countries, infrastructure has to be shared. For example, developed countries allow developing countries to use their infrastructure free of charge for mutual benefit. One participant from Kazakhstan warned that the neighboring Kyrgyz and Uzbek countries are attracting more tourists to their countries due to the better infrastructure in Kazakhstan:

> **Informant KZ 7**: The most populated cities of KZ, such as Almaty and Shymkent, serve as a great example of how such infrastructure is shared in the border regions of the KG and UZ. ... As you know, tourists from faraway countries choose Kazakhstan first to visit other countries of Central Asia.

Tourism infrastructure has long been regarded as a component of tourism and is essential to attracting visitors. One of the main elements of attracting tourists is the improvement of tourism infrastructure, which increases the attractiveness of the destination (Nguyen 2021). The infrastructure of a nation affects how desirable it might be as a travel destination (Seetanah, Khadaroo 2009). Furthermore, recent studies have shown that tourism infrastructure has a positive impact both directly and indirectly on the quality of life of residents through sustainable tourism development (Mamirkulova et al. 2020). As we can see from the answers of the interviewees above, during the last 10 years, when the cooperation in the field of cross-border tourism between the three countries began to revive, a number of developments took place in infrastructure between the countries. However, most of those changes are limited to the renovation and expansion of the border crossing points. The infrastructures of the cities and villages near the border points that work for the benefit of local residents are very little developed. In conclusion, generally speaking, the infrastructure of the three countries in Central Asia has been improved by the impact of cross-border tourism development between countries, and these positive changes have been said to be working for the comfort of the people. Thus, we can say that hypothesis 1 in our research has been proven.

5.2 Strengthening of Joint Tourism Product Marketing

Tourism product marketing refers to the management process by which national tourism organizations and/or tourism enterprises identify the specific potential of their target tourists and communicate with them to determine and influence their desires, needs, motivations, likes and dislikes. It is believed that cooperation in the implementation and control of tourism marketing management, marketing plans and designed plans can not only create benefits for the participating countries, but also create, establish and maintain mutual benefits for tourists and other stakeholders (Tosun, Parpairis 2001). To better understand the positive impact of cooperation in the development of cross-border tourism between the three selected countries on the strengthening of joint tourism product marketing, we asked the survey participants the following question:

> *How to describe the positive impact of cooperation in the development of cross-border tourism between the three countries on the strengthening of joint tourism product marketing? (Main tourism products are tourist attractions, accommodation, transportation, travel agencies, shopping centers and restaurants).*

Joint marketing and regional identities to attract tourists are considered to be one of the most important outcomes of further cross-border tourism cooperation confirmed by the respondents. Clearly, the advantage lies in reaching distant markets and competing with similar regions in Central Asia. This is of great importance because a strong international identity in the tourism industry is highly valued only when aiming to reach a large market Timothy (2002). Most of the informants from the three countries mentioned that Central Asian states are working together on marketing and regional identities to attract more tourists from nearby markets such as China, India and Europe now:

> **Informant UZ 1:** The three neighboring countries, which previously developed tourism as independent competitors, now feel foreign tourists want to organize trips to the entire Central Asian region under the influence of cross-border tourism cooperation between them, and they gradually began to jointly strengthen tourism product marketing. ... For example, the cities of Turkistan (KZ), Samarkand (UZ) and Osh (KG) can be considered as a network of pilgrimage tourism in Central Asia (Seen in Figure 1).

> **Informant KG 5:** Taking into account the priority directions of tourism (business tourism in Almaty-KZ, mountain tourism in Karakol-KG and cultural tourism in Samarkand-UZ) established in these three countries, one of the main goals of cooperation in the field of tourism between countries is to create a marketing network of tourism by combining various destinations of Central Asian tourism. ... such a diverse trip, in turn, gives a good mood to tourists who are tired of monotony, and it would be an inspiration for them to invite others to travel to this region.

Most respondents agree that UZ has a very strong international brand of cultural heritage that represents Central Asia, such as Samarkand, which is often cited as one of the best places to experience ancient culture and the world's oldest historical cities. This advantage makes Uzbekistan a strong attraction in the region for international visitors. However, one survey participant from Kazakhstan stated that there is potential to create other brands such as healing water tourism in Kazakhstan and Kyrgyzstan with the initiative of Central Asian trans-border tourism:

> **Informant KZ 3**: Since the establishment of cross-border tourism between the three countries, healing waters such as Issyk-Kul (KG), Balkash and Alakol (KZ), which are very popular in the CIS countries, have presented Central Asia in a different light to large tourist markets such as China and India. As a result, the number of tourists coming for treatment from them is increasing every year.

A joint effort between countries in marketing can maximize the tourism potential of the border region and bring more benefits to all stakeholders (Timothy 2002). Furthermore, through cross-border tourism cooperation, some survey participants say that because the various attractions and cities in the region complement each other, it is possible to combine the border tourism destinations of these three countries to form a unique brand for tourists:

> **Informant KZ 3**: It can be said that Kazakhstan and Kyrgyzstan have created a common ecotourism brand within the framework of the Almaty-Bishkek corridor cross-border tourism project. The Issyk-Kol region in the KG can be considered as the Switzerland of Central Asia, including its unique nature and unforgettable tourist experience. At the same time, the amazing view of the Kazakhstan's Kolsai Lakes National Park and the Sharyn Canyon (it is described as the third most beautiful Grand Canyon in the world) are the unmissable opportunity for Eco tourists.

> **Informant UZ 6**: It can be easily seen that the inclusion of the Western Tien-Shan territory between the three countries into the natural world heritage list, which is jointly protected by the state, has given an impetus to the cross-border tourism cooperation between the countries. in this context, the common tourist marketing of Central Asia, which shows the biodiversity in the region, was formed.

The place of food of that region in promotion of tourism marketing is special because the guests who come here do not want to feel only the nature and culture, and also the taste of food will be a special surprise for them. According to an interviewee from Uzbekistan, a strong brand has been formed in the food marketing of Central Asia due to the development of cross-border tourism among the three countries:

> **Informant KZ 8**: People of these countries travel to Uzbekistan or the southern regions of Kazakhstan and Kyrgyzstan if they want to eat Pilaf, if they want to eat meat and drink Kumyz, they go to the northeastern regions of Kazakhstan and Kyrgyzstan, and if they want to eat fish, they travel to the Caspian coast in the west of Kazakhstan.

One of the most important types of tourist products is service, while in the past technology and production were the main factors determining competitiveness, now it is true that countries compete with service industry. For the tourism and hospitality industry, accommodation, catering and leisure services are of particular importance, as they contribute greatly to meeting the needs of tourists (Ionel 2016). The development of cross-border tourism in Central Asia contributed to the development of the country's service sector. According to a Kyrgyz survey participant, two different brands can be promoted in the tourism service of Central Asia:

> **Informant KG 3:** In my opinion, in the tourist service of the north-eastern regions of Central Asia, friendly and kind characteristics in service have been recognized due to the mentality of the Kazakh and Kyrgyz peoples, while in the south of the region where the Uzbek population is concentrated, there are humble and fast advantages in providing services. ... These types of services are improved within the framework of the development of cross-border tourism and promoted as one of the important elements in attracting foreign guests.

Almost all of the responses of the participants in the above survey prove that thanks to the cross-border tourism development cooperation between the countries, the three mentioned countries have achieved excellent results in the joint promotion of tourism products. Summing up, we conclude that the development of cross-border tourism between countries can create a common tourist product market that accelerates the sale of tourist products in those countries. Therefore, we can say that hypothesis 2 in our study was proven.

5.3 Promoting innovation and knowledge transfer

Knowledge transfer is an important element of productivity, competitiveness and innovation in tourism organizations (Shaw, Williams 2009, Weidenfeld et al. 2010). In many industries, the survival and competitiveness of firms depends on how well they can use past experience to innovate their products and combine knowledge with re-use experience. This entails managing the sharing and transfer of vast amounts of knowledge from one project to another over time, facilitating synergy and learning (Corso, Paolucci 2001). The diffusion of knowledge is closely related to the concept of innovation. Innovation has many different conceptual definitions, but it is usually defined as a new or improved product or process which is successfully introduced to the market (Lorenz 2010). When analyzing and discussing the positive impacts of cross-border tourism development cooperation between these three nations on the improvement of innovative and knowledge flows in detail, the following survey question was taken into consideration:

> *How to describe the positive impact of the cooperation in the development of cross-border tourism between the three countries on the improvement of innovative and knowledge exchanges? (increasing the exchange of innovations, experience and theoretical knowledge between countries).*

Most of the informants stated that there have been many exchanges in the field of knowledge and technology between countries along with the development of cross-border tourism in the Central Asian region. Some of them mentioned that travelers of various purposes between countries share innovations and technologies from their country wherever they go. As a result, the people of the host country will contribute to the development of their regions by using those experiences.

> **Informant UZ 3:** It is known that every year Uzbek tourists travel to Kazakhstan and the Kyrgyz Republic to visit their relatives or friends. Uzbek travelers usually teach local people the secrets of building houses and gardening in the places they visited because the Uzbek people have specialized in construction and horticulture.

> **Informant KG 6:** Kyrgyz and Kazakh peoples are the descendants of ancient nomads, since the development of cross-border tourism between the countries, they have been traveling to Uzbek country in order to teach the knowledge of animal husbandry to the neighboring Uzbek peoples.

There is no doubt that the above narratives are a vivid example of cross-border tourism-led knowledge exchange. Since the movement of people between countries has been made more convenient, a number of opportunities for the exchange of knowledge and innovation have appeared. One survey participant from Kazakhstan stated that more and more Uzbek and Kyrgyz students are attending universities in Kazakhstan now:

> **Informant KZ 4**: In Central Asia, Kazakhstan has the most developed education and the most grants have been awarded, which, in turn, has increased the opportunities for students of the other Central Asian countries that have cooperated in cross-border education. ... As a result, every year, hundreds of Uzbek and Kyrgyz students study at higher educational institutions of the Kazakhstan.

Similarly, another Uzbek interviewee said that many Kyrgyz and Kazakh merchants come to Uzbekistan to learn production technologies within the framework of shopping tourism cooperation between the countries:

> **Informant UZ 7**: It is known that light industry is better developed in Uzbekistan than in other Central Asian countries. Since cross-border tourism between the three countries has received interstate support, many Kazakh and Kyrgyz businessmen come to Uzbekistan to learn production technologies.

It is a natural phenomenon that the rapid development of the tourism industry in one country affects the development of tourism in neighboring countries. About the exchange of experience in the field of tourism development between the three mentioned countries, two surveys participants from Kazakhstan expressed their opinion:

> **Informant KZ 10**: With a large number of cultural and historical tourist destinations at the UNESCO level, Uzbekistan has gained a lot of experience in the development of cultural tourist destinations. Under the influence of cooperation in the field of cross-border tourism between countries, the experiences of Uzbekistan are currently being used in the promotion of tourism in Kazakhstan, which has a high cultural tourism potential.
>
> **Informant KZ 9**: The abundance of unspoiled beautiful mountains, rivers, and lakes in Kyrgyzstan has motivated developed countries to develop community-based rural tourism there. As everyone knows CBT was set up by Swiss development agency Helvetas in the early 2000s to develop tourism in Kyrgyzstan. . . . In other words, Kazakh tourists who traveled to that country learned the practices of community-based rural tourism development in the neighboring country of Kyzgyz and started to develop it in their regions after returning.

The participants of the survey confirmed the fact that cooperation in the field of cross-border tourism between countries is conducive to the transfer of theoretical knowledge. According to a Kyrgyz survey participant, with the improvement of cross-border relations between countries, the number of people from other countries of Central Asia who go to Kazakhstan for treatment has increased:

> **Informant KG 2:** Patients who come for treatment to Kazakhstan, where medicine is relatively well developed, go to their country and give advice to other patients around them after receiving advice from a doctor about prevention of pain and self-treatment. In this way, I can say that theoretical knowledge was exchanged between countries due to the effect of traveling across borders.

Based on the answers of the interviewees mentioned above, it was determined that the cooperation in the development of cross-border tourism between the three countries has promoted the exchange of knowledge, experience, technology and innovation in many fields. In short, we come to the conclusion that the development of cross-border tourism contributes to the exchange of theoretical knowledge, technology and innovations between countries. Consequently, based on the views analyzed above, we can say that the 3rd hypothesis in our study is also fully proven.

6 Conclusion

Cross-border cooperation between public entities within the framework of tourism development is considered as one of the new directions in the Central Asian region. The study's informants have positive experiences of such cooperation and seem to strongly support large-scale initiatives in the region. By analyzing the responses of the survey participants, the results of the study can be summarized as follows:

- If we evaluate the impact of cross-border tourism development on the joint development of infrastructures of countries, we can say that a number of infrastructural projects have been realized between countries, but we witnessed that they are implemented only on a very limited scale;

- We can highly appreciate the role of cooperation in the field of cross-border tourism in the joint development of the tourist product market of the three mentioned countries in Central Asia.

- Similar to the above, we can say that cooperation in the field of cross-border tourism is an important factor that accelerates the exchange of knowledge and innovation between the peoples of the three countries.

This case study showed that the development of cross-border tourism is relevant among regions located near the border in Central Asian countries. The study was very relevant due to the purpose of analysing the attitudes and expectations of qualified specialists in the field of tourism, as well as the implementation of a number of large-scale socio-economic projects among Central Asian countries. It is important to clarify that the collected information on experiences and expectations is representative of a specific region and cannot be generalized to a wider scale, as they are location-specific and cover only some of the many public actors in the Central Asian region. However, it still provides a perspective for new directions of cross-border tourism development research and valuable insights from experts in the field of tourism.

Unfortunately, the voices of the residents of the border towns were left out of the research work, but considering the diversity of the participants' experience and the fields in which they work, the data increases the scientific value of the research. Further research should be analysed from the perspective of border residents and administrative staff. Recommendations for such studies are to carry out a similar study after two, three or more years, when specific projects within the framework of cross-border tourism development between the three countries are implemented. It may also be interesting to study the interest, perception and expectations of tourism researchers in other Central Asian countries (Tajikistan and Turkmenistan) for the large-scale development of cross-border tourism among neighbouring states. Such studies could focus on how the views of tourism experts in other Central Asian countries relate to their branding in individual countries and what other benefits such large-scale collaborations could bring.

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Conflicts of Interest

No potential conflict of interest was reported by the authors.

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Varying size and shape of spatial units: Analysing the MAUP through agglomeration economies in the case of Germany

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Abstract. When an analysis over a specific geographic area is performed, the way that area is divided into regions can affect the outcome of the analysis. Results obtained based on different geographic units can be conflicting. This issue is known as the Modifiable Areal Unit Problem (MAUP). The objective of this paper is to understand the extent to which the regional setting influences the results of an analysis with spatially aggregated variables, with a focus on agglomeration effects, in the case of Germany. Relying on a sample of manufacturing firms over 7 years we estimate a fixed effects model to explain the firm-specific total factor productivity in dependence of region-based agglomeration variables. We simulate 1000 regional settings of Germany on three scales and overtake thereby some characteristics of the administrative units, which are used as the baseline. We infer that the spatial scale and shape matter in the case of Germany.

1 Introduction

Most regional studies rely on the administrative regions as the standard geographical units. It is well known that the results might vary considerably if an analysis is conducted at different regional aggregation levels. Moreover, if geographic units are constructed on other ground than administrative borders, the results can be conflicting to the ones gathered while using the administrative areas. The issue of statistical results being influenced by the choice of the geographical setting is known as the Modifiable Areal Unit Problem (MAUP).

The MAUP has been analysed in different contexts over the years starting from analysis of correlation coefficients (Gehlke, Biehl 1934, Yule, Kendall 1950, Openshaw, Taylor 1979, Arbia 1989) to different multivariate analyses including agglomeration economies (Briant et al. 2010, Andersson et al. 2016, Békés, Harasztosi 2018). The results on the MAUP have been varied depending on the methods used or the country, especially when analysing agglomeration economies, since they are aggregate variables based on regions.

Industrial agglomeration refers to firms locating in specific geographic area from which they can benefit. In this paper, we focus on two types of agglomeration economies: localisation and urbanisation. The localisation externalities, also known as Marshall-Arrow-Romer (MAR) externalities (Marshall 1890, Arrow 1962, Romer 1986), arise if firms locate in close proximity to other firms from the same industrial sector. This enhances the transfer of industry-specific knowledge and extends the pool of labour with skills that are relevant for this industry. The urbanisation or Jacobs externalities (Jacobs

1969) refer to the advantages from locating in an area with a lot of firms from other industrial sectors. Urbanised locations are often diverse and are believed to contribute to the innovation potential of firms because of a high variety of knowledge and ideas.

Germany has been underexplored, both with respect to the MAUP as well as to agglomeration effects. While Ehrl (2013) is a prominent exception with respect to the agglomeration analysis on different administrative levels based on plant level data, further information is needed on how serious the MAUP is in the case of Germany. We aim to fill this gap.

Germany has a unique federal system, where political decisions that affect economic activities can be taken at all administrative levels from municipalities, over districts (Kreise, in the European Nomenclature of territorial units for statistics NUTS3 regions), governmental regions (Regierungsbezirke, NUTS2) and federal states (Bundesländer, NUTS1) to the central government. With information about the sensitivity of the results of an agglomeration analysis with respect to the underlying regional units the policy for the economic development of regions can be designed more precisely with respect to their spatial impact.

Unlike some other European countries, Germany has very strict privacy laws, which often leads to aggregating data at a higher level. This means that in many cases, analysing data at a smaller regional level is not possible. Therefore, understanding the effect of aggregated data is very important.

The rest of the paper is organised as follows. In the next section an overview of the relevant literature is given. In Section 3, the zoning systems are presented. After that, Section 4 describes the set up of the model, the construction of the variables, the estimation procedure of the model and the data used for the analysis. Empirical results are presented and discussed in Section 5. The final section concludes.

2 Literature review

2.1 The MAUP

The analysis of the MAUP goes back to Gehlke, Biehl (1934). They were the first ones to take a close look at the problem of varying size of correlation coefficients in answer to a change in the scale of the underlying regions. Also in the subsequent years the authors that examined the MAUP focused on the correlation coefficients, for example Yule, Kendall (1950) and Openshaw, Taylor (1979). The latter expanded the study of the MAUP from the *scale problem*, 'the variation in results that may be obtained when the same areal data are combined into sets of increasing larger areal units of analysis', to the interconnecting *aggregation problem*, 'any variations in results due to alternative units of analysis where n, the number of units, is constant' (Openshaw, Taylor 1979, p. 108).

In the last few decades the MAUP has also received substantial attention in multivariate analysis. For example, Briant et al. (2010) analysed agglomeration economies, spatial concentration and trade determinants in France. They relied on three zoning systems: the administrative, a grid and a partly random system. Moreover, each of the systems was looked at on three different scales. Briant et al. (2010) conclude that in the case of France the underlying regional system is not as relevant for the estimation results as the model specification.

For other countries this result is not confirmed in the context of an agglomeration analysis. For instance, Andersson et al. (2016) observe differences in Sweden while analysing square grid data at different scale. Furthermore, Békés, Harasztosi (2018), tackling both the scale and the aggregation problem, conclude that in the case of Hungary the composition of regions is as important as the model specification.

Therefore, the literature thus far has delivered contradictory results on the MAUP in the context of agglomeration effects. Békés, Harasztosi (2018) argue that the diverging results may result from the underlying regional structure of the analysed countries: while France has a relatively homogeneous regional structure, this is not the case for Hungary.

2.2 Agglomeration economies

The impact of agglomeration has been of interest to researchers since the end of the 19th century (Marshall 1890), resulting in hundreds of studies. This research has by summarized in many different meta-analyses (Rosenthal, Strange 2004, Beaudry, Schiffauerova 2009, Melo et al. 2009, De Groot et al. 2016).

Most studies report a positive effect of agglomeration economies. For example, Henderson (2003) and Martin et al. (2011) find mostly significant positive effects of localisation for the manufacturing firms in the US and France, respectively. However, Melo et al. (2009), which analyse estimates of 34 studies where the estimation of agglomeration economies is done by using a production function or a wage model, find that there is a positive reporting publication bias. De Groot et al. (2016) find that analysis outcomes have changed over the years and that more recent studies are more likely to report negative results for diversity.

The literature suggests that conclusions on the effects of agglomeration depend on the country, regional level, time period, industries as well as the methodology used in the analysis.

3 Zoning systems

The baseline zoning system in the analysis of this paper corresponds to the administrative regions. Specifically, we use the NUTS (Nomenclature of territorial units for statistics) regions according to the NUTS 2016 classification at 3 scales. NUTS regions are areas created by Eurostat[1] in collaboration with each European country for statistical purposes. We use three scales: the NUTS1 regions (Figure 1a) correspond to the 16 federal states of Germany (Bundesländer), the NUTS2 regions (Figure 1b) to the 38 governmental regions (Regierungsbezirke) and the NUTS3 regions (Figure 1c) to the 401 districts (Kreise).

In order to test for the MAUP, we simulate additional 1,000 regional settings for each of the three administrative types of regions. We consider the investigation of the different regional shapes as relevant since most of the German NUTS regions are not homogeneous, in regard to both population and area, especially NUTS1 regions whose borders have historic origin. For constructing the simulated regions, we use the German municipalities (LAU2), 11,271 in total.[2] We build on previous research from Openshaw, Taylor (1979) and Openshaw (1977) for the USA and Briant et al. (2010) for France. However, in addition to keeping the number of regions in accordance with the number of administrative units, we set some constraints to achieve artificial regional systems that account for the characteristics of the heterogeneous regional system of Germany. Moreover, a nested structure is constructed.

The procedure for creating the artificial regions starts by setting a random seed. After that the municipalities are aggregated to obtain SMALL regions, comparable to NUTS3 regions. Next, the SMALL regions are aggregated into MEDIUM regions, comparable to NUTS2 regions. Finally, the MEDIUM regions are aggregated into LARGE regions, comparable to NUTS1 regions. This way, we obtain a nested structure of each scale, in the same way that the administrative regions are nested in each scale. In addition, during the aggregation process we use some restrictions like population size in order to produce regional structures which resemble the real world administrative regions. The German NUTS regions with the lowest population size, as well as the limits provided by Eurostat for each NUTS level are used as benchmarks. A detailed description of the procedure is given in the Appendix A.

Additionally, we also simulate 1,000 regions at each scale where no nesting structure or any population restrictions are implemented. The only condition is to have regions with approximately similar size.

Figure 2 shows the standard deviations of the population in the regions obtained from the two types of simulation approaches, as well as a box-plot of the population of

[1] Statistical Office of the European Union.

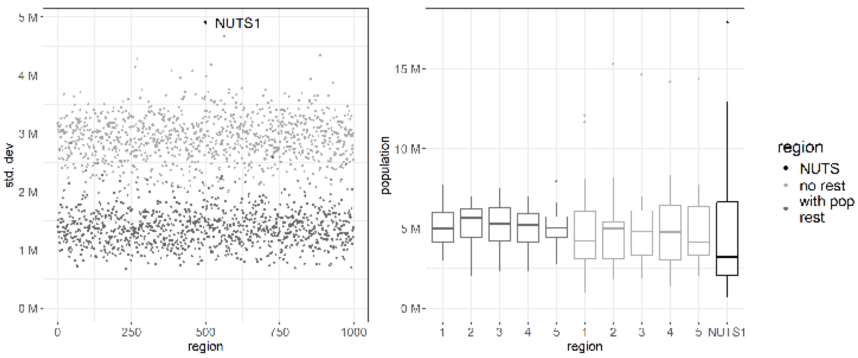
[2] Local administrative units (LAU) are a subdivision of NUTS3. The number as well as the borders of municipalities vary over the years. We rely on municipality borders from 31.12.2016. The population of German municipalities is given in Table A1.

(a) NUTS1

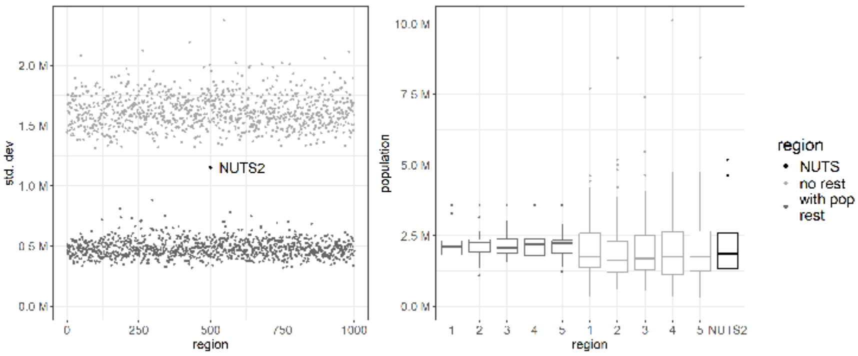
(b) NUTS2

(c) NUTS3

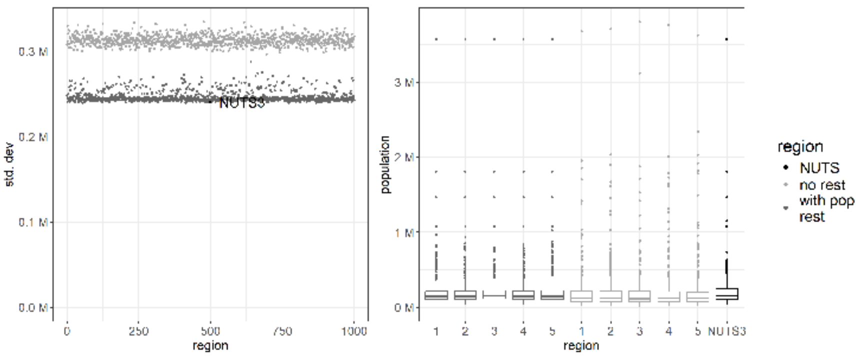
Figure 1: NUTS regions in Germany



(a) NUTS1



(b) NUTS2



(c) NUTS3

Figure 2: Standard deviation and population distribution of simulated German regions

the first 5 regional settings from the two simulation approaches and the corresponding administrative region at each of the 3 scales. We see that introducing a constrain for the regional population size in the simulation algorithm leads to a distribution of the population in the simulated regions which resembles the one of the districts (Kreise), whereas the simulated regions without a population restriction have higher standard deviation. However, at NUTS3 level, even for the algorithm with population restrictions, it was not possible to reduce the standard deviation for the simulated regions below the one of the administrative regions. The reason for this is that there are some municipalities with a very large population size, such as Berlin and Hamburg on one hand, and on another, in order to achieve faster convergence of the algorithm, the minimal population of the simulated regions had to be reduced in a few instances. When it comes to population size in the higher administrative levels, even though the variability in population is reduced when the population restriction is used, because of the non-balanced structure of administrative regions, both types of simulated regions (with or without a population restriction condition) have different variability in population compared to the actual administrative regions.

We further simulated 1,000 artificial regional settings for each of the two simulation approaches for a few other European countries based on data from Eurostat, from 2020. We find that the position of the standard deviation of the administrative NUTS regions compared to the simulated regions with or without population restrictions varies between countries[3]. For the Netherlands and France, for example, in most cases we find that the regions simulated without population restrictions are more similar to the administrative regions. In Hungary, on the other hand, the simulated regions with population restrictions have more similar characteristics to the corresponding administrative regions. Therefore, a simulated regional setting such as the grid-based regional setting is less likely to produce a different results compared to the administrative regional in the case of the Netherlands and France. We expect, that based on our simulations, there should be no effect of the MAUP, more specifically the aggregation or shape effect, on the Netherlands and France, while we expect to find distortions related to the MAUP in Hungary, as reported by Békés, Harasztosi (2018). Therefore, we expect that the MAUP analysis on Germany would be more similar to the one of Hungary, compared to MAUP analysis on France.

4 Data and model

4.1 Data

The main source of data for this analysis is the AMADEUS database. This database, managed by the Bureau van Dijk (BvD), contains information on over 21 million companies across Europe with more than 1.4 million of those having their headquarters in Germany. Information about the number of employees, tangible fixed assets, cost of materials and value added for firms in the manufacturing sector is downloaded from this database. Also the location information (city, ZIP code, NUTS1, NUTS2, NUTS3), the number of branches, NACE Rev. 2 industry code, category of company variable, yearly turnover and the consolidation code are retrieved from AMADEUS. We use the time period 2009-2015. A detailed overview of the data selection and sample construction is given in the Appendix B.

All monetary variables used in this paper, given in thousands of Euros, are deflated with an industry-specific deflator at 2-digit industry level. The deflator for the firm-level value added and the cost of materials is a producer price index. The total fixed assets are deflated with an asset price deflator. Both deflators are obtained from Eurostat.

The focus of this paper is on analysing firms in the manufacturing sector (NACE Rev.2 2-digit codes from 10-33). Data availability was the main reason for the choice of this sector, as well as the possibility for better comparability with previous research. However, because of a small number of firms we excluded the sectors manufacture of tobacco products (NACE 2-digit code 12), manufacture of coke and refined petroleum

[3]See Figures A2 - A6 in the Appendix for additional box-plots for each country.

Figure 3: Heat map of the 7317 firms

products (NACE 2-digit code 19) and manufacture of leather (NACE 2-digit code 15). This leads to a sample of 7,317 firms. The spatial distribution of the firms is shown in Figure 3[4]. We notice that most of manufacturing is located in the most populated cities and we can also observe a large cluster in western Germany.

For calculating the agglomeration variables a larger sample of 54,529 firms is used, forming an unbalanced panel of 328,881 observations (see Figure B1 in Appendix B). An additional source of data for the independent variables is the Federal Statistical Office of Germany, from where we gather information on the number of employees in each 2-digit sector in Germany for the period 2009-2015.

For the construction of the artificial regions we use vector data files from The Federal Agency for Cartography and Geodesy (BKG). The control variables rely on the data from the German Employment Agency and the Federal Statistical Office of Germany.

4.2 Model

In order to estimate the strength of the agglomeration externalities, we set up a firm-level model for total factor productivity (TFP). In this model, the TFP of a firm depends on two agglomeration variables. The first variable, following the MAR theory, measures the extent of *localisation* of the firm's industrial sector in the home region of the firm. The second variable, *urbanisation*, is used for estimating the Jacobs externalities: it measures how large or diverse the region is bar the sector of the firm under observation.

Formally, the model can be expressed as

$$TFP_{it} = \alpha_1 loc_{it} + \beta_1 urb_{it} + e_{it} \tag{1}$$

where TFP_{it} is the log of total factor productivity of the firm i in the year t, loc_{it} and urb_{it} denote the localisation and urbanisation variables, respectively. e_{it} denotes an error term.

For both explanatory variables we use two alternative definitions to check for the robustness of the results, because previous studies, for example Beaudry, Schiffauerova (2009), have shown that the results of an agglomeration analysis depend on the measurement method of the two aspects of agglomeration. We test these two models, one

[4] The 20 most populated cities are shown. For better legibility labels are not displayed for some cities in western Germany (including: Düsseldorf, Dortmund, Essen, Duisburg, Bochum, Wuppertal, Bonn and Münster).

with absolute and one with relative measures, with and without control variables, against simulated regions with and without population restrictions.

We rely on a two-step procedure in which firm level TFP is estimated in the first step based on a production function and the model (1) in the second step.

4.2.1 Estimation of TFP

In order to estimate TFP, it is assumed that output of the firm i in the year t follows the Cobb-Douglas production function

$$Y_{it} = A_{it} K_{it}^{\mu} L_{it}^{\nu} \tag{2}$$

where Y denotes the output, A total factor productivity, K capital and L labour. Symbols μ and ν represent the capital and labour elasticities, respectively. The production factors and output are understood as physical quantities in a production function. For the practical implementation, however, we will rely in case of the output and capital on their monetary values that are deflated by appropriate price indices. Specifically, the output of a firm is quantified as the value added of the firm, the capital as the value of the total fixed assets. The labour variable is quantified as the number of employees. Unlike the other variables in the equation (2), A is unobservable to the researcher.

Applying natural logarithms to (2) yields the log-linear equation:

$$y_{it} = \beta_0 + \mu k_{it} + \nu l_{it} + \epsilon_{it} \tag{3}$$

where the lower case letters denote the corresponding logarithmic variables from equation (2). The logarithm of the firm-specific TFP is understood as a composition of the general level of productivity in the society (β_0) and the firm-level deviations from that (ϵ_{it}). Accordingly, $\log(A_{it}) = \beta_0 + \epsilon_{it}$.

Since factor input quantities k_{it} and l_{it} tend to be correlated with the error term, the endogeneity problem appears in the model (3). This implies that the Ordinary Least Squares (OLS) estimator is biased. To account for this issue, different approaches have been used in the literature. Those include instrumental variable (IV), General Method of Moments (GMM), fixed effects (FE) and semi-parametric approaches.

In the following we focus on semi-parametric approaches as according to Van Beveren (2012) the alternative methods tend to be biased or have a poor performance. Among the most widely used are the two-step semi-parametric approaches of Olley, Pakes (1996), Levinsohn, Petrin (2003) and Ackerberg et al. (2015). Subsequently, Wooldridge (2009) combined those with the GMM methodology.

Contrary to the Olly-Pakes (OP), Levinsohn-Petrin (LP) and the Ackerberg-Caves-Frazer (ACF) methods, TFP is estimated in one step in the Wooldridge (2009) approach. As explained in Van Beveren (2012), this enables standard calculation of robust standard errors instead of bootstrapping. Moreover, the resulting estimators are more efficient than in the two-step approaches of OP and LP as the latter cannot account efficiently for heteroscedasticity and serial correlation in the error terms. Additionally, the Wooldridge estimator accounts for the estimation problem in the first stage, which was noted by Ackerberg et al. (2015). Because of those advantages, we use the Wooldridge approach in this paper.

After estimating firm-level TFP, the results are used in the model (1) for the dependent variable in order to estimate the strength of the agglomeration effects.

4.2.2 Agglomeration variables

The localisation and urbanisation variables loc_{it} and urb_{it} for the firm i in period t are dependent on the firm's region of location and its sector. The localisation variable characterises the economic volume of the firm's sector in its region of location, the urbanisation variable captures the volume of economic activity in a given region in general. In both cases, the indicators can rely on the absolute or relative magnitude.

The localisation variable varies with time and firm over sectors and regions, $loc_{it} = loc_{it}^{sr}$ ($i \in A_t^{sr}$, where A_t^{sr} denotes the set of firms located in region r from industrial sector s in year t, see Martin et al. 2011). The urbanisation variable is constant for all firms for a given time period, sector and region: for each $i \in A_t^{sr}$, $urb_{it} = urb_t^{sr}$.

As the absolute magnitude of a sector in a region, we calculate loc_{it}^{rs} as the number of employees employed by firms that belong to the same sector s and operate in the same region r as the firm i, excluding the employees from the firm i. Formally,

$$loc_{it}^{sr} = \ln(empl_t^{sr} - empl_{it}^{sr} + 1), \tag{4}$$

where $empl_t^{sr} = \sum_{j \in A_t^{sr}} empl_{jt}^{sr}$ is the number of all employees in the region r in the industrial sector s in the year t.

The respective urbanisation measure is calculated as the number of employees in year t in all other sectors different from the sector s to which the firm i belongs to, i.e.

$$urb_{it}^{sr} = \ln(empl_t^{r} - empl_t^{sr} + 1) \quad i \in A_t^{sr}, \tag{5}$$

where $empl_t^r$ is the total number of employees in the region r across all sectors and firms.

In the following, *Model I* will denote the model (1) with the localisation and urbanisation variables as defined in equations (4) and (5), respectively.

As mentioned above, also relative measures can be used for describing the extent of localisation and urbanisation. Accordingly, we analyse the MAR spillovers alternatively with the help of the location quotient, denoted by $locLQ_{it}^{sr}$. It is defined as the share of the own industry employment in a region relative to its national share, i.e.

$$locLQ_{it}^{sr} = \ln\left(\frac{\dfrac{empl_t^{sr} - empl_{it}^{sr} + 1}{empl_t^{r} + 1}}{\dfrac{empl_t^{s}}{empl_t}}\right). \tag{6}$$

Thus, the location quotient shows if the industry s is overrepresented in the region r compared to the industry's national share.

As for the Jacobs' externalities we use the diversity index div_{it}^{sr} as a relative measure. It is defined as the inverse of the quotient with the Hirschman-Herfindahl index of industry concentration in a region in the numerator and the Hirschman-Herfindahl index of industry concentration at national level in the denominator:

$$div_{it}^{sr} = \ln\left(\frac{\sum_{s' \neq s}\left(\dfrac{empl_t^{s'r}}{empl_t^{r} - empl_t^{sr}}\right)^2}{\sum_{s' \neq s}\left(\dfrac{empl_t^{s'}}{empl_t - empl_t^{s}}\right)^2}\right)^{-1} \qquad i \in A_t^{sr}. \tag{7}$$

Accordingly, in the following analysis our *Model II* is expressed as

$$TFP_{it} = \alpha_2 locLQ_{it} + \beta_2 div_{it} + e_{it}. \tag{8}$$

4.2.3 Control variables

We expect that some firm-level characteristics that are related to a firm's TFP are omitted from the models. In order to avoid the omitted variable bias, we include firm level fixed effects ϕ_i and time fixed effects μ_t in the Models I and II.

Since further factors can have an effect on the productivity of a firm, we include two control variables in the Models I and II. Both variables vary with time and region.

First, we control for the employment size in neighbouring regions by including a variable for the market potential:

$$mp_{it}^{r} = \ln\left(\sum_{r'} \frac{allEmpl_{r't}}{D_{r,r'}}\right) \tag{9}$$

where $mp_{it}^r = mp_t^r$ for each $i \in A_t^r$ is the market potential for the region r at time t, $allEmpl_{r't}$ is the number of employed people subject to social insurance in the neighbouring regions r' at time t and $D_{r,r'}$ is the Euclidean distance between the centroids of the regions r and r'. A region is considered to be a neighbouring region of the region r if they share a border.

The second control variable, transported goods tg_{it}^r, measures the accessibility of a region and is constant for all firms for a given time period and region: for each $i \in A_t^r$, $tg_{it}^r = tg_t^r$. It is calculated as the logarithm of the share of the sum of all transported freight in 1,000 t in a region based on airports, sea and river ports, highways and rail, over the total area of the region[5], i.e.

$$tg_{it}^r = \ln\left(\frac{air_{rt} + water_{rt} + road_{rt} + rail_{rt}}{area_r}\right) \tag{10}$$

Therefore, after including these two variables we get two new models:

$$TFP_{it} = \alpha_3 loc_{it} + \beta_3 urb_{it} + \gamma_3 mp_{it} + \delta_3 tg_{it} + \phi_i + \mu_t + e_{it} \tag{11}$$

and

$$TFP_{it} = \alpha_4 locLQ_{it} + \beta_4 div_{it} + \gamma_4 mp_{it} + \delta_4 tg_{it} + \phi_i + \mu_t + e_{it} \tag{12}$$

which we will refer to as the *Model III* and the *Model IV*, respectively.

5 Results

The estimation results of the Models I and II (equations (1) and (8), respectively, including firm and time fixed effects) for the three scales of administrative regions are presented in Table 1. We find no statistically significant effect of the agglomeration variables on TFP.[6]

The simulations of the 1,000 sets of artificially created regions based on population restrictions confirm this result: in most of the cases the parameter estimates of the localisation and urbanisation/diversity variables are insignificant, see Figures 4 and 5. However, in the settings with LARGE and MEDIUM regions the parameter estimate of the location quotient is statistically significant for more than 50 or 40 % of the regional settings, respectively, at the 10 % significance level in the Model II (Figure 5). In all those cases, the parameter estimate is negative. In addition, the mean (as well as the median) of the parameter estimates for the location coefficient shifts towards zero when the regions are scaled down. The results for the simulated regions with no population restriction are similar[7].

As for the urbanisation/diversity variable, in both models the corresponding parameter estimate only in a few cases is found to be statistically significant. Also, here the statistically significant estimates are mostly negative.

We conclude that localisation and urbanisation/diversity are not significant factors in determining a firm's productivity in Germany[8]. However, belonging to an industry that is overrepresented in its wider region of location compared to the industry's national share might have a negative effect to a firm's productivity.

If a model is estimated only for one regional setting, statistically significant parameter estimates might be obtained. This can easily lead to a strong conclusion by an analyst.

[5]The data and the description for the transported goods variable is given in Appendix B.3.2.

[6]We also estimated alternative specifications of the models. Especially, if the time fixed effects are excluded, the parameter estimates for the urbanisation/diversity variables are statistically significant. However, if the model is augmented with control variables like market potential or the quantity of goods that are transported on the infrastructure of the region, the parameter estimates of the urbanisation/diversity variable turn insignificant. Accordingly we conclude that the model without time fixed effects is misspecified.

[7]Appendix C, Figures C3 and C4

[8]The significance of the agglomeration variable can be affected by the model specifications. As previously mentioned, if no time fixed effects are included, the probability of finding significant estimates increases. Furthermore, other model specifications, such as using robust standard errors also affects the amount of significant values, that is, the significance decreases when robust standard errors are used.

Table 1: Estimation results for the Models I and II

	NUTS1	NUTS2	NUTS3
	Model I		
localisation	-0.0250	0.0264	-0.0102
	(0.0796)	(0.0481)	(0.0174)
urbanisation	-0.0879	-0.1221	-0.0043
	(0.3318)	(0.1099)	(0.0376)
firm FE	yes	yes	yes
year FE	yes	yes	yes
observations	25,676	25,676	25,676
R-squared	0.00006	0.00037	0.00003
	Model II		
localisationLQ	-0.0545	-0.0135	-0.0115
	(0.0361)	(0.0259)	(0.0129)
diversity	0.0157	0.0209	-0.0182
	(0.0354)	(0.0312)	(0.0137)
firm FE	yes	yes	yes
year FE	yes	yes	yes
observations	25,676	25,676	25,676
R-squared	0.00062	0.00012	0.00026

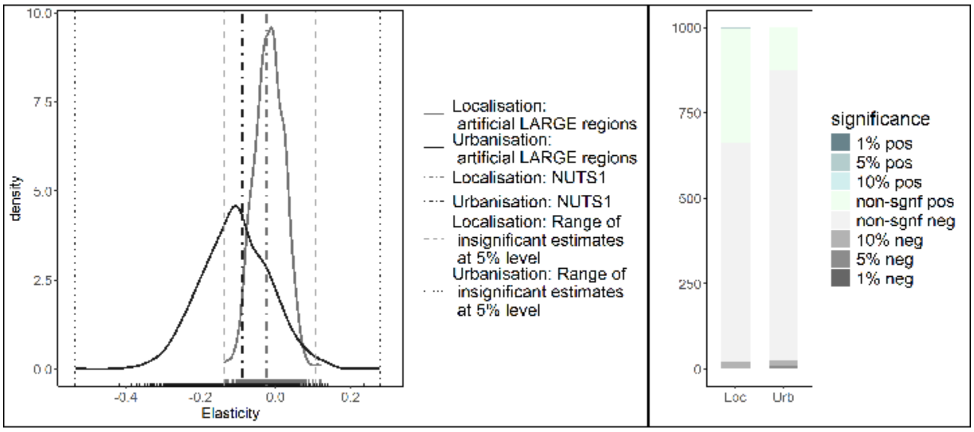
Note: Agglomeration variables are based on employment (equations (4)-(7)). Independent variables are standardised to have zero mean and standard deviation 1. Dependent variable is ln(TFP) estimated with the Wooldridge method. The time period is 2009-2015, the number of firms 7,317. Cluster robust standard errors at region level are given in parentheses.

Table 2: Parameter estimates in Models III and IV

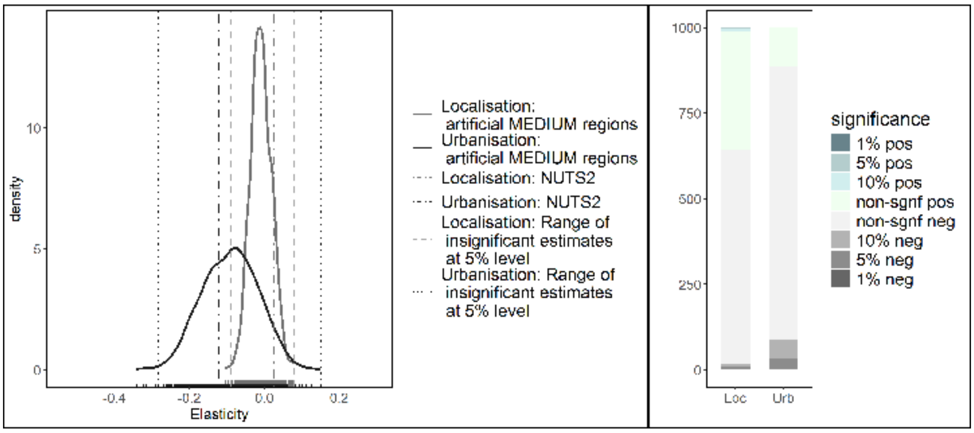
	NUTS1	NUTS2	NUTS3
	Model III		
localisation	-0.0302	0.0246	-0.0095
	(0.0770)	(0.0477)	(0.0174)
urbanisation	0.0301	-0.0978	0.0075
	(0.2885)	(0.1085)	(0.0373)
market potential	0.6274**	0.4583*	0.3437***
	(0.2222)	(0.2350)	(0.0994)
transported goods	0.2460*	0.1173	0.2987*
	(0.1551)	(0.1667)	(0.1544)
firm FE	yes	yes	yes
time FE	yes	yes	yes
observations	25,676	25,676	25,676
R-squared	0.00131	0.00132	0.00167
	Model IV		
localisationLQ	-0.0600	-0.0159	-0.0122
	(0.0346)	(0.0253)	(0.0130)
diversity	0.0026	0.0198	-0.0186
	(0.0324)	(0.0318)	(0.0135)
market potential	0.6342**	0.4881**	0.3450***
	(0.2538)	(0.2345)	(0.0994)
transported goods	0.2591	0.1202	0.2972*
	(0.1538)	(0.1642)	(0.1534)
firm FE	yes	yes	yes
firm FE	yes	yes	yes
observations	25,676	25,676	25,676
R-squared	0.00195	0.00121	0.00192

Note: Agglomeration variables are based on employment (equations (4)-(7)). Explanatory variables are standardised to have zero mean and standard deviation 1. Dependent variable is ln(TFP) estimated with the Wooldridge method. The time period is 2009-2015, the number of firms 7,317. Cluster robust standard errors at region level are given in parentheses.

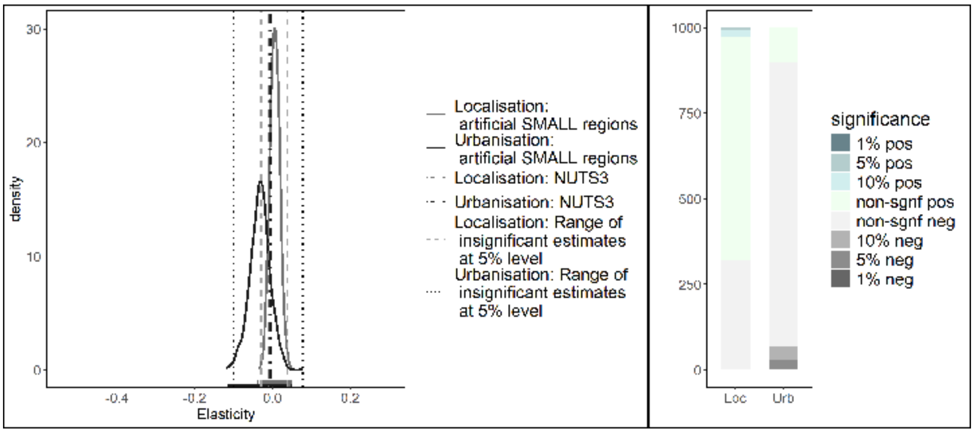
*, ** and *** denote significance at 10%, 5% and 1% level, respectively.



(a) Large regions



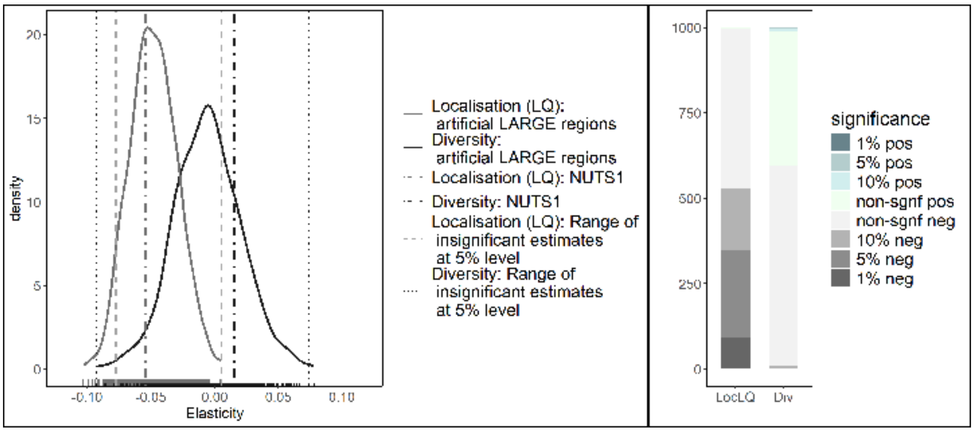
(b) Medium regions



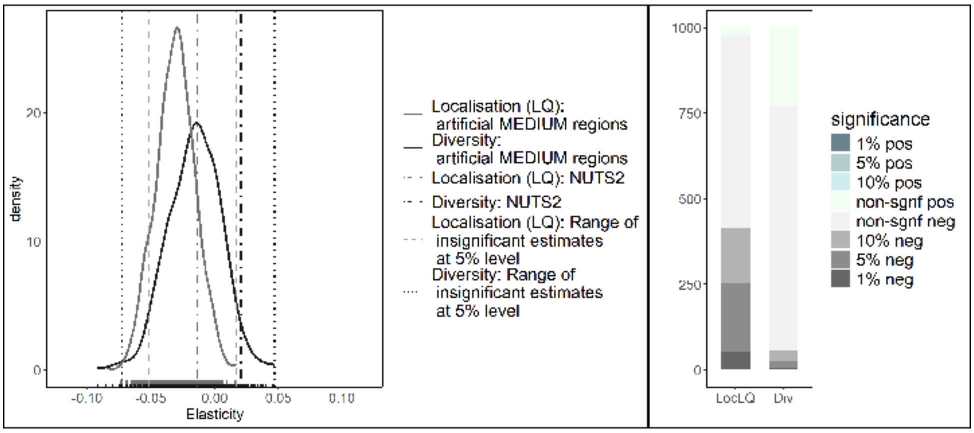
(c) Small regions

Figure 4: Parameter estimates of the localisation and urbanisation variables in the Model I and the distribution of their significance

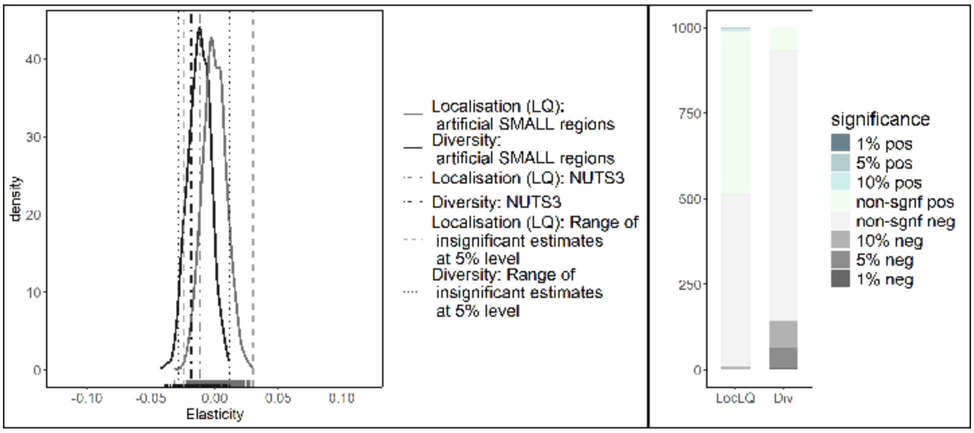
Note: The densities of the parameter estimates rely on 1,000 settings of artificial regions. The range of insignificant estimates at 5 % level covers all parameter estimates that are not statistically significant at 5 % significance level.



(a) Large regions



(b) Medium regions



(c) Small regions

Figure 5: Parameter estimates of the localisation and urbanisation variables in the Model II and the distribution of their significance

Note: The densities of the parameter estimates rely on 1,000 settings of artificial regions. The range of insignificant estimates at 5 % level covers all parameter estimates that are not statistically significant at 5 % significance level.

A careful analysis could reveal, however, that such a result arose only because of randomness: if 1,000 different regional settings are analysed, it is probable that statistically significant parameter estimates are found for one or a few of them even if the true parameter value is zero. One of those random cases could correspond to the administrative regions. Thus, the simulations with artificial regional settings help to assess the validity or strength of the conclusions obtained from a statistical model.

Examples for such a scenario are the extended Models III and IV. As revealed in Table 2, the parameter estimate of the market potential variable is for all three scales positive and statistically significant at 10% level, in the case of the NUTS3 regions even at 1% level. However, even though over 99% of the estimates are statistically significant at SMALL level, for MEDIUM regions in model III, in only around 55% of the regional settings the parameter estimate is statistically significant at 5% level (see Tables C3-C4 and Figures C1-C2 in Appendix C). For the transported goods variable, the mean of the 1,000 estimates from the simulated regional settings is far from the estimated coefficient from the administrative regions when looking at a higher aggregation level. However, at a smaller scale the mean of the 1,000 estimates and the transported goods estimate for the NUT3 regions are closer. Also both the administrative and the simulated regions suggest a higher probability of finding a positive significant effect of the transported goods variable at the smallest scale. Furthermore, a very high estimation uncertainty is revealed by the simulations. Therefore, simulating artificial regional settings helps to assess the validity of the results of a model that relies on regional data.

6 Conclusion

The goal of this paper was to understand the relevance of the underlying regional setting when analysing the effect of spatially aggregated variables such as localisation and urbanisation in the case of Germany. To achieve the goal, we looked at 1,000 artificially created zoning systems at three different scales and with two types of simulation methods and for each of the settings as well as for the administrative regional units we estimated regression models with Total Factor Productivity as the dependent variable and varying measures of localisation and urbanisation as explanatory variables.

As expected, the statistical significance of the localisation and urbanisation effects varies with the geographical settings. Based on the administrative regions, no significant results for the base models are found. However, the analysis of the artificial regional settings provides evidence of possibly adverse effects to TFP of a firm if the firm locates in a region with an over-proportional share of the firm's branch (as compared to the national average). This result holds only if sufficiently large regions are examined. The simulated results for the extended models confirm the results of the agglomeration estimates from the base models.

Though there is evidence for the MAUP if agglomeration effects are analysed in the context of Germany, we also find that the model specification is important – possibly even more important than the MAUP. For example, the choice of certain specifications in the model, such as removing time fixed effect can lead to significant results. Furthermore, the way of measuring the agglomeration variables localisation and urbanisation should be carefully considered.

In addition, we show that the estimation uncertainty rises with the aggregation level of the regions. This results is expected if some variables are defined at the level of the regions as aggregation leads to a loss of information. Therefore, small regional units should be preferred for an analysis of the effects of localisation and urbanisation. Moreover, the results for one regional level cannot necessarily be transferred to other regional levels. Accordingly, the policy implications of a regional analysis are reliable only if the goals of the corresponding policy measures are to be achieved at the regional aggregation level that was used in the underlying analysis.

Acknowledgement

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Appendices

A Creating the artificial regions

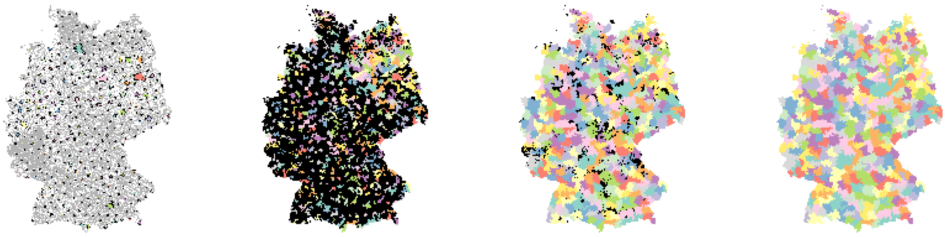
In order to create the artificial regions, we use German municipalities (LAU2), as the smallest administrative unit in Germany. However, over the 7 year period considered in our analysis, there have been a number of changes in the borders of many municipalities in Germany. Therefore, we use the municipality and NUTS stand from 2016. Furthermore, for the variables in which we use municipality level data[9], we use the municipality stand in 2016 and for the whole period of analysis, that is the municipality data is transformed to correspond to the stand in 2016.

Prior to starting with the simulation process, the neighbours list and the distance between municipality centroids are determined. Since neighbours are used for aggregating, we assigned the two closest municipalities as neighbours to the municipalities which do not have a shared border with any other municipalities (i.e. islands and Büsingen am Hochrhein, a German enclave surrounded by Swiss municipalities). Additionally, islands consisted of multiple municipalities are connected by mainland Germany, that is, a municipality from the island and the closest mainland municipality are considered as neighbours.

First, for each of the 1,000 settings a different starting seed is set in order to aggregate the 11,271 municipalities into 401 regions. From the total set of municipalities, 401 initial ones are selected. However, in Germany there are a number of municipalities with a large population, for example Berlin and Hamburg. These municipalities cause non-convergence of the algorithm if they are added to a region in a later step. To avoid this, all municipalities with a population above a threshold[10] are selected as part of the 401 initial regions. For these regions no additional municipalities will be added in later steps since they are over the population threshold. Next, one by one, the remaining starting municipalities are added to the initial 401 such that every other that is selected has to be at a certain predetermined distance from the previously selected starting municipalities. After the starting 401 municipalities are selected, if the population of that municipality in 2016 is smaller than the population of the smallest district in Germany (34,270 inhabitants), a neighbouring municipality is added to the initial one and they are aggregated. The step is repeated until the population in the aggregated region is larger than the threshold or the region has run out of neighbours to be added. If there are aggregated regions whose population is smaller than the threshold[11] and they have no available neighbours to be added to that region, then the procedure is restarted and the initial seed is increased by one. Next, the threshold for adding neighbouring municipalities to a region is increased step by step. First it is set to be the total population of Germany divided by the number of regions (401) and afterwards in following steps it is duplicated. In a next step, the threshold is set as the maximum population for a NUTS3 region (800,000 inhabitants). In the final step, any remaining municipalities which are not assigned to an aggregated region, are then added to a neighbouring region. With this procedure the first scale of the artificially created regions is completed. These regions are referred to as SMALL regions and they correspond to the NUTS3 regions (Kreise).

Similarly to the creation of SMALL regions, we use population properties of NUTS2 in Germany and the general intervals from the NUTS classification to create the artificial regions corresponding to NUTS2 regions. Because NUTS regions are nested in each other, the goal is for the artificial regions to be nested as well. Therefore, already created SMALL regions are used for creating the next scale, MEDIUM regions. As in the procedure for small regions where municipalities were used as starting point, in the creation of MEDIUM regions we use SMALL regions as the starting point for aggregation. Firstly, the initial 38 regions are selected such that they are at a minimal predetermined distance. Next, similar to the procedure for SMALL regions, neighbours of the initial regions are added until the threshold is exceeded. At the end, any remaining

[9] Market potential.
[10] 800,000 for creating the first scale, based on the NUTS criteria for NUTS3 regions.
[11] The starting threshold for this step is 80% of the population of the least populated NUTS3 region (27,542) and with every iteration we reduce it with the final being 50% of the population (17,214).



(a) Step 1 (b) Step 2 (c) Step 3 (d) Step 4

Figure A1: Simulation steps

non-assigned SMALL regions are added to aggregate regions. The final scale, LARGE regions, are created in a similar procedure, aggregating the 38 MEDIUM regions into 16 regions.[12]

The procedure for simulating regions with no population restrictions involves fewer steps. As in the procedure using population restrictions, the initial step is choosing N initial regions at a certain distance, where $N = 401$ for NUTS3, $N = 38$ for NUTS2 and $N = 16$ for NUTS1. No nesting structure is implemented, therefore each scale starts with municipalities. In the next step, if the area of the initial N regions (municipalities) is less than 70% of the average area of the corresponding level, then neighbouring regions are added until the area is over this condition or there are no more neighbouring regions to be added. In the following step, similarly to the previous one, the average area is used as a condition, however it is increased to 90% of the average area. In the final step, the remaining regions are added to the aggregated regions.

Figure A1 shows the process of simulating regions.

1. Set a different starting seed for each simulation. Select a random region. Repeat selecting regions until N is reached, such that the centroid of each region which is selected as next is at a distance of at least $0.7 * \sqrt{(totalarea/n)}$ of previously selected regions, Figure A1a.

2. If the population size of the N selected regions is smaller than the smallest population size of the corresponding NUTS region (i.e. NUTS3 for SMALL regions), then merge neighbouring regions with the starting region. If there are regions which have no remaining neighbouring regions, but still do not fulfil the criteria for having population size larger or equal to the smallest corresponding administrative region, then return to Step 1 and increase the seed by one (after 3 seeds-increase the threshold is reduced to 80% of the population size of the smallest corresponding administrative region, then to 66,7% and to 50%), Figure A1b. This step is only performed when population restrictions are used. When there are no population restrictions, then this step is omitted.

3. Use average population/area to add neighbouring regions to regions from *Step 2*(*Step 1* when no population restriction is used), Figure A1c.

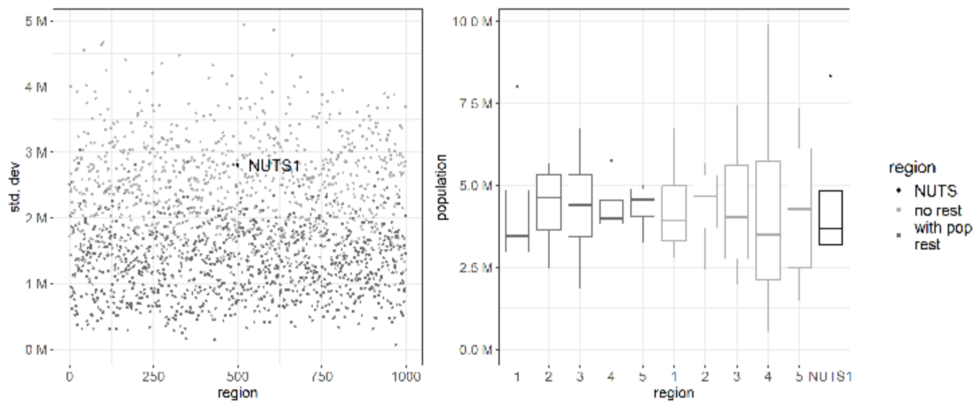
4. Any remaining regions (regions in black in Figure A1c) are assigned to one of the neighbouring regions from the N groups, Figure A1d.

[12]The R package for creating simulated regions *RegionSim* is available on `https://github.com`.

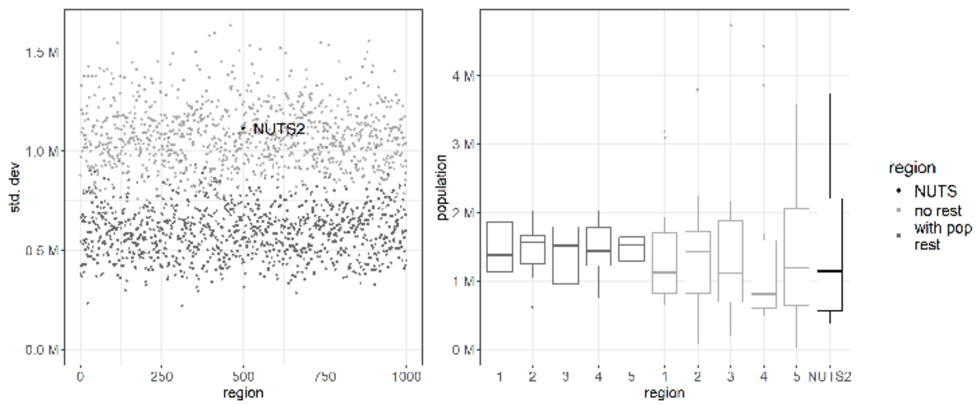
Table A1: Regional structure of Germany

		number of regions		
	NUTS1	NUTS2	NUTS3	municipality
	Baden-Württemberg	4	44	1,103
	Bavaria	7	96	2,237
	Berlin	1	1	1
	Brandenburg	1	18	417
	Bremen	1	2	2
	Hamburg	1	1	1
	Hesse	3	26	430
	Mecklenburg Western Pomerania	1	8	753
	Lower Saxony	4	45	969
	North Rhine-Westphalia	5	53	396
	Rhineland-Palatinate	3	36	2,305
	Saarland	1	6	52
	Saxony	3	13	426
	Saxony-Anhalt	1	14	218
	Schleswig-Holstein	1	15	1,112
	Thuringia	1	23	849
Total:	16	38	401	11,271
		population		
min	678,753	528,728	34,428	9
	(Bremen)	(Trier)	(Zweibrücken)	(Gröde)
max	17,894,969	5,191,702	3,574,830	3,574,830
	(North Rhine-Westphalia)	(Dusseldorf)	(Berlin)	(Berlin)
mean	5,157,908	2,171,751	205,801	7,462

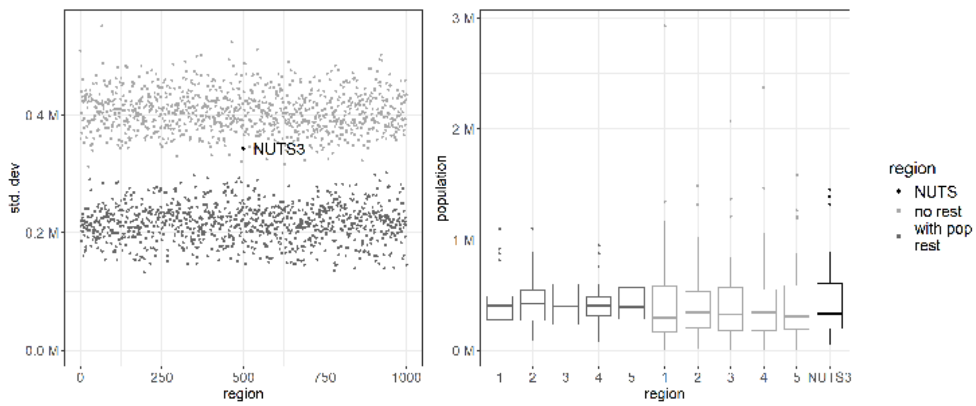
Note: Population numbers are for the year 2016. A number of municipalities, called unincorporated areas (in German Gemeindefreies Gebiet) are not populated.



(a) NUTS1

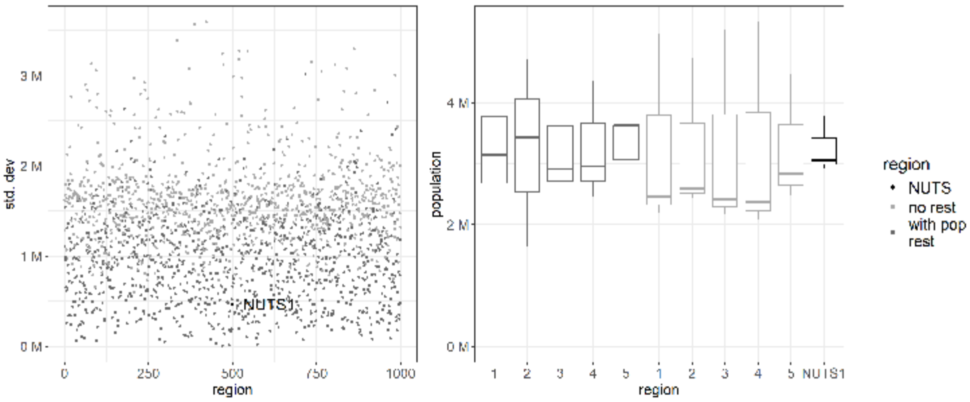


(b) NUTS2

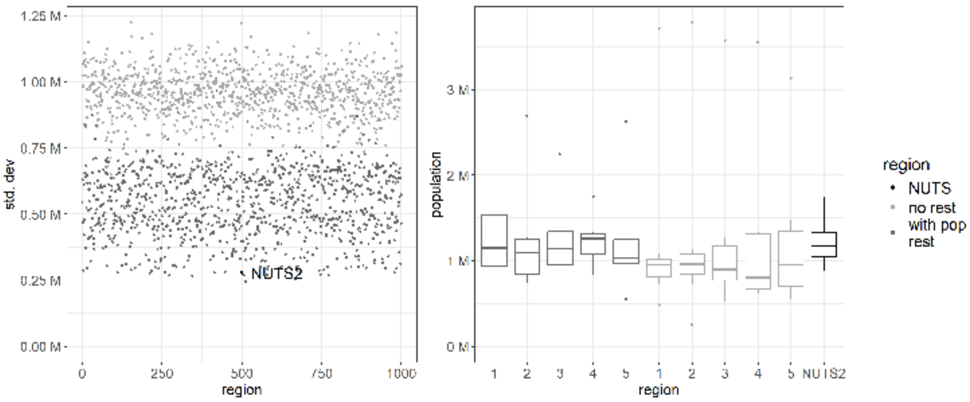


(c) NUTS3

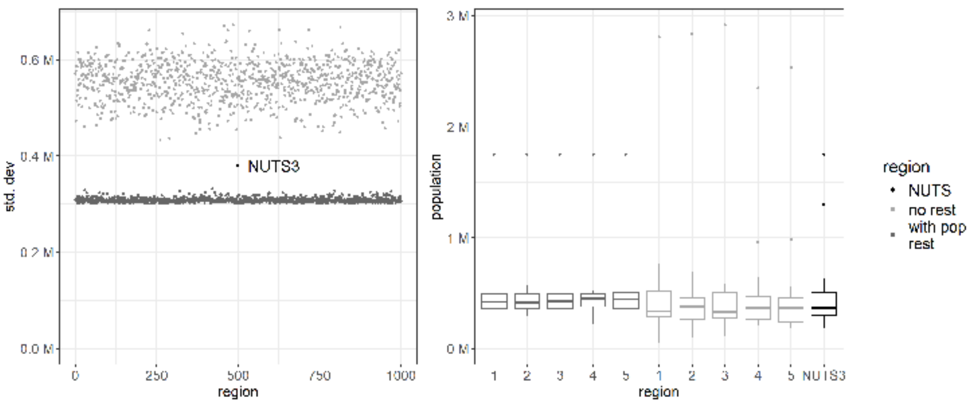
Figure A2: Standard deviation and population distribution of simulated regions for the Netherlands



(a) NUTS1

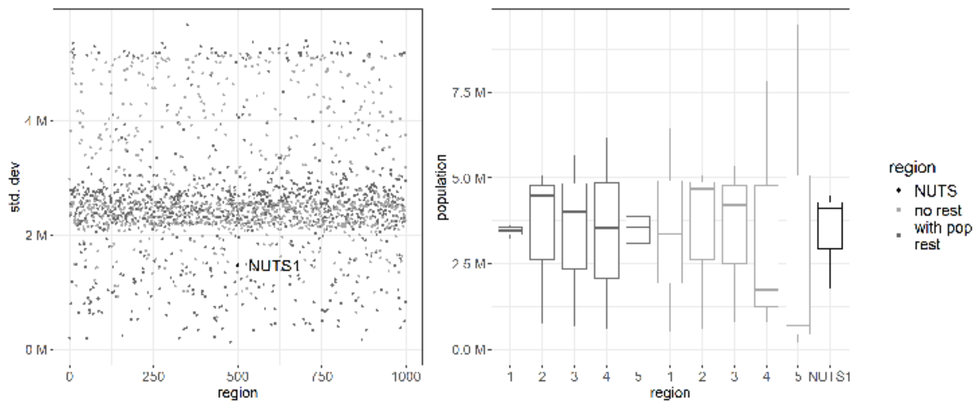


(b) NUTS2

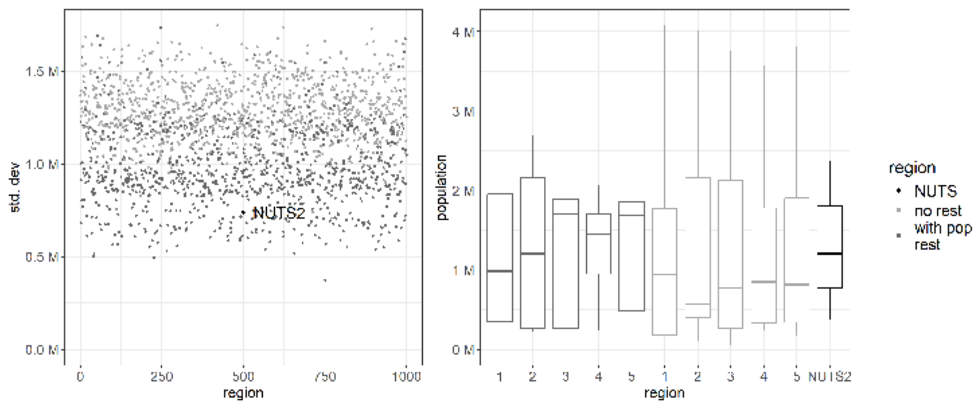


(c) NUTS3

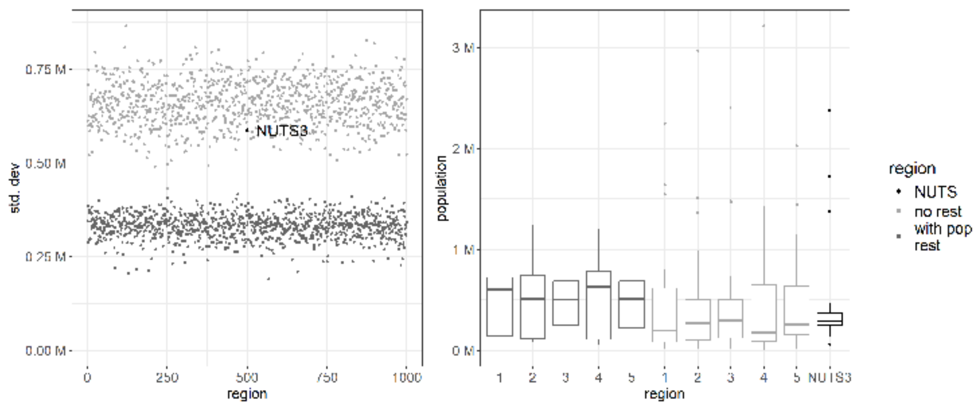
Figure A3: Standard deviation and population distribution of simulated regions for Hungary



(a) NUTS1

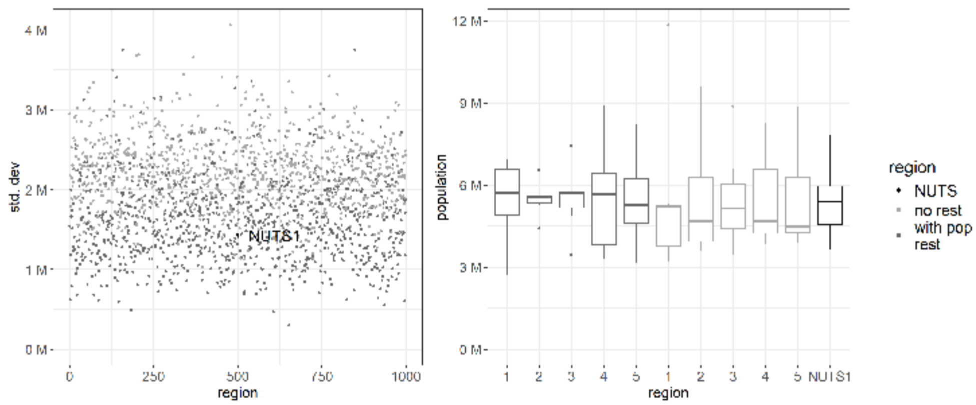


(b) NUTS2

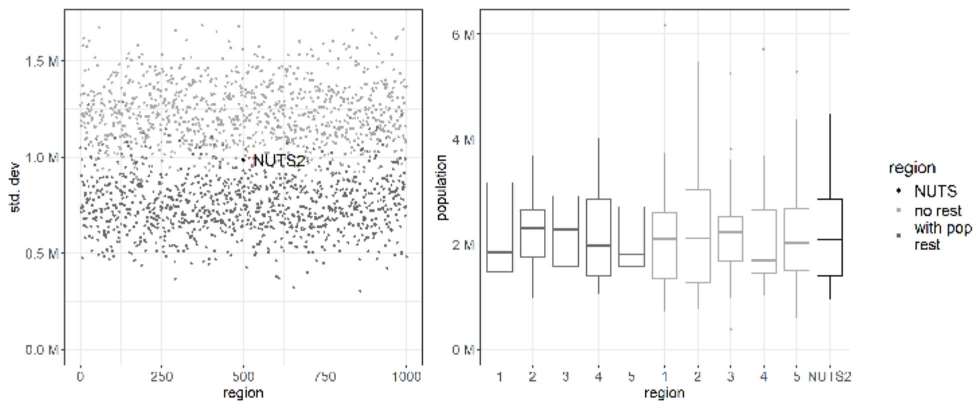


(c) NUTS3

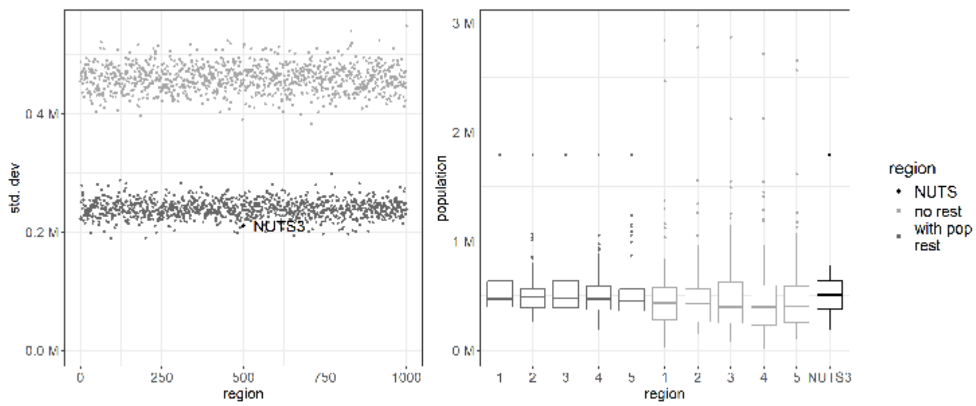
Figure A4: Standard deviation and population distribution of simulated regions for Sweden



(a) NUTS1

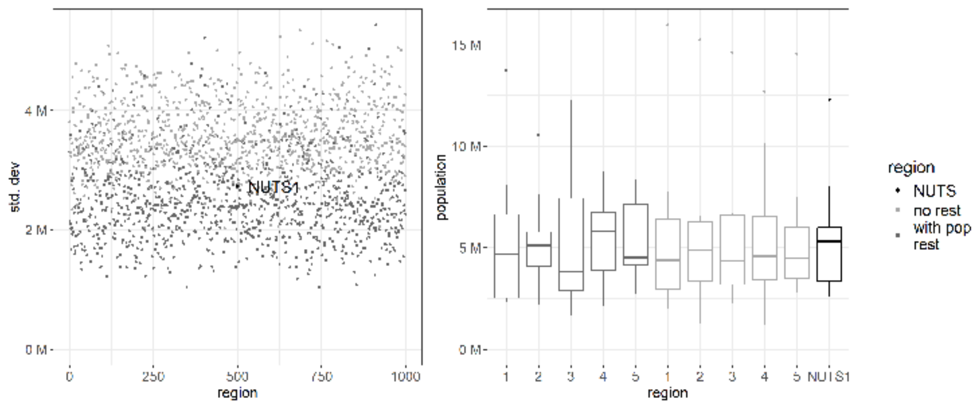


(b) NUTS2

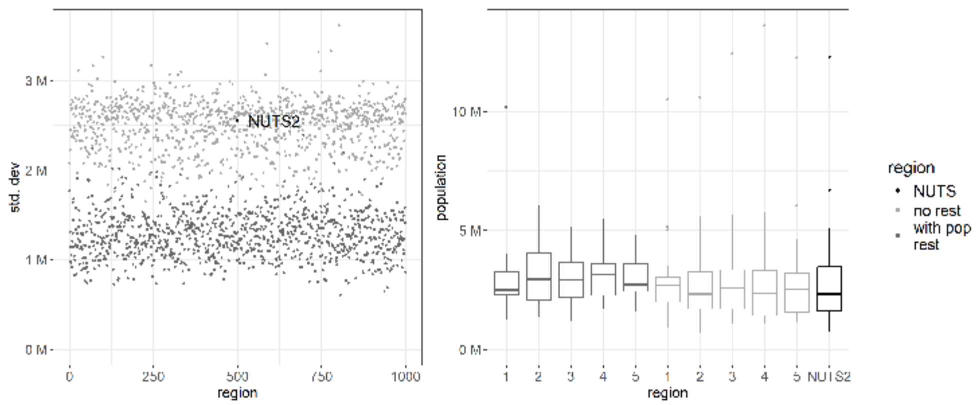


(c) NUTS3

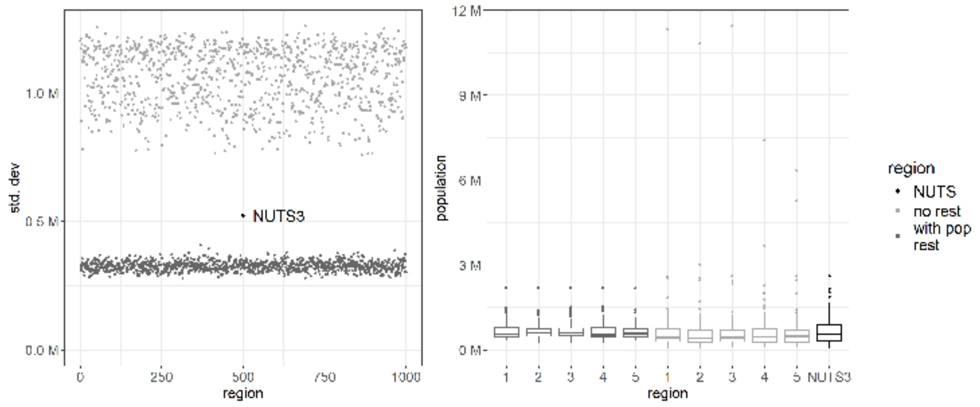
Figure A5: Standard deviation and population distribution of simulated regions for Poland



(a) NUTS1



(b) NUTS2



(c) NUTS3

Figure A6: Standard deviation and population distribution of simulated regions for France (The outermost regions and Corsica were excluded from the analysis)

B Sample Construction and Data Selection

B.1 TFP

The firm data set, obtained from the BvD AMADEUS database, is constructed based on multiple criteria. First, firms in the manufacturing sector located in Germany are selected. Our starting dataset of over 120,000 has a range between 2004 and 2018. However, the earlier and later years are excluded because in those years the number of firms for which the relevant data are available is small. The final time period of our analysis is 2009-2015.

Specifically, the following characteristics of firms are used to exclude units that might distort our analysis.

- Not enough location information (no information about the city and the NUTS 3 region or no data on Zip code and NUTS 1 region) or conflicting location information (city and NUTS regions do not match).
- Unambiguous mother companies: The statement of a company integrates the statements of its controlled subsidiaries or branches (consolidation codes C1 and C2).
- Firms with more than 10 branches.
- No data for at least one of the variables value added, total fixed assets, number of employees and cost of materials.
- The number of employees is below 10 for any of the available years.
- The number of employees exceeds 3,500 for any of the available years.
- Non-positive values for the financial variables.
- Large changes in the number of employees, material cost, value added.

Next, two and three in-between missing values over the available period are imputed. If the number of missing values between two years is larger than 3, the smaller available edge period is excluded. Finally, after the estimation of TFP, outliers for log(TFP) are also excluded (firms with productivity lower than 3 or higher than 6).

Table B1: Variable description

Variable name	Name in AMADEUS	AMADEUS description	unit
capital	Tangible Fixed Assets	All tangible assets such as buildings, machinery etc.	thousands of Euros
employment	Number of employees	Total number of employees included in the company's payroll	
materials	Material's cost	Detail of the purchases of goods (raw materials + finished goods). No services.	thousands of Euros
value added	Added value	Profit for period + depreciation + taxation + interests paid + cost of employees	thousands of Euros

Note: All monetary variables are later converted into real values, by using industry specific deflators obtained by EUROSTAT.

Table B2: Number of firms for calculating TFP in each year of the 7-year period

year	2009	2010	2011	2012	2013	2014	2015
observations	2,949	3,353	3,697	4,028	5,122	3,735	2,792

Note: The total number of observations is 25,676.

Table B3: Summary statistics

Variable	Mean	St. Dev.	MAX	MIN	No. of observations	time period
ln(TFP)	4.5003	0.4706	6.0429	2.9899	25,676	2009-2015
Value added	11,704.36	19,929.11	443,252.7	184.81	25,676	2009-2015
Employment	164.68	220.56	3,088	10	25,676	2009-2015
Materials	23,579.24	64,164.74	2,398,243	0.9381	25,676	2009-2015
Capital	6,754.56	18,706.95	646,448.20	0.9237	25,676	2009-2015

Note: All monetary variables have been converted into real values by using industry level deflators. Total number of firms is 7,317. Unbalanced panel.

B.2 Agglomeration variables

For the calculation of the variables measuring MAR and Jacobs spillovers we use a larger set of firms. In this data set a firm is maintained if all of the following criteria are fulfilled:

- it has reliable location information,
- the consolidation code is different from C1 or C2,
- the firm has less than 10 branches,
- for the whole available period the number of employees is not smaller than 5 or larger than 3,500, and
- there have not been any large changes in the number of employees over the available time period.

For calculating the agglomeration variables, all manufacturing firms (including NACE rev. 2 sector 12, 15 and 19) with data on employment in a given year form 2009-2015 are considered. Missing values for number of employees between two years are interpolated. Furthermore, if other information (value added, tangible fixed assets, turnover) is available in a given year, but not the employment, then we set the number of employees to the number in closest year for which data is available. This data set contains 54,529 firms.

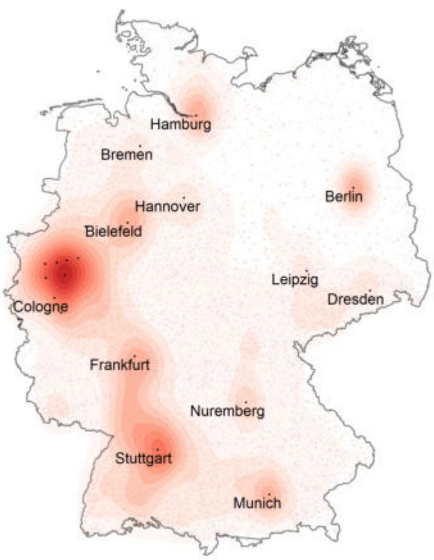


Figure B1: Heat map of the 54,529 firms

B.3 Control variables

B.3.1 Market potential

Market potential is calculated by using the number of employees subject to social insurance based on their place of residence[13]. The municipality level data is obtained from the Federal Employment Agency of Germany for the period 2013–2015 and from the Database of the Federal Statistical Office of Germany for the period 2009–2012.

B.3.2 Transported goods

For the calculation of the control variable transported goods (tg_{rt}), data on all transported freight by airports, river and see ports, rail and highways is used.

For transported freight in airports, data from 24 airports in Germany (Berlin-Schönefeld, Berlin-Tegel, Bremen, Dortmund, Dresden, Düsseldorf, Erfurt, Frankfurt/Main, Friedrichshafen, Hahn, Hamburg, Hannover, Karlsruhe, Köln/Bonn, Leipzig/Halle, München, Münster/Osnabrück, Niederrhein, Nürnberg, Paderborn/Lippstadt, Rostock-Laage, Saarbrücken, Stuttgart, Zweibrücken) is considered. This includes data on loaded and unloaded freight (including mail).

For river and sea ports, data from 65 ports is taken, for which there is information over the period from 2009–2015.

For roads only highways are considered, as they are the most important for transportation of goods. However, data about the amount of freight transported on roads is available only at the national level. Therefore, to obtain a proxy of the variable for a region, we assume that the region's share of national amount of freight that is transported on its highways corresponds to the share of the region's highways in the national highway network, based on the length of the highways.

For freight amounts transported on rail only data at the NUTS2 level is available. However, for 2009 and 2010 there is only data at the national level. Therefore, the annual change rates of the transported freight on rail are used to approximate the variable at the NUTS2 level for these two years. To obtain respective estimates of freight for the NUTS3 and artificial regions, a proportional approach based on the length of the rail is used, similarly as for the freight transport on roads. However, for regions without a railway stop the variable is set to equal zero.

It is assumed that there are no changes in the railway lines and the roads during the 7 year period.

All data for transported goods in 1,000t are obtained from the German Federal Statistical Office and the geographic data about airports, water ports, rail and roads are taken from EuroGeographics.

After approximating the regional amounts of freight for each of the four types of transportation, the total amount of transported goods in a region is calculated and then it is divide by the area of the region.

[13] First we considered looking at employees based on their place of work, however the data had many missing values.

C Additional results

Table C1: Descriptive statistics of estimates of Model I

	localisation	localisation 5% sign	urbanisation	urbanisation 5% sign
		LARGE regions		
N	1,000	6	1,000	10
Mean	-0.0165	-0.0056	-0.1077	-0.3183
SD	0.0397	0.1299	0.0941	0.0491
Min	-0.1365	-0.1327	-0.5357	-0.3865
Median	-0.0162	-0.0038	-0.1077	-0.3195
Max	0.1207	0.1207	0.2787	-0.2409
		MEDIUM regions		
N	1,000	12	1,000	35
Mean	-0.0091	-0.0277	-0.0908	-0.2337
SD	0.0280	0.0739	0.0746	0.0413
Min	-0.1051	-0.1051	-0.3413	-0.3413
Median	-0.0102	-0.0690	-0.0884	-0.2285
Max	0.0801	0.0760	0.1502	-0.1435
		SMALL regions		
N	1,000	10	1,000	31
Mean	0.0059	0.0315	-0.0327	-0.0926
SD	0.0126	0.0247	0.0261	0.0119
Min	-0.0370	-0.0370	-0.1193	-0.1193
Median	0.0057	0.0377	-0.0325	-0.0911
Max	0.0485	0.0485	0.0780	-0.0714

Table C2: Descriptive statistics of estimates of Model II

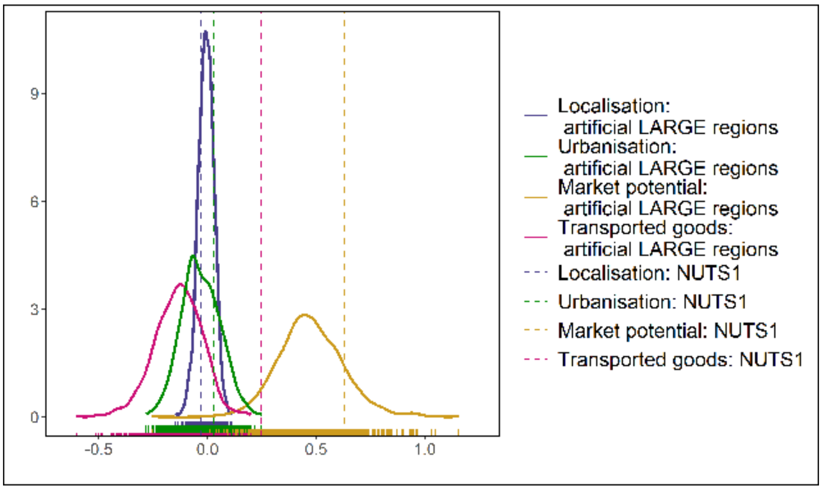
	localisation	localisation 5% sign	diversity	diversity 5% sign
		LARGE regions		
N	1,000	349	1,000	6
Mean	-0.0481	-0.0653	-0.0057	0.0144
SD	0.0184	0.0114	0.0263	0.0667
Min	-0.1031	-0.1031	-0.0927	-0.0736
Median	-0.0485	-0.0645	-0.0058	0.0439
Max	0.0050	-0.0297	0.0781	0.0781
		MEDIUM regions		
N	1,000	254	1,000	25
Mean	-0.0309	-0.0488	-0.0157	-0.0635
SD	0.0154	0.0094	0.0206	0.0123
Min	-0.0849	-0.0849	-0.0921	-0.0921
Median	-0.0305	-0.0489	-0.0146	-0.0596
Max	0.0168	-0.0290	0.0472	-0.0488
		SMALL regions		
N	1,000	3	1,000	66
Mean	-0.001	0.0075	-0.0121	-0.0282
SD	0.0091	0.0339	0.0087	0.0041
Min	-0.0316	-0.0316	-0.0427	-0.0427
Median	-0.0003	0.0264	-0.0118	-0.0272
Max	0.0302	0.0279	0.0114	-0.0216

Table C3: Descriptive statistics of estimates of Model III

		LARGE regions		
	localisation	localisation 5% sign	urbanisation	urbanisation 5% sign
N	1,000	10	1,000	4
Mean	-0.0068	-0.0549	-0.0305	-0.2432
SD	0.0363	0.0983	0.0894	0.0617
Min	-0.1476	-0.1476	-0.2816	-0.2816
Median	-0.0064	-0.1022	-0.0361	-0.2700
Max	0.1120	0.0873	0.2488	-0.1510
	market potential	market pot. 5% sign	transported goods	transp. goods 5% sign
N	1,000	724	1,000	111
Mean	0.4764	0.5225	-0.1346	-0.2950
SD	0.1532	0.1358	0.1100	0.0855
Min	-0.2550	0.2020	-0.6030	-0.6030
Median	0.4678	0.5054	-0.1296	-0.2832
Max	1.1576	1.1576	0.2001	-0.1405
		MEDIUM regions		
	localisation	localisation 5% sign	urbanisation	urbanisation 5% sign
N	1,000	16	1,000	19
Mean	-0.0028	0.0009	-0.0505	-0.1855
SD	0.0279	0.0732	0.0624	0.0234
Min	-0.1056	-0.1056	-0.2324	-0.2154
Median	-0.0024	0.0464	-0.0499	-0.1871
Max	0.0906	0.0906	0.1378	-0.1418
	market potential	market pot. 5% sign	transported goods	transp. goods 5% sign
N	1,000	546	1,000	5
Mean	0.2587	0.2974	0.0015	-0.2162
SD	0.0686	0.0556	0.0820	0.0271
Min	0.0439	0.1585	-0.2555	-0.2454
Median	0.2562	0.2955	3e-04	-0.2229
Max	0.5018	0.5018	0.2547	-0.1775
		SMALL regions		
	localisation	localisation 5% sign	urbanisation	urbanisation 5% sign
N	1,000	15	1,000	1
Mean	0.0070	0.0380	-0.0216	-0.1009
SD	0.0124	0.0068	0.0252	/
Min	-0.0300	0.0305	-0.1043	-0.1009
Median	0.0071	0.0368	-0.0211	-0.1009
Max	0.0529	0.0529	0.0555	-0.1009
	market potential	market pot. 5% sign	transported goods	transp. goods 5% sign
N	1,000	997	1,000	198
Mean	0.3476	0.3480	0.1625	0.2981
SD	0.0423	0.0417	0.0990	0.0684
Min	0.1964	0.2333	-0.0928	0.1963
Median	0.3453	0.3453	0.1574	0.2823
Max	0.5368	0.5368	0.5308	0.5308

Table C4: Descriptive statistics of estimates of Model IV

	LARGE regions			
	localisation	localisation 5% sign	diversity	diversity 5% sign
N	1,000	342	1,000	21
Mean	-0.0462	-0.0630	0.0065	0.0481
SD	0.0181	0.0119	0.0297	0.0677
Min	-0.1146	-0.1146	-0.1015	-0.1015
Median	-0.0468	-0.0621	0.0059	0.0672
Max	0.0195	-0.0355	0.1344	0.1344
	market potential	market pot. 5% sign	transported goods	transp. goods 5% sign
N	1,000	764	1,000	153
Mean	0.4947	0.5363	-0.1432	-0.2878
SD	0.1552	0.1379	0.1077	0.0804
Min	-0.2407	0.2068	-0.6198	-0.6198
Median	0.4871	0.5230	-0.1378	-0.2787
Max	1.1540	1.1540	0.1980	-0.1161
	MEDIUM regions			
	localisation	localisation 5% sign	diversity	diversity 5% sign
N	1,000	219	1,000	18
Mean	-0.0302	-0.0499	-0.0148	-0.0568
SD	0.0158	0.0103	0.0196	0.0081
Min	-0.0856	-0.0856	-0.0738	-0.0738
Median	-0.0302	-0.0478	-0.0152	-0.0571
Max	0.0150	-0.0296	0.0451	-0.0443
	market potential	market pot. 5% sign	transported goods	transp. goods 5% sign
N	1,000	617	1,000	7
Mean	0.2698	0.3005	-0.0091	-0.2077
SD	0.0666	0.0558	0.0817	0.0297
Min	0.0378	0.1477	-0.2449	-0.2449
Median	0.2669	0.2980	-0.0094	-0.1979
Max	0.5272	0.5272	0.2442	-0.1652
	SMALL regions			
	localisation	localisation 5% sign	diversity	diversity 5% sign
N	1,000	6	1,000	37
Mean	-0.0002	-0.0051	-0.0098	-0.0283
SD	0.0088	0.0294	0.0090	0.0039
Min	-0.0270	-0.0270	-0.0391	-0.0391
Median	-0.0002	-0.0219	-0.0098	-0.0269
Max	0.0342	0.0342	0.0155	-0.0243
	market potential	market pot. 5% sign	transported goods	transp. goods 5% sign
N	1,000	997	1,000	202
Mean	0.3505	0.3509	0.1639	0.2984
SD	0.0421	0.0414	0.0990	0.0685
Min	0.1977	0.2378	-0.0889	0.1907
Median	0.3484	0.3485	0.1590	0.2837
Max	0.5310	0.5310	0.5317	0.5317



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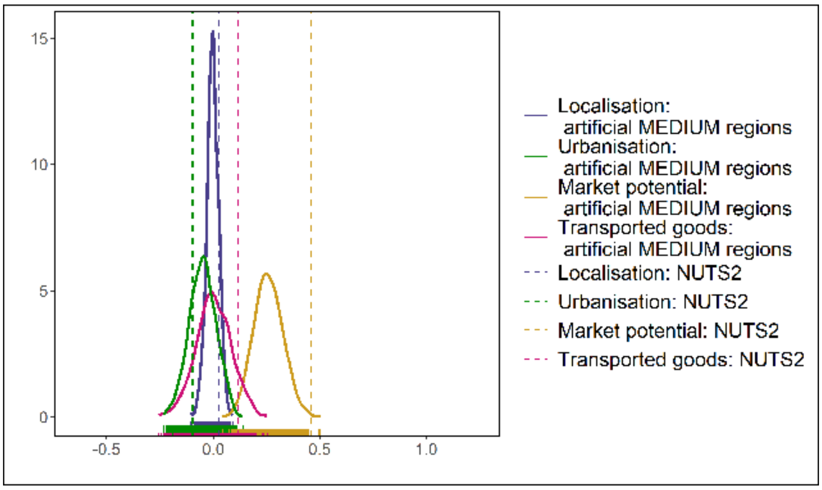

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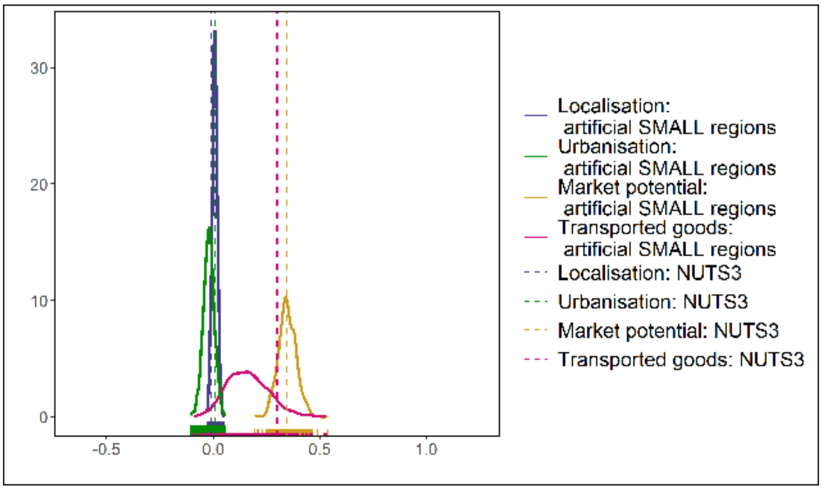

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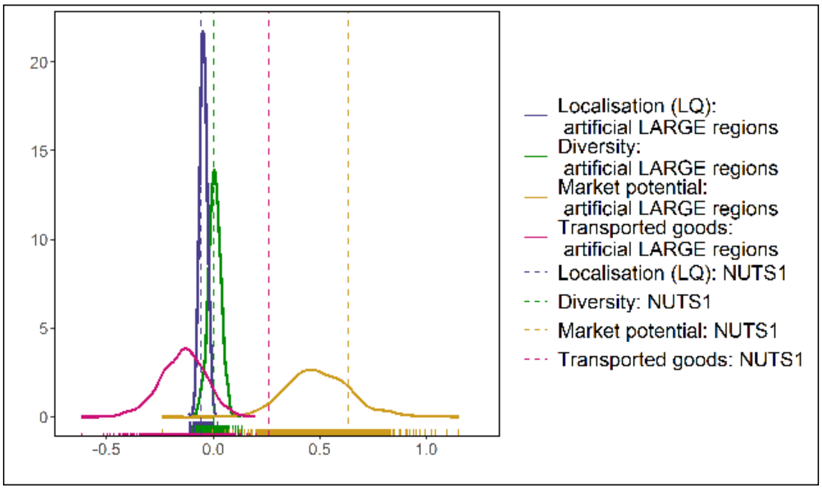
Figure C1: Model III based on simulated regions with population restriction

Note: Estimates for equation 11 with both time and firm fixed effects. The densities of the parameter estimates rely on 1,000 settings of artificial regions.



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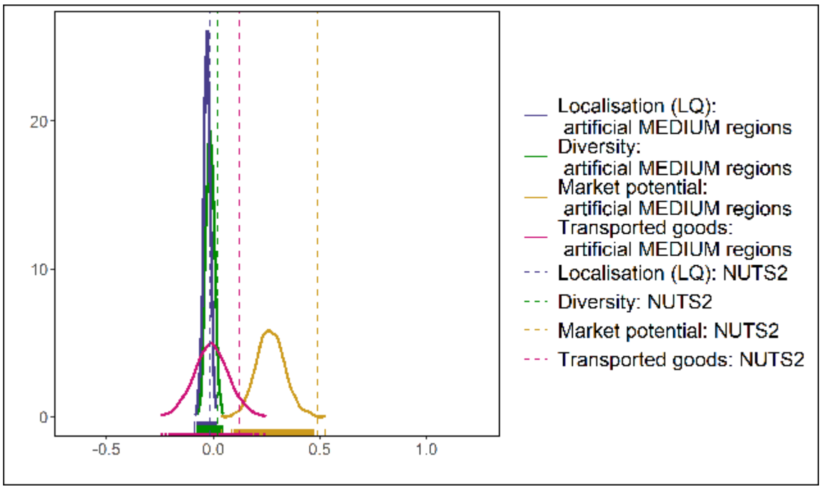

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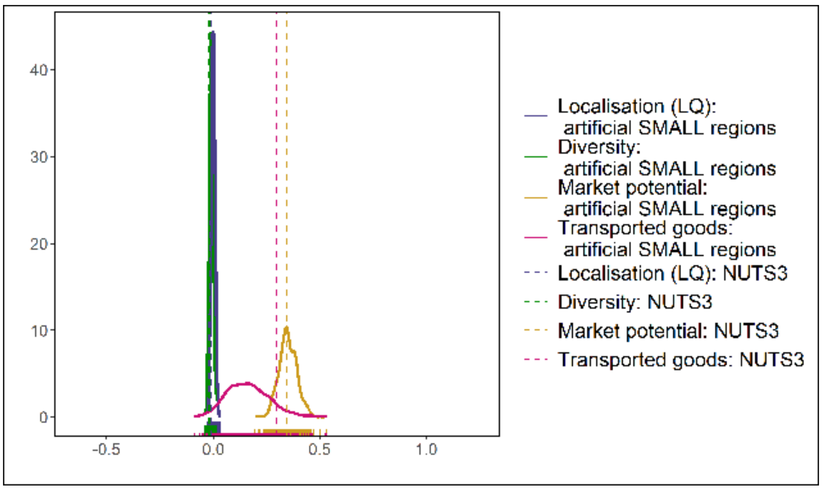

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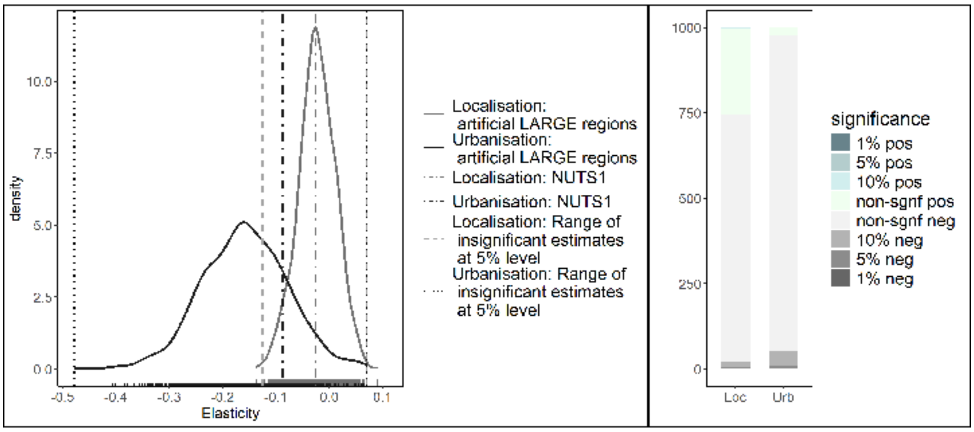
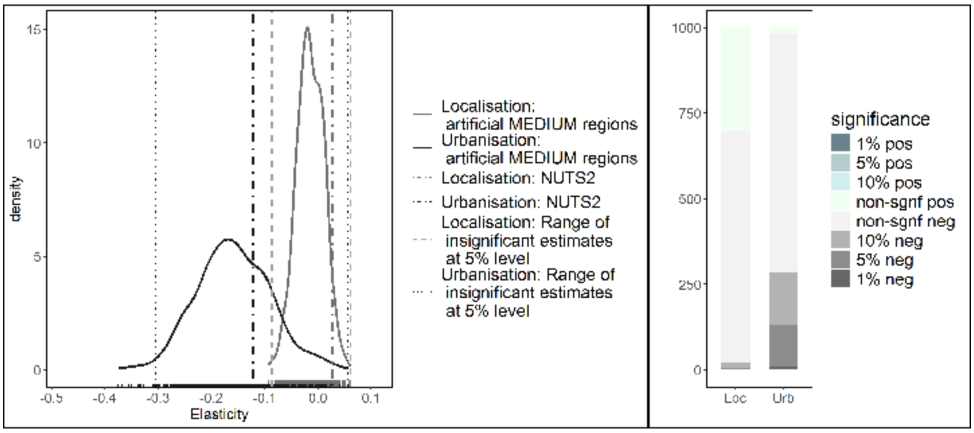
Figure C2: Model IV based on simulated regions with population restriction

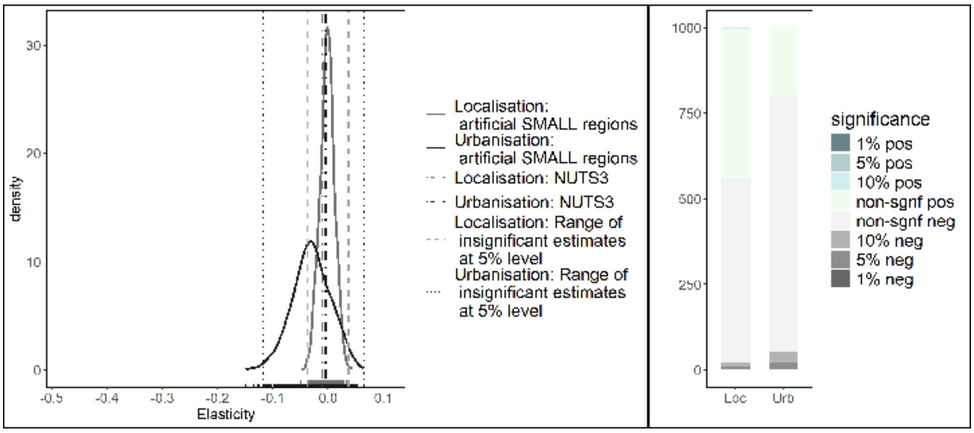
Note: Estimates for equation 12 with both time and firm fixed effects. The densities of the parameter estimates rely on 1,000 settings of artificial regions.



(a) Large regions



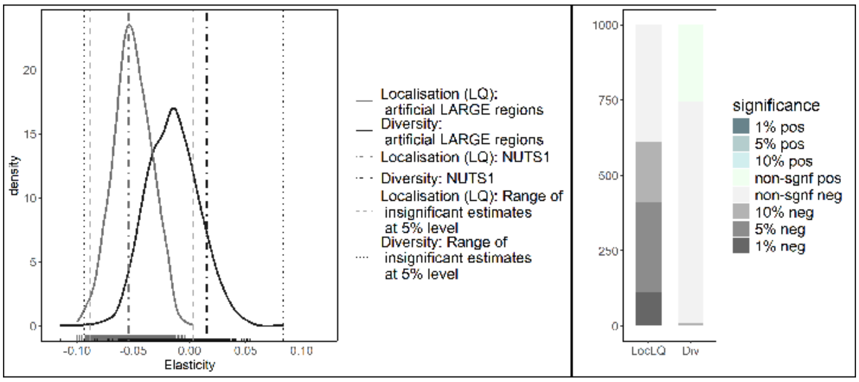
(b) Medium regions



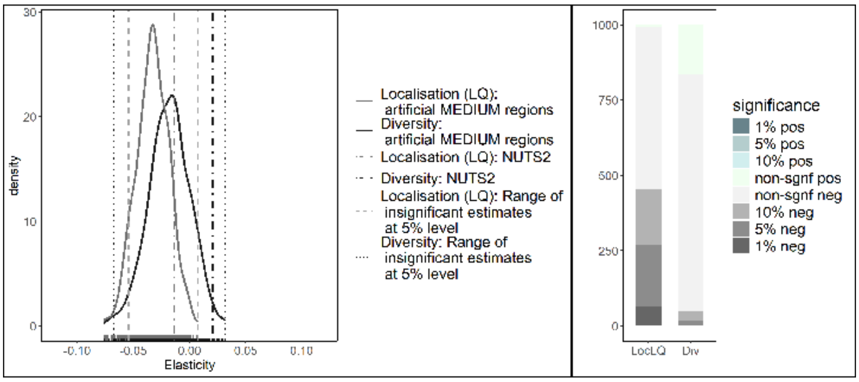
(c) Small regions

Figure C3: Parameter estimates of the localisation and urbanisation variables in the Model I and the distribution of their significance (no population restriction simulation model)

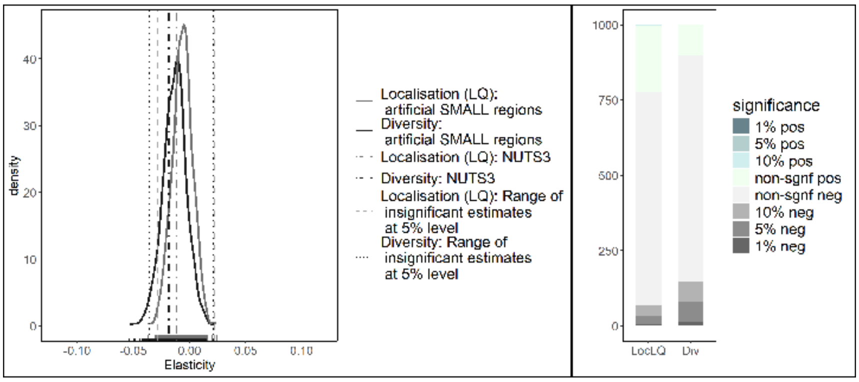
Note: The densities of the parameter estimates rely on 1,000 settings of artificial regions. The range of insignificant estimates at 5 % level covers all parameter estimates that are not statistically significant at 5 % significance level.



(a) Large regions



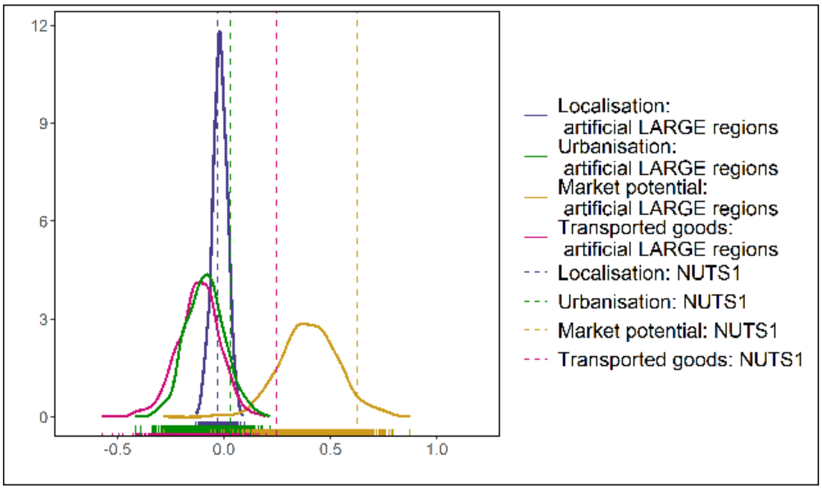
(b) Medium regions



(c) Small regions

Figure C4: Parameter estimates of the localisation and urbanisation variables in the Model II and the distribution of their significance (no population restriction simulation model)

Note: The densities of the parameter estimates rely on 1,000 settings of artificial regions. The range of insignificant estimates at 5 % level covers all parameter estimates that are not statistically significant at 5 % significance level.



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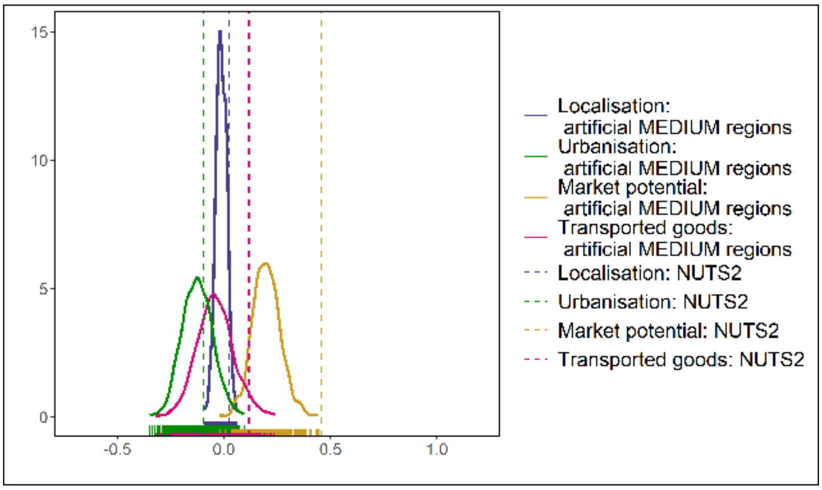

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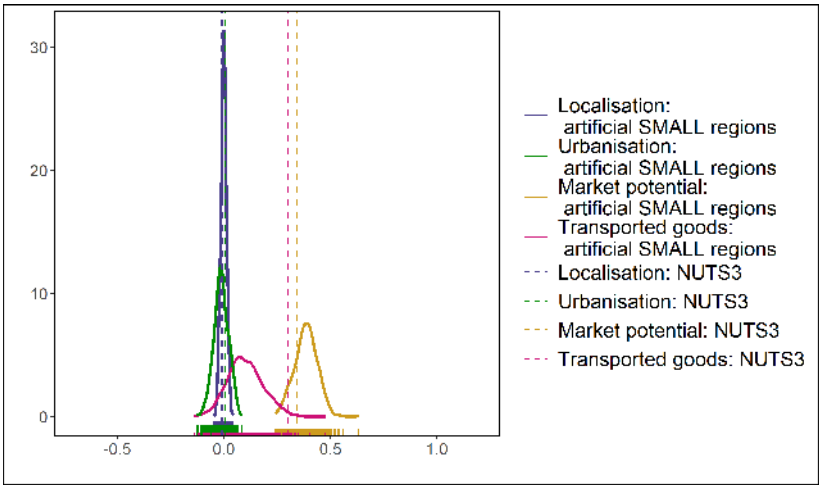
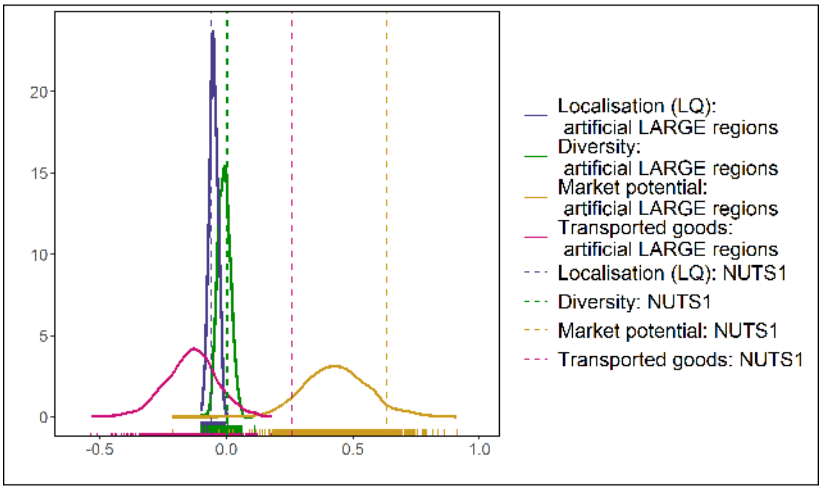


(c) Small

Figure C5: Model III based on simulated regions with no population restriction

Note: Estimates for equation 11 with both time and firm fixed effects. The densities of the parameter estimates rely on 1,000 settings of artificial regions.



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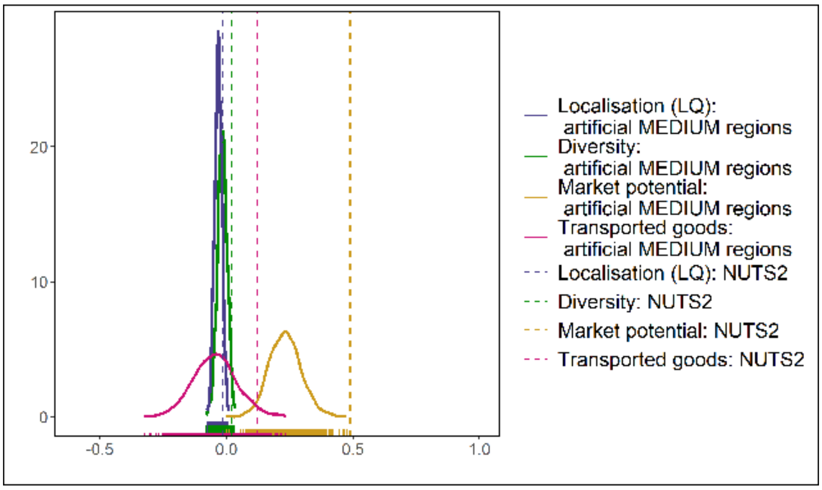
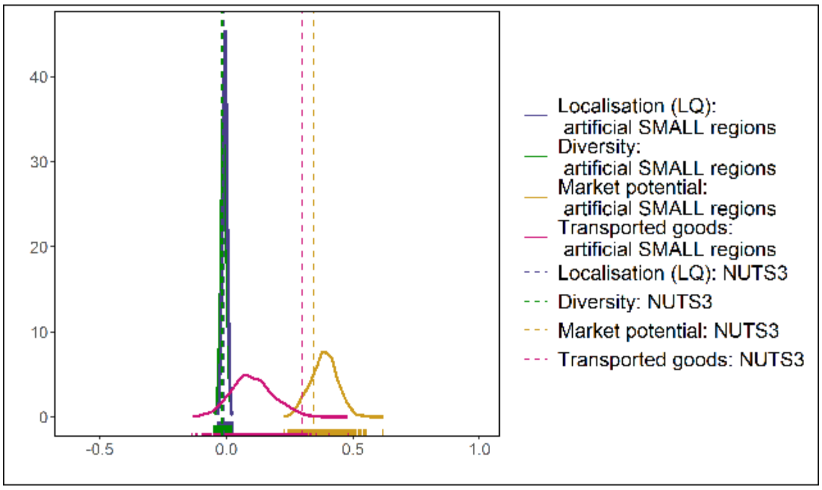


(b) Medium



(c) Small

Figure C6: Model IV based on simulated regions with no population restriction

Note: Estimates for equation 12 with both time and firm fixed effects. The densities of the parameter estimates rely on 1,000 settings of artificial regions.

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The Impact of Education (Level of Knowledge) on the Prevalence of Obesity in Different Urban Environments

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Abstract. We investigate the impact of high-rise buildings on the prevalence of obesity in the US during 2011-2020 stratified by educated vs. non-educated populations. We use a quadratic specification that accounts for non-monotonic variation. Findings demonstrate that concentration of above 146 skyscrapers in a state is detrimental with regards to the projected prevalence of obesity. The main public policy repercussions of our study are: 1) the promotion of education for medical literacy due to the fact that for each number of skyscrapers the prevalence of obesity is lower among educated populations. 2) widening pavements, pathways and open spaces following urban development.

Key words: High-Rise Buildings, Obesity; Health Literacy

1 Background

Previous studies found fundamental differences in health behavioral patterns among different groups stratified by education levels. According to the allocated efficiency hypothesis, higher level of human capital, proxied by education level, is positively associated with accumulated health information and knowledge. This, in turn, permits more efficient health choices and decisions (Grossman 1972, Muurinen 1982, Wagstaff 1986). Recent empirical studies demonstrate that schooling is significantly associated with health knowledge levels, which explain up to 69% of the education effect on health lifestyle in the Philippines (Hoffmann, Lutz 2019). Higher education levels among women in Australia promotes non-monetary benefits, such as, hedonic well-being, and reduced psychological distress (Tran et al. 2021). Referring to acquired information from schools, Arbel et al. (2022) discuss children-parents knowledge spillover in the context of the COVID19 pandemic. This context may be extended to include physical activity and healthy nutrition so as to reduce obesity.

Another strand of the literature relates to the urban environment advantages and disadvantages in terms of physical activity, nutrition and obesity. On the one hand, such environments may promote walkability by including mixed uses of land, stairways, gyms, green spaces and parks, bicycle and running tracks. Several studies stress the claim that some built environment characteristics encourage people to increase their walking distances (Handy et al. 2006, Chaix et al. 2014, Sun et al. 2014). In this context and based on longitudinal study of Canadians, Wasfi et al. (2016) concluded that exposure to walkable neighborhoods in urban areas increases utilitarian walking. On the other hand, crowded cities, characterized by high population densities, may discourage physical activity and provide more opportunities for increased consumption of ill-nutritional food during the nights and concurrent sleep deprivation (Fatima et al. 2015, Winston 2015, Mayne et al. 2021). Given studies that found no correlation between specific built environments and walking, Feuillet et al. (2016) suggested that more subtle analysis is required. Chen, Zhou (2016) found that the densities of 4-way intersections and more than 5-way intersections and land use mixture are positively correlated with the pedestrian crash frequency and risk in Seattle, Washington. Recently, Nigg et al. (2021) demonstrated that for each additional ten citizens per square kilometer in Germany, less positive physical activity changes were observed during the first Covid-19 lockdown in April 2020 among children. Finally, referring to the older population in Japan, high walkability neighborhood (i.e., high population density, proximity to railway stations) adversely affected their step counts, whereas proximity to large parks had a positive effect during the COVID19 state-of-emergency period (Hino, Asami 2021).

The objectives of the current study are twofold. The first objective is to link between these two strands of the literature. This is done by investigation of the relationship between the prevalence of obesity (the endogenous variable); the time variable (the first exogenous variable) and the urban environment proxied by two variables: the number of skyscrapers (the second exogenous variable); population density (the third exogeneous variable). The former environmental variable is interacted with the education level (a dummy variable that equals one for educated and zero for non-educated populations; the fourth exogenous variables). Given the unclear relationship between built environments and walkability, the second objective is to propose a simple methodology to address this issue. We employ the quadratic model, which permits non-monotonic relationship between the number of skyscrapers and obesity prevalence[1]. With the exception of Sun, Yin (2018), we found no other paper that employs this methodology in this context. The underlined research hypothesis is that up to (above) a certain level of population density, the advantages (disadvantages) of agglomeration (congestion) effect dominates.

The validity of the number of skyscrapers as a measure of dense urban environments derives from the economic theory as well as from a long series of empirical studies, which show an association between high–rise construction and dense urban areas (for an extensive review on urban spatial structure see, for example, Anas et al. 1998). According to McDonald, McMillen (2011): "Residential buildings are typically built at a very high density – tall buildings with many units built atop small land parcels" (page 121).

Practitioners and urban planners utilize similar metrics to gauge the density of urban environments and the intensity of land use (McDonald, McMillen 2011, p. 128-131). One such metric is the floor-area ratio (FAR), which is defined as the ratio of a building's total floor space to the area of the land it occupies. In Chicago, the R1 to R8 zoning categories demonstrate a range of FAR values: for example, R1 allows for a FAR of 0.5 for detached units on lots of 6,250 square feet, meaning the maximum floor area of the unit could be 3,125 square feet. In contrast, R8 zoning permits a FAR of up to 10 for apartment buildings on lots as small as 115 square feet, allowing a 20-story building to occupy 50% of the lot's area.

Theoretically, there is a one-to-one match between population density and high-rise buildings. The implication of high (low) population density is residence in high rise buildings at the city centers where land is expensive and scarce (land detached single-family housing units in the suburbs, where land is cheap). This point is formally demonstrated, for instance, in Mills, Hamilton (1989, p. 425-434).

The validity of the relationships between dense urban environments and walkability comes from a long list of empirical studies (e.g., TRB 2005, Frank et al. 2010, Ewing et al. 2014, Mulalic, Rouwendal 2020). In TRB (2005), the US Committee on Physical

[1]When the relationship between two variables is quadratic and we run: 1) a simple linear model, and 2) a quadratic model, for the (former) latter model ($R^2 = 0$ indicating no correlation) $R^2 = 1$ implying perfect correlation. (e.g., Kmenta 1997, page 241 panel (b)). As a simple exercise, we artificially constructed a sample based on the following equation: $Y = \widehat{Y} = 6 + 5X^2$ for $X = -18, -17, -16, \ldots, 16, 17, 18$. While a simple linear regression between Y and X gives zero correlation, a quadratic regression between Y, X and X^2 yields a perfect fit (see Appendix C).

Activity, Transportation, and Land Use, the Transportation Research Board, and the Institute of Medicine identified the role of urban environments in physical activity levels as a relative new field of study (page 5). Physical inactivity has been identified as one of the leading risk factors for noncommunicable diseases, such as, obesity, mortality.

In sum, this study addresses the following research questions:

1a) What are the relationships between sparse/dense urban environments (proxied by the number of skyscrapers) and the prevalence of obesity?

1b) Are these relationships linear or quadratic?

2) Given that the urban environment is controlled, are the differences in obesity prevalences between educated and on-educated populations still preserved?

Based on a sample of 47 US States during 2011-2020, the outcomes show that, as anticipated, for each number of skyscrapers, compared to non-educated population, projected obesity is lower among educated population. For a model that includes standardized normal distribution transformations of each variable, education has the highest weight in explaining obesity prevalence. For both groups of educated and uneducated populations the model predicts a U-shaped curve. Yet, the incremental effect of each additional skyscraper is steeper among the educated group.

An important contribution of this study is the use of a quadratic model. Compared to the linear model, the quadratic model may describe more complex relationship. The model allows the fall and rise of the dependent variable with the number of skyscrapers thus demonstrating a crowding out effect in terms of obesity prevalence. Differently put, obesity prevalence reaches its basin when the urban environment is relatively sparse. This is represented by an amount of approximately 146 skyscrapers. This crowding out effect cannot be investigated by employing the linear model. Failure to test the possibility of quadratic relationships might cause a type two error namely non-rejection of the null hypothesis where it should be rejected. This possibility is demonstrated in Appendix C. In this context, Wilkins et al. (2019) argue that null association between obesity and food environment dominated across all measurement methods comprising 76.0% of 1937 associations in total.

The remainder of this manuscript is organized as follows. Section 2 gives a literature review on walkability, obesity and population density. Section 3 provides the description of data sources, the descriptive statistics of variables that are latter incorporated in the empirical model and describes the empirical model. Section 4 gives the results obtained from the empirical model. Section 5 provides robustness tests. Finally, Section 6 concludes and summarizes.

2 Literature Review (Walkability, Obesity and Population Density)

Walkability is a vital link between the number of skyscrapers and obesity. A few studies have tried to define objective and subjective measures for 'walkability' in a built environment. Mayne et al. (2013), for instance, stated that 'walkability' describes the ability of a built environment to support walking for multiple purposes. Increasing local opportunities for walking and sports activities through strategic development and efficient land use is a cornerstone of the city's correct policy. Walking for utilitarian purposes is related to the features of the built environment near certain destinations, mixed land use, connectivity between the streets and population density. The authors developed an objective measure of the ability to predict utilitarian walking in the city of Sydney.

In contrast, Rodrigue et al. (2022) developed a subjective index to measure the perceived friendliness of walking in a certain area or, in other words, what is the subjective 'walking experience' in that area. For example, the ability to predict walking for the purpose of a trip versus walking for the purpose of leisure or work at the street or neighborhood level.

In the context of walkability, Baobeid et al. (2021) noted that the need for rigorous assessment tools for policy evaluation and urban planning is important. Yet, there is no unified universal standard walking theory.

Other studies have indicated that the relationship between the built environment and excess weight lies, among other things, in the ability to walk and the physical activity that results from the infrastructures that exist in that environment. According to Mariela, one of the factors that lead to the desire to walk, and exercise is socioeconomic status, which prevents obesity and weight gain. Wei et al. (2016) also pointed out that one of the factors influencing the "willingness to go" is socioeconomic status, while the use of land has less influence on people's behavior.

Baobeid et al. (2021) recommended the creation of incentive structure associated with developing walking abilities for urban residents. This includes discouragement of private vehicles owning and transportation consumption, thus creating long-term health benefits from walking and physical activity. In addition, they examine objective and subjective indicators of the built environment that make walking possible and desirable. For example, connectivity, accessibility and proximity to destination points, the presence of greenery and parks, commercial retail and proximity to transit hubs and stations.

Lopez, Hynes (2006) state that factors such as low density, poor street connectivity and the absence of sidewalks will lead to a decrease in physical activity in the suburbs and an increased risk of being overweight, while in dense neighborhoods high density, excellent connectivity between streets and sidewalks will lead to obesity. In their opinion, the reasons for the consulting paradox lie in the complex interaction between land use, infrastructure and social factors that affect the city's population.

In addition to the number of skyscrapers, another proxy for the urban environment is population density. This variable is closely associated with but not identical to the number of skyscrapers (e.g. Mills, Hamilton 1989, McDonald, McMillen 2011, Pomponi et al. 2021). Net population density is defined as the ratio between population and land allocated for residence. This can be discussed from two perspectives:

Theoretically, there is a one-to-one match between population density and high-rise buildings. The implication of high (low) population density is residence in high rise buildings at the city centers where land is expensive and scarce (land detached single-family housing units in the suburbs, where land is cheap). This point is formally demonstrated, for instance, in Mills, Hamilton (1989, p. 425-434). Accordingly, the derivation procedure yields the following solutions: $R(u) = \bar{R}e^{tE(\bar{u}-u)}$ and $\frac{N(u)}{L(u)} = ER(u)$ where $R(u)$ is the land rent as a function of the distance from the city center (u), $\bar{R}$ is the lowest land rent at the city suburbs at the distance $\bar{u}$ from the city center, t is the commuting cost per two units of distance (either mile or km) and E is a parameter. Most importantly, $N(u)$ is population, $L(u)$ is land allocated for residence, where both are functions of the distance from the city center (u). Consequently, $\frac{N(u)}{L(u)}$ is population density, which is proportionate by a factor of E to the land rent. Differently put, as land price increases at the city center, construction will become higher and population density will rise.

Empirically, these two variables are closely associated, but not identical. McDonald, McMillen (2011, p. 120-122) distinguish between gross and net population density. As the authors demonstrate, gross population density is equal to $\frac{N(u)}{L(u)}$ where all land uses are included. Consequently, the tendency of population density is to rise until a certain distance from the city center, and then fall. Pomponi et al. (2021) argue that increasing population densities without construction of taller buildings will end up in reduction of green-house-gas (GHG) emission. A possible method to increase the population densities without heightening the structures is simply to populate larger families in each apartment.

Pomponi et al. (2021) stress further the difference between population density and tall buildings. According to the authors, part of the difference is the regulatory requirements to preserve public areas (staircases, elevators), preserve reasonable standards of daylight within the high-rise buildings, space between adjacent structures and green spaces and parks. Consequently, there is no maximum utilization of the area and therefore maximum urban density is not generated.

Table 1: Descriptive Statistics

Variable		Obs.	Mean	Std.Dev.	Min	Max
Obesity prevalence	Prevalence of population in the US state that suffers from obesity ($BMI \geq 30$ where) measured in percentage points	928	22.54	6.55	7.6	37.6
($Year - 2011$)	The year in which the prevalence of obesity was measured in the state	928	4.53	2.86	0	9
Educated	1=Educated (College Education); 0=Non-Educated (Less than high-school education)	928	0.5	0.50	0	1
Skyscrapers	Number of skyscrapers in the state	928	15.86	42.87	0	267
Pop_Density	(in square km.)	928	192.68	629.95	0.5	4,361

Notes: The statistical test of Non-Educated vs. Educated obesity prevalence difference of means with unequal variances is given in Table 2.

3 Methods

3.1 Description of Data

Data for this study were obtained from several sources. Obesity prevalence data were provided by the CDC website. Prevalence of obesity is calculated as the ratio of obese persons (i.e., with BMI ≥ 30) and the group population. Data for the number of skyscrapers in each state were obtained from MapPorn. The population densities of the US states were obtained from the United States Census Bureau (2010, 2020).

Appendix A describes the data structure and stratification by states. Referring to obesity prevalence, the data includes up to ten years per state (Year$= 2011, 2012, \ldots, 2020$) for the most educated vs. most uneducated group. Consequently, the full sample per-state includes 20 observations (10 years×2 obs. for educated and non-educated in each state). There are 44 US states with the full sample of 20 observations ($44 \times 20 = 880$), and three US states with missing observations: (Idaho – 14 obs., North Dakota – 18 obs. and Utah – 16 obs.) The total sum is: $880 + 14 + 18 + 16 = 928$.

In addition, originally the CDC dataset includes four groups: 1) College graduates; 2) High School graduates; 3) Less than high school; and 4) Some college or technical schools. To simplify and avoid confusion, we chose to analyze only the two most extreme groups (the most uneducated – group 3; and the most educated – group 1). Appendix B demonstrate graphically the outcomes obtained for the four groups when the mid-range groups are not omitted.

3.2 Descriptive Statistics

Table 1 reports the descriptive statistics of the dependent variable and the predictors that are later incorporated in the empirical model. The variable (year-2011) is defined as the number of years (minus one) in which the prevalence of obesity was measured in the state starting from 2011. Note that following this transformation, the constant term in the empirical model displayed in the subsequent section becomes the baseline projected prevalence of obesity at states without skyscrapers in 2011 (Ramanathan 2002, Hoaglin 2016a,b)[2]. The sample mean of (year-2011) is 4.53, the standard deviation is 2.86, the minimum is 0 and the maximum is 9. The implication is that referring to the prevalence of obesity the sample covers 10 years.

Table 2 gives the outcomes of the difference of means statistical test. This is a crude measure for educated vs. non-educated differences of obesity prevalence without adjust-

[2]In this context, Hoaglin (2016a) states that: "Many presentations tend to use the same letters in models that involve different sets of other predictors, which makes it easy to overlook the role of the other predictors in the definition of the coefficient of each predictor. For example, if $2x + 5t$ is a good fit to the data on y, then $-3x + 5(t + x)$ is also a good fit to those data (it gives exactly the same predicted values)." (page 7)

Table 2: Obesity Prevalence: Test of Non-Educated vs. Educated

Group	Obs.	Mean	Std.Err.	Std.Dev.	95% Conf.Intervall
Educated	464	24.1321	0.213697	4.60317	23.71218 to 24.55205
Non-Educated	464	33.9748	0.192328	4.14286	33.59684 to 34.35273
combined	928	29.0535	0.21626	6.58796	28.62903 to 29.47787
diff		-9.8427	0.2875		-10.40691 to -9.278437

Notes: diff = mean(Educated) − mean(Non-Educated); Ho: diff = 0; Satterthwaite's degrees of freedom: 915.908. The calculated t-value with 915.908 degrees of freedom is -34.2354, compared to the 1% critical value of -2.5812.

Table 3: Pearson Correlation Matrix

	Obesity Prevalence	$(Year - 2011)$	Educated	Skyscrapers	Pop_Density
Obesity prevalence	1.0000				
$(Year - 2011)$	0.2365***	1.0000			
	(<0.01)				
Educated	-0.7474***	0.0000	1.0000		
	(<0.01)	(1.000)			
Skyscrapers	-0.1220***	-0.0042	-0.0000	1.0000	
	(0.0002)	(0.8987)	(1.0000)		
Pop_Density	-0.0886***	0.0036	-0.0000	0.2323***	1.0000
	(0.0069)	(0.9122)	(1.0000)	(<0.01)	

Notes: P-values for the rejection of zero correlation are given in parentheses. Number of observations: 928. ***: $p < 0.01$

ments to other predictors[3]. The test clearly demonstrates an average lower prevalence of obesity among educated population in the state by 9.8427% (95% confidence interval of [-10.40691, -9.278437]). The null hypothesis of zero difference of means is clearly rejected. The calculated t-value with 915.908 degrees of freedom is -34.2354, compared to the 1% critical value of -2.5812.

3.3 The Pearson Correlation Matrix

Prior to the estimation of the empirical model, Table 3 reports the Pearson correlation matrix. This is considered important information regarding the relationships between variables. High Pearson correlations between independent variables might distort the sign and significance of the coefficients.

It may be readily verified that the highest Pearson correlation is between the variables Education and Obesity Prevalence (-0.7474) and the null hypothesis of zero correlation is clearly rejected ($p < 0.01$). The implication is the decrease in obesity prevalence with higher education level. In addition, there is a positive correlation between obesity prevalence and the Year variable (+0.2365) and the null hypothesis of zero correlation is clearly rejected ($p < 0.01$). The indication here is the increase of obesity prevalence with the time variable. Finally, the Pearson correlations between obesity prevalence and the number of skyscrapers and density has the "correct" minus sign. This indicates a drop in obesity prevalence with densely populated environment. For both variables, the null hypothesis of zero correlation is clearly rejected ($p = 0.0002$ and $p = 0.0069$).

The Pearson correlation between the variables skyscrapers and population density measured in square kilometers is +0.2323. Despite the fact that: a) the null hypothesis of zero correlation is rejected, and b) the sign of the correlation is in the right direction; this measure is not considered to be a very high Pearson correlation. As discussed in the literature review section, these variables are similar but not identical.

[3]This is the correct terminology that should replace the terminology of "control of other explanatory variables". The correct interpretation actively keeps in view the adjustments for the contributions of the other predictors (Hoaglin 2016a,b).

3.4 The Empirical Model

Consider the following interaction model consisting of the structural equation:

$$\begin{aligned} \mathit{Obesity\_Prevalence} \quad = \quad & a_1^{'}(\mathit{Year}-2011)^2 + a_2^{'}(\mathit{Year}-2011) + a_1 \mathit{Skyscrapers}^2 + \\ & a_2 \mathit{Educated} \times \mathit{Skyscrapers}^2 + b_1 \mathit{Skyscrapers} + \\ & b_2 \mathit{Educated} \times \mathit{Skyscrapers} + c_1 \mathit{Educated} + d_1 \mathit{Pop\_Density} + \\ & c_2 + \mu_1 \qquad (1) \end{aligned}$$

where *Obesity_Prevalence* is the dependent variable, $(\mathit{Year}-2011)^2$, $(\mathit{Year}-2011)$, $\mathit{Skyscrapers}^2$, *Skyscraper*, *Educated* and *Pop_Density* are the independent variables, $a_1^{'}$, a_1, a_2, b_1, b_2, c_1, c_2, d_1 are the parameters, and μ_1 is the classical random disturbance term.

According to Chiang, Wainwright (2005, p. 229-231), the general form of the quadratic function is: $y = ax^2 + bx + c$ $(a \neq 0)$ with a second derivative equals to $2a$. Given that this derivative will always have the algebraic sign of the coefficient a, a U-shaped curve with a global minimum at $(\frac{-b}{2a}, \frac{-b^2+4ac}{4a})$ is obtained if $a > 0$, and an inverted a U-shaped curve with a global maximum at $(\frac{-b}{2a}, \frac{-b^2+4ac}{4a})$ is obtained if $a < 0$.

Compared to the linear model, the quadratic model may describe more complex relationships. The model allows the fall and rise of the dependent variable with the number of skyscrapers thus demonstrating a crowding out effect in terms of obesity prevalence. Differently put, and as demonstrated below, obesity prevalence reaches its basin when the urban environment is relatively sparse. This is represented by an amount of approximately 146 skyscrapers. This crowding out effect cannot be investigated by employing the linear model.

In their review, Wilkins et al. (2019) argue that null association between obesity and food environment dominated across all measurement methods comprising 76.0% of 1937 associations in total.

A possible interpretation for the domination of this null association is the linear restriction imposed on the empirical model. In his econometric textbook, Kmenta (1997) demonstrates a quadratic relationship between variables. However, the imposition of linear restriction yields a poor fit, namely, no association between Y and X (page 241).

To demonstrate this point, we now performed the following exercise. We constructed a tailored made quadratic function $\widehat{Y} = 6 + 5X^2$ and ran a linear and a quadratic regression. The outcomes are given in Appendix C. As can be seen, while the quadratic relationship exhibits a perfect fit, the linear model exhibits no fit at all.

To test whether the specification of the model is appropriate, namely, whether the model excludes important omitted variables, we employ the Ramsey's RESET procedure, where the RESET stands for Regression Specification Error Test (e.g., Ramanathan 2002, p. 270). This procedure is based on two steps. The first step of the procedure is the construction of vector of predictions $(\widehat{Y})$ from the model given in equation (1). The second step is the incorporation of $\widehat{Y}^2$, $\widehat{Y}^3$ and $\widehat{Y}^4$ in equation (1) as additional independent variables and testing the joint null hypothesis that their coefficients equal zero. If the null hypothesis is not rejected, one could argue that the model specification is appropriate.

Another concern the empirical model addresses is the possibility of spurious or non-sense correlation in time series analysis. This is done by incorporation of the time variable $(\mathit{Year}-2011)$. According to Johnston, DiNardo (1997, p. 9), series, responding to unrelated mechanisms, such as, death rates in England and Wales and the proportion of all marriages solemnized in the Church of England from 1866 to 1911 (Yule 1926), may display contemporaneous upward or downward movement[4]. This problem may be addressed by fitting trends to such series.

[4] Referring to Yule (1926), Johnston, DiNardo (1997) state that: "However, no British politicians proposed closing down the church of England to confer immortality on the electorate." (page 10)

Table 4: Regression Analysis

Individual Effect Time Dummies (Full/Stepwise)	(1) No (Full)	(2) No (Stepwise)	(3) Yes (Stepwise)
Variables	Obesity Prevalence	Obesity Prevalence	Obesity Prevalence
$(Year - 2011)^2$	0.00768	-	-
	(0.655)	-	-
$(Year - 2011)$	0.472***	0.542***	-
	(0.00261)	(<0.01)	-
Skyscrapers^2	0.000139**	0.000145**	0.000146**
	(0.0172)	(0.0136)	(0.0139)
Educated× Skyscrapers^2	0.000323***	0.000323***	0.000323***
	(1.55×10^{-5})	(1.49×10^{-5})	(1.58×10^{-5})
Skyscrapers	-0.0407***	-0.0426***	-0.0426***
	(0.00532)	(0.00383)	(0.00406)
Educated×Skyscrapers	-0.0933***	-0.0933***	-0.0933***
	(1.13×10^{-6})	(1.06×10^{-6})	(1.20×10^{-6})
Educated	-9.036***	-9.036***	-9.036***
	(<0.01)	(<0.01)	(<0.01)
Pop_Density	-0.000115	-	-
	(0.703)	-	-
Constant	31.99***	31.89***	31.90***
	(<0.01)	(<0.01)	(<0.01)
Observations	928	928	928
R-squared	0.667	0.667	0.667
Minimum Obesity College Education			
Skyscrapers	145 [141, 149]	145 [142, 149]	145 [141, 149]
Projected Prevalence of Obesity	17 [16, 18]	15 [14, 17]	15 [14, 17]
Minimum Obesity less than High School Education			
Skyscrapers	146 [122, 169]	146 [109, 183]	146 [110, 183]
Projected Prevalence of Obesity	30 [28, 31]	31 [29, 33]	31 [29, 33]

Notes: The Educated variable receives 1 for college education and zero for less than high school education in the state. The Ramsey's RESET (Regression Specification Error Test – see Ramanathan 2002, p. 270) procedure is based on two steps. The first step of the procedure is the construction of vector of predictions ($\widehat{Y}$) from the model. The second step is the incorporation of $\widehat{Y}^2$, $\widehat{Y}^3$ and $\widehat{Y}^4$ as additional independent variables and testing the joint null hypothesis that their coefficients equal zero. If the null hypothesis is not rejected, one could argue that the model specification is appropriate. According to this procedure, the null hypothesis is not rejected ($F(3, 918) = 2.59$; $p = 0.0514$). Robust p-values are given in parentheses. 5% confidence intervals are given in square brackets. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$.

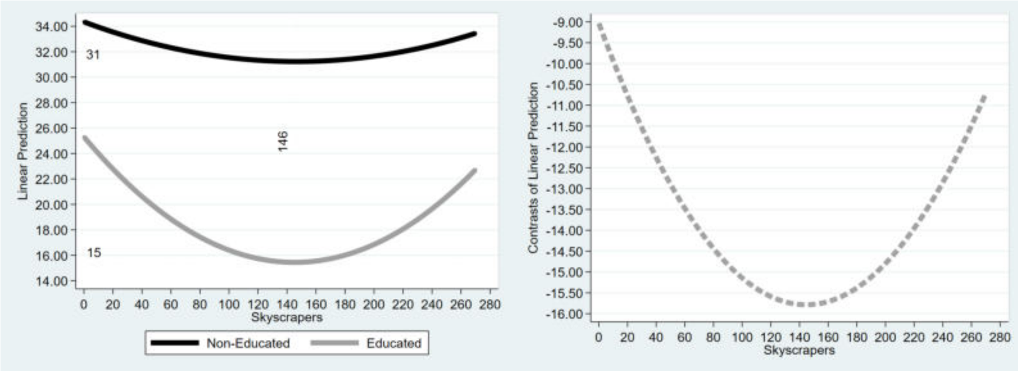
4 Results

Table 4 reports the regression outcomes. The table is divided to three columns. Column (1) gives the outcomes of the full model described by equation (1). Column (2) provides the outcomes obtained from the stepwise regression. This procedure gradually omits variables with the most insignificant coefficients (one variable for each step), until we are left with significant coefficients at a pre-determined level. Finally, column (3) gives the results obtained from the stepwise model, where the time variable is replaced with dummies for each year.

As can be seen from Table 4, 66.7% of the variance of the dependent variable (at the US States) is explained by the independent variables of education levels, the time variable and the number of skyscrapers. Application of the RESET procedure supports the conclusion that the incorporation of $\widehat{Y}^2$, $\widehat{Y}^3$, and $\widehat{Y}^4$, is unnecessary at the 5% and 1% levels ($F(3, 918) = 2.59$; $p = 0.0514$). Consequently, according to the statistical test, the specification of the empirical model described by equation (1) is appropriate.

The outcomes of column (1) in Table 4 demonstrate that the coefficient of the variable $(Year - 2011)^2$ is statistically insignificant ($p = 0.655$). In addition, the coefficient of the "control" variable population density, where land area is measured in square km., has the "correct" minus sign, but the variable is statistically insignificant ($p = 0.703$).

According to column (2) in Table 4, the 2011 baseline projected obesity prevalence



(a) Obesity Prevalence by Education

(b) Difference

Notes: Figure 1b refers to the difference between projected obesity prevalence of educated minus non-educated populations at the same US states obtained from column (2) in Table 4. All the projection differences are statistically different from zero at the 1% level and range between −16 and −9.

Figure 1: Impact of Skyscrapers on the Prevalence of Obesity: Educated vs. Non-Educated

for non-educated population in regions without skyscrapers is 31.89 percent ($p < 0.01$). Projected obesity prevalence *rises* by 0.542 percent per annum ($p < 0.01$) and *drops* by 9.036 percent ($p < 0.01$) with a shift from the non-educated to the educated population after the adjustment of contributions of other predictors[5]. When we add the variable population density measured in square kilometers to the regression analysis as a "control" variable, the parameter has the "correct" minus sign, but the variable is statistically insignificant ($p = 0.703$).

Figure 1 reports the impact of skyscrapers, as a proxy of denser urban environment, on the prevalence of obesity among educated vs. non-educated persons. Figure 1a is based on the outcomes obtained from column (2) in Table 4. Figure 1b refers to the difference between projected obesity prevalence of non-educated minus Educated populations at the same US states obtained from Table 1. All the projection differences are statistically different from zero at the 1% level and range between −16 and −9.

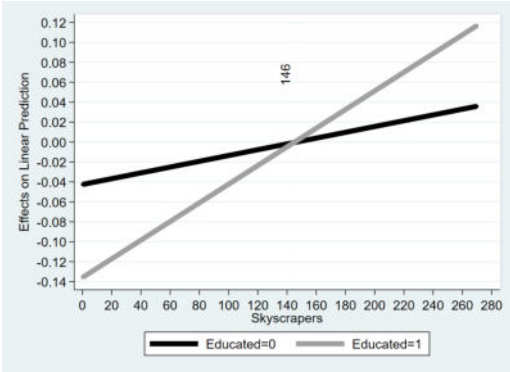
In line with previous literature, Figure 1b indicates lower projected obesity prevalence among educated population, where projections are adjusted for the number of skyscrapers. The gap ranges between 9 and 16 percent in favor of the educated population. A possible explanation to these outcomes is that as part of more efficient health literacy, compared to non-educated, educated people make more extensive use in urban infrastructure, such as, stairways, gyms, green spaces and parks, bicycle and running tracks.

Figure 1a demonstrates a U-shaped curve for both groups. The implication is that within the range of 0 to 146 (146 to 267), skyscrapers projected obesity prevalence *drops* (*rises*) with the number of skyscrapers. Very few studies tested the possibility of non-monotonic change. Based on population density analysis in China, Sun, Yin (2018) demonstrated similar outcomes to our Study. The authors demonstrate that within the range of population density of 50 to 1255 (1,255 to 202,800) persons per square kilometer, projected obesity decreases (increases).

Figure 1 may be interpreted in the following manner:

1. The descending part of the graph: educated persons exploit the urban infrastructure more efficiently. Urban infrastructure includes bicycle and walking lanes; benches and gym installations in parks; the possibility to engage in utilitarian walk on the way to work and on the way from work. This is possible as long as congestion effect is weak and the extent of crime incidences are low.

[5]In this context see footnote 3. Hoaglin (2016b) states that: "If one wants to estimate the effect of making a unit change in x while holding w constant, one must have data in which values of x differ by one unit and w remains constant, so that one can actually observe that effect. Designed experiments in applied science often do this." (page 32).



Notes: The graphs are based on the outcomes reported on column (2) in Table 4. The Educated variable receives 1 for college education and zero for less than high school education in the state.

Figure 2: Incremental impact of Skyscrapers on the Prevalence of Obesity among Educated vs. Non-Educated populations

2. The ascending part of the graph: As urban areas become more crowded, the urban infrastructure are exploited beyond their capacity (the congestion effect). This is particularly true for tourist attractions, which bring more people. The growth of cities avoids utilitarian walking in shaded parks at night due to increased crime rates. Consequently, educated persons gain weight and return to their initial weight.

Our interpretation to the educated vs. non educated difference is the following: the construction and study of the exploitation of the urban infrastructure evolves with the development of the urban areas. Walkable lanes are constructed at a later stage. Consequently, the mid-range of skyscrapers captures the full relative advantage of the educated population, where congestion effect is still weak.

Finally, based on the same regression analysis, Figure 2 displays the incremental impact of skyscrapers on the prevalence of obesity among Educated vs. Non-Educated populations. According to the figure, the incremental change of one additional skyscraper is steeper among the educated population. Up to 146 skyscrapers, the exclusion of individuals from the group of obese population with each additional skyscraper is faster among educated persons. While the first skyscraper reduces the expected proportion of obese population by 14% among educated persons, the equivalent figure is only 4% reduction among non-educated persons. But the picture reverses above 146 skyscrapers. For 260 skyscrapers, the other extreme, while the last skyscrapers increases the anticipated proportion of obese population by 12% among the educated population, the rise among non-educated becomes only 4%.

5 Robustness Tests

To further corroborate the relative contribution of education on the reduction of obesity prevalence we run a robustness test. We transformed the variables given in equation (1) to the standard normal distribution function. The analysis enables equals units of measurement of one standard deviation increase for each explanatory variable. This gives the possibility to rank the explanatory power of variables based on the absolute values of the coefficients. Results of this exercise are given in Table 5.

The outcomes show that education has the highest explanatory power (0.6862 in absolute value), followed by the number of skyscrapers (0.2771 in absolute value) and the time variable (0.2352). To offset the impact of the education *drop* on projected obesity prevalence, an *increase* of almost three standard deviations are required in the time variable.

As an additional robustness test, Table 6 includes a random effect regression for the educated vs. non-educated groups. This procedure corrects the serial correlation between the generic dummies for each state and the independent variables and thus improves the

Table 5: Regression Analysis: Beta Coefficients

Variables	(1) $\mathcal{Z}$(Obesity Prevalence)
$\mathcal{Z}(Year - 2011)$	0.2352***
	(<0.01)
$\mathcal{Z}$(Educated)	-0.6862***
	(<0.01)
$\mathcal{Z}$(Skyscrapers)	-0.2771***
	(0.000623)
$\mathcal{Z}$(Educated×Skyscrapers)	-0.4440***
	(1.29×10^{-7})
$\mathcal{Z}$(Skyscrapers×Skyscrapers)	0.2312***
	(0.00428)
$\mathcal{Z}$(Educated×Skyscrapers×Skyscrapers)	0.3664***
	(7.84×10^{-6})
Constant	0
	(<0.01)
Observations	928
R-squared	0.667

Notes: The $\mathcal{Z}(.)$ is the standard normal distribution transformation with zero mean and standard deviation of 1. *P*-values are given in parentheses. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$.

Table 6: Random effect Regressions

Variables	(1) Educated Obesity prevalence	(2) Non-Educated Obesity prevalence
$(Year - 2011)$	0.598***	0.481***
	(<0.01)	(<0.01)
Skyscrapers×Skyscrapers	0.000467***	0.000145
	(0.000614)	(0.266)
Skyscrapers	-0.135***	-0.0424
	(0.000206)	(0.233)
Constant	22.59***	32.16***
	(<0.01)	(<0.01)
Observations	464	464
Number of States	47	47

Notes: The random effect regression corrects for serial correlation between the 46 dummy variables included in the random disturbance term (one for each state with the exception of the base category) and the independent variables. Robust *p*-values are given in parentheses. 5% confidence intervals are given in square brackets. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$.

efficiency of the model (e.g., Wooldridge 2009, 489-491). The outcomes remain robust with respect to previous procedures.

As can be seen from Table 6, obesity prevalence initially drops by 0.135 percent ($p = 2.0610^{-4}$) for the educated group and by only 0.0424 percent ($p = 0.233$) per additional high-rise building for the uneducated group. Moreover, for the uneducated population, the random effect regression makes the skyscrapers variables irrelevant.

Finally, one issue that warrants attention is the validity of the relationships among the variables. The validity of using the number of skyscrapers as a proxy for dense urban environments is supported by economic theory and a considerable body of empirical studies that demonstrate a correlation between high-rise construction and dense urban areas (for an extensive review on urban spatial structure, see, for example, Anas et al. 1998). According to McDonald, McMillen (2011), "Residential buildings are typically built at a very high density—tall buildings with many units built atop small land parcels" (p. 121). High-rise buildings and skyscrapers are distinctive forms of construction that have been infrequently explored in academic literature. The development of skyscrapers generates a blend of residential and commercial uses, job opportunities, and cultural amenities (Brueckner et al. 1999) and influences the behaviors of residents in these areas. This necessitates specialized planning characterized by pedestrian access between buildings and decreased reliance on automobiles.

The validity of the connection between dense urban environments and walkability is substantiated by a substantial number of empirical studies (e.g., TRB 2005, Frank et al. 2010, Ewing et al. 2014, Mulalic, Rouwendal 2020). In TRB (2005), the US Committee on Physical Activity, Transportation, and Land Use, and the Institute of Medicine recognized the influence of urban environments on physical activity levels as an emerging field (p. 5). Physical inactivity is recognized as one of the leading risk factors for non-communicable disease-related mortality (Ewing et al. 2014, WHO 2022). The probability of mortality is projected to increase by 20% to 30% due to insufficient physical activity (WHO 2022). It is expected that physical activity levels will decline over time due to the ongoing decentralization of urban areas, resulting in longer travel distances and making private vehicles the most convenient mode of transport. Indeed, in 2005, 55% of the US adult population reported not meeting the recommended standard of 30 minutes of daily brisk walking (TRB 2005, p. 2). In urban planning, compact development (i.e., dense construction) is linked to decreased automobile dependence (Ewing et al. 2014).

Other confounding factors include access to healthcare services. In this context, Hamidi et al. (2020) investigate the relationship between COVID-19 infection and dense urban environments in the United States. One the one hand, dense areas lead to more face-to-face interaction among residents. On the other hand, dense areas may have greater implementation of social distancing practices and policies and better access to health care facilities. Indeed, as the authors suggest, counties with higher densities have significantly lower virus-related mortality rates than do counties with lower densities, possibly due to superior health care systems.

Using a worldwide examination, Arbel et al. (2023b) found that a one STD increase in the population density and the number of beds is expected to decrease the STD of COVID-19 mortality rate by 0.127 and 0.0920, respectively.

In addition to the aforementioned justifications, we conducted a cross-validation procedure as illustrated in Table 7. This method stems from the foundational work of Milton Friedman (Friedman 1966, p. 9), who differentiated between “on sample,” “off-sample,” and “out-of-sample” groups, where the latter pertains to anticipated future events (forecasts) and the former relates to past events—whose outcomes remain uncertain due to insufficient information (predictions)[6]. The cross-validation procedure is applicable only to cross-sectional datasets because the off-sample subset is randomly selected from the entire sample pool. In time series analysis, the sequence is critical, preventing the procedure from sampling a random subset. The cross-validation process generates a prediction vector, denoted as $\widehat{P}$, where each of the five folds randomly assigns a portion of the off-sample group and performs an OLS regression on the training on-sample group. The vector $\widehat{P}$ comprises only predictions from the off-sample group. The table presents the Pearson correlations between Obesity Prevalence and $\widehat{P}$. The markers † ($p < 0.01$), indicate the rejection of the null hypothesis of zero correlation. The results of this procedure revealed a Pearson correlation coefficient ranging from 0.2926 to 0.7109. In all cases, the null hypothesis of zero correlation was rejected at the 1% level.

6 Discussion

A possible interpretation of the outcomes is the failure to utilize the urban infrastructures (e.g., bicycle and walking lanes; pedestrian pavements; benches and gym installations in parks) due to congestion problems at a densely populated urban environments (a possibility that cannot be considered in an empirical study that imposes a linear and a monotonic restriction). Up to 146 skyscrapers, the density is sufficiently low to facilitate

[6] According to Friedman (1966): “To avoid confusion, it should perhaps be noted explicitly that the ‘predictions’ by which the validity of a hypothesis is tested need not be about phenomena that have not yet occurred, that is, need not be forecasts of future events; they may be about phenomena that have occurred but observations on which have not yet been made or are not known to the person making the prediction. For example, a hypothesis may imply that such and such must have happened in 1906, given some other known circumstances. If a search of the records reveals that such and such did happen, the prediction is confirmed; if it reveals that such and such did not happen, the prediction is contradicted.” (page 9)

Table 7: Cross Validate for Educated vs. Non-Educated

Rounds	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
First	0.6222†	0.3821†	0.7109†	0.3847†	0.4650†	0.4957†	0.5938†	0.5012†	0.3563†	0.2926†	
Obs.	90	90	92	94	94	94	94	94	92	94	928

Notes: The cross-validation procedure can only be performed on cross-sectional datasets. This procedure creates a vector of predictions denoted as $\widehat{P}$ where each of the five folds randomly assigns a subset of the off-sample group and runs an OLS regression on the training on-sample group. Vector $\widehat{P}$ contains only the predictions from the off-sample group. The table shows the Pearson correlations between Obesity Prevalence and $\widehat{P}$. †: $p < 0.01$, for the rejection of the null hypothesis of zero correlation.

the use of the urban infrastructures within and outside the high-rise buildings. In terms of density of people per pathways, it is more convenient to use staircases and gyms inside the high-rise buildings, where population densities (proxied by the number of skyscrapers) are low. Under such circumstances, it is still convenient to walk on pavements, use the bicycle and running tracks, swimming pools, basketball halls and engaging in recreational sport. As the number of skyscrapers (a proxy for population density) become higher, the type and objective of walking modifies. The pace of walking becomes slower due to elevated density, so that it can no longer be considered walking for the objectives of physical activity. The public transportation system also becomes crowded. The convenience in delivery services, along with the disincentive for walking, promotes the consumption of innutritious food and the reduction in physical activity. Combined with the slower pace of walking, the multitude of stimuli outside the perimeter (restaurants, food stands) and availability of fast-food increase food consumption. These reasons, in turn, promote the obesity prevalence of the population. The growth of cities avoids utilitarian walking in shaded parks at night due to increased crime rates. Consequently, educated persons gain weight and return to their initial weight with the evolution of the urban environment.

7 Summary and Conclusions

The objective of the current study is to examine the relationship between the prevalence of obesity and the urban environment proxied by the number of skyscrapers and stratified by education level (educated vs. non-educated populations). The study is based on a sample of 47 US States during 2011-2020. A unique feature of this study is the employment of a quadratic model, which permits non-monotonic change in obesity prevalence with the number of skyscrapers. With one exception (Sun, Yin 2018), we are unaware of any study in the field that employed a quadratic model.

The public policy repercussions of our study may be divided into the short and long run. The long run objectives should be the increase and improvement of the education attainment and level. This type of solution was proposed or indicated *inter alia* by Ross, Wu (1995), Devaux et al. (2011), and Tran et al. (2021). Using data from France, Devaux et al. (2011) find support to a causal relationship from education to obesity, and not vice versa. Their argument is based on the minimal effect on the strength of the association when reduced educational opportunities for those who are obese in young age are considered (page 140).

Given the difficulty to raise the education levels, particularly among the adult population, the short run objectives should be acquired health literacy via the media and schools. Another possibility is the use of pharmacological means and bariatric surgeries in extreme cases combined with proper nutrition and physical activity (Cannon, Kumar 2009).

In sum, the role of the government should be manifested in the following fields:

1. Improving urban planning in the areas of establishing schools and academic educational institutions, cultural institutions, educational youth movements. All these issues will fall into the realm of land allocation for urban educational development, including health institutions, sports infrastructure of all kinds, and programs for teaching medical literacy. The planning should include provisions on educational and health infrastructure.

2. Children-parents knowledge spillover via special nutritional and physical activity training programs in schools.

3. Popular training courses, particularly for uneducated populations.

4. Generating a new index, which accounts for optimal exploitation of urban infrastructure for health objectives with respect to congestion.

5. Constructing an incentive structure to encourage walkability instead of transportation.

Like any other research this study has its strength and limitations. A possible limitation is the grid at the US statewide level. Yet this grid has its advantage and disadvantage. Another limitation is the potential problem of omitted variable. Yet, the RESET test rejects the possibility of an additional independent variables.

Strengths

A comparison across US states permits a global perspective. This comparison controls for weather, economic and cultural differences and intensity of land use, particularly given the generic dummies for each state used in a random effect regression framework (see Table 6).

A cross comparison at a country level (a higher grid than our own research) is a very well-known and a conventional methodology. Three examples are Barro et al. (2020) and Arbel et al. (2023a,b). Barro et al. (2020) compared the mortality rate from the Spanish flue pandemic during the Great Influenza Pandemic, 1918-1920 and War Death Rates for Military in Combat during World War I, 1914-1918 at a country level. Arbel et al. (2023a,b) investigated a data source at a country level and demonstrated that from the examined independent variables the most influential on COVID19 morbidity and mortality is the age variable.

Moreover, this is the first article that investigates the relationship between education, the urban environment and obesity – using a non-linear model, which allows non-monotonic increase or decrease, and relaxes the linear restrictions. Results show that a quadratic model better fits the data particularly as far as the educated population is concerned. For the uneducated population. the random effect regression, given in Table 6, makes the skyscrapers variables irrelevant. The outcomes also demonstrate that: 1) the few independent variables explain 66.7% of the variance of the dependent variable and 2) the RESET (Regression Specification Error Test – see Ramanathan 2002, p. 270) procedure supports the absence of omitted variables.

Limitations

Given the data structure at a macro level, incorporating additional "control" variables is problematic – because there is a one-to-one match between the independent and dependent variable. Differently put, if we compare education with gender, for instance, the numerical prevalence of obesity (the dependent variable) for the same state will be different. Note, however, that the RESET procedure clearly supports the null hypothesis that all the empirical models employed in this article are correctly specified.

The grid of the data might be considered too high. Average data might be exposed to aggregation bias and information loss referring to the variance of variables at a lower grid of the data. Future research should employ datasets at a lower grid, at least at a city level.

Finally, future research regarding non-linearities in the data could be benefitted from the employment of non-parametric or semi-parametric methodologies instead of the parametric ones. These methodologies are beyond the scope of the current research.

Abbreviations

BMI = Body Mass Index
CDC = Center for Disease Control and Prevention
RESET = Regression Specification Error Test

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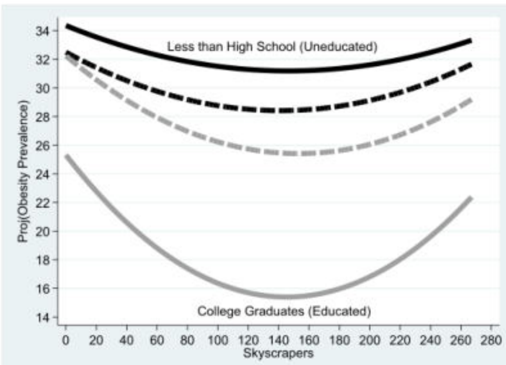
A Appendix: Data Structure

Table A.1: US states and observation numbers

Number	State	Observations	Number	State	Observations
1	Alabama	20	25	Missouri	20
2	Alaska	20	26	Montana	20
3	Arizona	20	27	Nebraska	20
4	Arkansas	20	28	Nevada	20
5	California	20	29	New Jersey	20
6	Colorado	20	30	New Mexico	20
7	Connecticut	20	31	New York	20
8	DC	20	32	North Dakota	18
9	Florida	20	33	Ohio	20
10	Georgia	20	34	Oklahoma	20
11	Hawaii	20	35	Oregon	20
12	Idaho	14	36	Pennsylvania	20
13	Illinois	20	37	Rhode Island	20
14	Indiana	20	38	South Dakota	20
15	Iowa	20	39	Tennessee	20
16	Kansas	20	40	Texas	20
17	Kentucky	20	41	Utah	16
18	Louisiana	20	42	Vermont	20
19	Maine	20	43	Virginia	20
20	Maryland	20	44	Washington	20
21	Massachusetts	20	45	West Virginia	20
22	Michigan	20	46	Wisconsin	20
23	Minnesota	20	47	Wyoming	20
24	Mississippi	20		Total	928

Notes: The full sample per-state includes 20 observations (10 years×2 obs. for educated and non-educated in each state).

B Appendix: Four Educational Groups



Notes: the CDC dataset includes four groups: 1) College graduates (the most educated); 2) High School graduates; 3) Less than high school (the least educated); and 4) Some college or technical schools.

Figure B.1: Four Educational Groups

C Appendix: Simple Exercise of a Quadratic vs. Linear Relationship

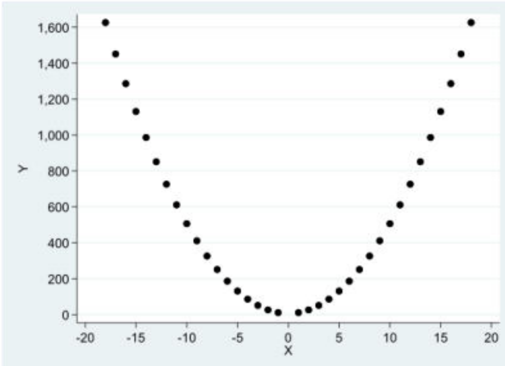


Figure C.1: A Scatter Diagram of the Quadratic Model $\widehat{Y} = 6 + 5X^2$

Table C.1: Regression outcomes

Coefficient of	Quadratic Y	Linear Y
X^2	5	-
		-
X	0	0
		(8.037)
Constant	6	591.83
		(86.99)
R-squared	1	0

Notes: Number in parentheses are standard errors.

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A spatial and demographic analysis of cycling safety perceptions: A case study in Eau Claire, Wisconsin, USA

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Abstract. Bike-friendly cities offer scores of benefits to both individuals and society, but a lack of safety is a major barrier to ridership. Significant research has been devoted to studying demographic drivers of ridership and what makes individuals feel unsafe on a bicycle, but there is lack of research utilizing quantitative approaches on spatial perceptions of safety, particularly with respect to gender. This paper seeks to close that gap using a crowd sourcing approach to spatial data collection, statistical comparisons of cycling behavior by gender, and spatial analyses of mapped points. The authors find parity between women and men in terms of number of trips taken per week but find significant differences in the spatial extent of mapped responses. This paper adds to academic discussions on cycling safety and sheds light on specific locations that could benefit from infrastructure improvements.

1 Introduction

Bikeable communities provide numerous benefits for citizens. It is well established that cycling produces positive health outcomes for individuals and reduces pollution (Pucher, Bueler 2010). Cycling also produces psychological and social benefits (Xu et al. 2019) and is a decidedly safe form of transportation barring encounters with automobiles. Additionally, a growing body of literature suggests significant economic benefits to de-emphasizing vehicular traffic in favor of other modes through greater local business revenue (NYDoT 2013), increased property values (Litman 1999), and tourism-related opportunities for municipalities (Blondiau et al. 2016). Alternative and moderately active forms of transportation have also long been shown to promote public health (Frank, Engelke 2001). Yet, there remain considerable barriers to creating bike-friendly communities.

A lack of safety has consistently been shown to be a major deterrent to cycling for both potential and current cyclists (Iwińska et al. 2018, Aldred, Dales 2017). Thus, identifying where and why cyclists feel unsafe is crucial to improving bikeability. In this article, the authors present a study on spatial perceptions of cycling safety in an Upper Midwest US city: Eau Claire, Wisconsin. Given the gender disparity of cycling rates in the United States (Pucher et al. 2011), the study pays particular attention to the differing perceptions of women and men. While considerable research has been conducted on cycling shares by demographic categories – which this paper adds to – this study is unique in specifically comparing gender differences in *spatial perception*.

Perceptions of cycling safety vary based on spatial context. Encounters with motor vehicles, fear of crime, and adverse weather conditions all pose significant threats (Rybarczyk, Gallagher 2014). Specific locations lacking designated bike paths exacerbate these concerns as cars are in closer proximity to cyclists (Gadsby et al. 2022). Perceptions of infrastructure safety vary demographically. Women in particular show preferences for well-protected bike lanes and tend to perceive roads as more dangerous, preferring shorter travel distances and avoiding areas with steep slopes (Manton et al. 2016, Misra, Watkins 2018, Hood et al. 2011). Factors like enclosed spaces, poorly lit streets, and limited visibility are also more concerning for women due to their potential to conceal threats (Xie, Spinney 2018).

Due to these differences and the dearth of literature on quantitative approaches to spatial perceptions of cycling safety particularly related to gender, this study seeks to close that gap. The authors first provide a brief review of the relevant literature and then discuss the study's methodology. To collect data, the authors created a web-based survey application to collect both demographic information and volunteered points the respondent perceived as unsafe. The demographic information is used to carry out statistical tests by gender on riding confidence, the influence of safety on where the respondent rides, and the number of cycling trips per week. The authors then use the DBSCAN algorithm to analyze the identified points perceived as unsafe and identify clusters, before creating convex hulls to compare minimum bounding geometry by gender. The results are analyzed and discussed before the authors present the final conclusions and significance of the study. Further, in line with greater calls for a process-based approach to geographic information science (Shannon, Walker 2018), the authors leverage the power of JavaScript-driven interactive maps and sortable tables within the body of the paper and encourage readers to explore the data for themselves.

2 Background

2.1 Deterrents to cycling

Previous studies have identified many reasons why cyclists may be deterred from riding, of which many revolve around safety. Given that the quality and style of cycling infrastructure can vary greatly, both between and within countries, context is important when synthesizing the literature. That said, some ubiquitous reasons can be found across spatial contexts. Encounters with motor vehicles are a consistent primary barrier to cycling (Iwińska et al. 2018, Rybarczyk, Gallagher 2014, Ahmed et al. 2013, Jacobsen et al. 2009). The danger posed by fast-moving automobiles can result in disastrous consequences for the cyclist if a collision occurs, and both cyclists and drivers of motor vehicles exhibit a dislike of interacting with operators of opposing vehicle types (Griffin et al. 2020). Aside from the risk associated with crashes, traffic is deemed unpleasant to be near due to noise and exhaust pollutants output by vehicles (Jacobsen et al. 2009). These factors lead to a general fear of injury and a reluctance to ride in car-centric societies (Iwińska et al. 2018).

In addition to the threat of motor vehicles, crime and adverse weather conditions are two other significant barriers to cycling (Rybarczyk, Gallagher 2014). Anticipations of crime may cause cyclists to fear for their health, safety, or the loss of their bike due to theft. The threat of crime deterring cycling is observed across demographic groups, significantly affecting behavior in all but the most regular cyclists. (Wang, Akar 2018, Rybarczyk, Gallagher 2014). Areas with many vacant homes or locations where transportation modes interconnect – such as train stations where bikes may be locked but left unattended – exhibit higher rates of cycling-related crime (Mburu, Helbich 2016). In other cases, a lack in the proper removal of winter precipitation leads to lower ridership (Iwińska et al. 2018, Ahmed et al. 2013).

In other instances, feelings of insecurity are tied to specific locations and infrastructure types rather than general feelings of trepidation. It has been demonstrated that policies focused on improving and creating relevant infrastructure have all contributed to increases in cycling rates in the present alternative transportation "renaissance" (Pucher et al.

2011), so it follows that infrastructure warrants special attention. While not completely detached from the fear of motor vehicles, a lack of necessary infrastructure leads to higher perceived risk, as the built environment offers fewer accommodations for potential cyclists.

Intersections, for instance, are common locations for possible conflict between cyclists and motor vehicles (Wang, Akar 2018, DiGioia et al. 2017). When cars and cyclists are forced to meet at intersections, additional infrastructure such as roundabouts, paved shoulders, or designated bike paths can alleviate concerns of crashes. Further, traffic proximity has been linked to negative perceptions, and areas with a higher concentration of paths distanced from roads have been shown to exhibit higher cycling rates (Carroll et al. 2020, Branion-Calles et al. 2019, Aldred, Dales 2017). This distancing reduces the perceived threat from cars by adding space that reduces the chance of a collision. Potholes, cracks, and other deformities in paved cycling spaces also deter cyclists by reducing safety and increasing levels of discomfort (Gadsby et al. 2022). These reasons collectively speak to the need for building and maintaining dedicated cycling infrastructure.

2.2 Demographics and cycling safety perceptions

Cities in North America have recently witnessed a growth in the number and frequency of trips by bike. However, this growth has not been experienced equally across the entire population. While the number of male cyclists aged 25-64 has increased dramatically, cycling rates among women and children have not exhibited the same pattern (Pucher et al. 2011). Present research identifies both physical and cultural reasons for these disparities.

As described in the previous subsection, the quality of cycling infrastructure has a significant impact on both perception and behavior. However, evidence indicates infrastructure does not affect demographic groups equally. Women, the elderly, and those under 18 are all more likely to use well-protected bike lanes rather than infrastructure in closer proximity to cars (Aldred, Dales 2017, Misra, Watkins 2018). Women are also more likely to perceive a road to be dangerous, travel shorter distances, and avoid areas with steep slopes (Manton et al. 2016, Misra, Watkins 2018, Hood et al. 2011). Enclosed spaces, poorly lit streets, and objects that limit visibility also tend to be of greater concern for women, as these manifestations could hide potential threats (Xie, Spinney 2018).

In addition to the physical environment, studies on cycling safety perception suggest that cultural and social factors drive gender differences. In countries with low cycling rates, such as the US, men are generally more likely to ride bikes and consider cities to be safe for cycling (Branion-Calles et al. 2019, Aldred et al. 2016). Women tend to have overall lower tolerance for risk than men in a variety of circumstances related to motor vehicles such as when cycling, when driving a vehicle, and in interacting with cyclists (Griffin et al. 2020). Women are more concerned about bullying and harassment when cycling than men, and as a result alter their routes accordingly (Graystone et al. 2022). However, in countries with high cycling rates – like the Netherlands, Denmark, Germany, and Japan – rates of women that cycle equal or even exceed the rates of men (Aldred et al. 2016, Goel et al. 2021). In particular, one recent study finds that almost all places where cycling represents at least eight percent of the transportation mode of travel have equal or overrepresentation of female cyclists (Goel et al. 2021). This suggests that as countries or cities invest in cycling infrastructure as a legitimate alternative to automobile transport, the gender disparity shrinks and can even reverse. In spaces such as the US and Australia, where cycling infrastructure is largely an afterthought to automobile infrastructure, cycling rates remain low and the gender disparity has grown (Pucher et al. 2011).

2.3 Methods of studying cycling safety perceptions

Given that general perceptions of cycling safety are driven by an array of factors, previous studies have used a variety of data collection methods to understand safety perceptions both qualitatively and quantitatively. Most studies involve two components: (1) an analysis of the infrastructure available to cyclists and (2) the self-reported safety perception of the individual. It is common to study responses using in-person (Iwińska et al. 2018, Manton et al. 2016) or online surveys (Wang, Akar 2018, Rybarczyk, Gallagher 2014, Branion-Calles et al. 2019), or in some cases, a combination of the two (Manaugh et al. 2017).

In a comprehensive literature review, Digiola et al. (DiGioia et al. 2017) categorized previous work into three groups based on the type of data utilized to perform analysis on cycling safety. These include exposure data, roadway characteristic data, and crash data or "other surrogate measures." Bicycle exposure data is used to estimate the frequency at which cyclists are exposed to risk. This could include bike travel distance, traffic exposure, or percentage of the population that travels by bike. Bicycle exposure can be used to estimate frequency of crashes based on how far the individual rides (Guo et al. 2018), or the amount of exposure to roads with trees can help in predicting the amount of bicycle theft (Mburu, Helbich 2016).

Exposure data is commonly used in tandem with roadway characteristic data. These datasets can be used to demonstrate the relationships between objects of interest and cycling risk, and data on bicycle crashes is often used as a proxy for estimating risk (DiGioia et al. 2017). This data, when combined with other sources, can be used to produce a prediction model of cycling risk (Yiannakoulias et al. 2012, Guo et al. 2018). Individual independent variables and their influence on resulting models allow for the determination of significant factors leading to crashes. The presence of intersections, narrow roads, bus and tram routes, hills, and curves are all shown to have a positive correlation with cycling risk using this approach (Morrison et al. 2019, Wang, Akar 2018, Aldred, Dales 2017, Misra, Watkins 2018, Branion-Calles et al. 2019). Other studies use mental mapping techniques and have participants annotate a map (Manton et al. 2016).

3 Methods and data

Few studies, aside from Manton (Manton et al. 2016), analyze spatial patterns in perceived cycling safety. The approach put forth in the present article has some similarities but is unique in several ways. First, the authors created and distributed a custom, free and open-source web application for the collection of data. Second, the authors focus on demographic differences in perceptions of cycling safety, particularly gender.

Specifically, the study addresses the following questions:

1. How do non-spatial survey responses differ by gender?
2. What are the general spatial patterns of unsafe cycling locations?
3. Where are clusters of perceived unsafe places for cycling located in Eau Claire?
4. How do spatial responses differ by gender?

Each of the four questions has a dedicated subsection in the *Results* section. The first question is addressed using a series of two-sample Mann-Whitney U tests. This is a non-parametric alternative to the two-sample t-test which can be used when the assumption of normality is violated. Additionally, this test can be used with ordinal data, including grouped numeric categories like number of trips per week. While a plethora of statistical tests could be conducted with the collected results, response limitations in demographic categories other than gender precluded the completion of additional comparisons.

To address the second question, the authors use interactive web maps and a heat map. To address the third question, the authors use density-based spatial clustering of applications with noise (DBSCAN). The DBSCAN algorithm searches for a specified minimum number of points within a defined search distance and groups them if they meet requirements. Not all points are grouped into clusters, thus separating "signal" from "noise". Using DBSCAN in an ad hoc manner like this is more of an art than a science; a researcher must balance the input parameters to produce clusters which help make sense of the data. Increasing the minimum number of points – and/or reducing the search distance – can greatly reduce the number of clusters. Conversely, reducing the minimum number of points and/or increasing the search distance increases the number of clusters, potentially to an unhelpful number. To address the fourth question, the authors compare clusters of unsafe points using DBSCAN but group responses by gender. Additionally, the authors compare convex hulls (i.e., minimum bounding geometries) by gender as well. The answers to the research questions – in connection with the authors' local knowledge – are discussed with respect to the relationship between urban form, transportation infrastructure, and perception.

3.1 Survey instrument and software

To complete this study, a custom web survey was created using the R Project for Statistical Computing and its web framework, Shiny (Chang et al. 2022). The survey was hosted on ShinyApps.io and administered to residents of Eau Claire, Wisconsin. An IRB-approved cover letter was obtained and embedded in a web page with a link to the survey included at the bottom of the page. The web survey consists of three tabs, each designating different sections of the survey (see Figure 1).

The first tab, containing a web map centered on Eau Claire, Wisconsin, contains a pane with the following instructions:

1a. First, select locations which you feel are notably unsafe for cycling near routes where you ride in Eau Claire. Start by clicking once on the map icon (just below the zoom control on the map). Then, click on the map to place a marker. You'll notice a checklist appears below the map. Select a reason for why that location is unsafe.

1b. Repeat for as many locations as you feel are necessary.

2. Then, click the 'Neighborhood' tab and select the square which corresponds to your approximate home location.

3. To complete the survey, click on 'Questions' tab and select your responses there. When you are finished, click on the 'Submit Response' button below the final question.

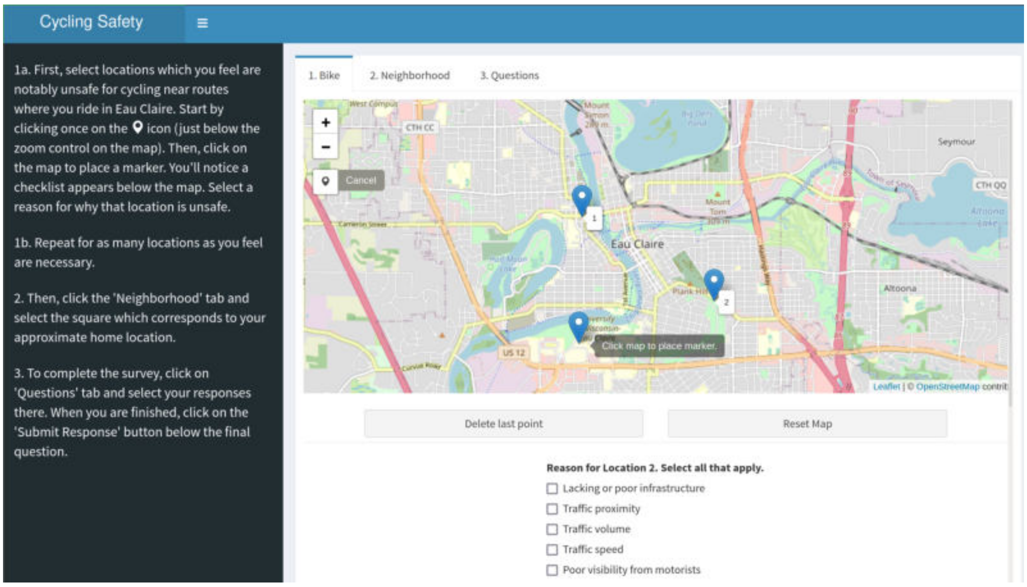

Figure 1: A screenshot of the web app developed for survey implementation with several example spatial responses

Careful consideration went into framing the first item in particular. The authors specifically chose the language "Select locations which you feel are notably unsafe for cycling *near routes where you ride* ..." (emphasis added) for two reasons. First, the authors wanted to avoid the possibility of respondents simply putting markers on places which are clearly unsafe but also are not feasible riding locations, such as interstate highways. Second, the authors sought to get a sense of where respondents actually ride, rather than have them label spots distant from their typical riding locations and thus not reflective of where potential infrastructure improvements might benefit the greatest number of cyclists.

The list of reasons for why respondents may feel unsafe was comprised of the following:

- Lacking or poor infrastructure
- Traffic proximity
- Traffic volume
- Traffic speed
- Poor visibility from motorists
- Potential conflicts with pedestrians
- Steep hills
- Other

The second tab contains another web map but with a grid of 1 mile x 1 mile squares where participants were instructed to click on the grid cell of their primary residence. This item was included to understand how responses might be biased by where respondents live. The third tab contains the following demographic and cycling behavior questions:

- How confident do you feel in your cycling ability? Assume 7 is 'Very confident' and 1 is 'Not confident'.
- How much does safety influence where you ride? Assume 7 is 'Very much' and 1 is 'Not at all'.
- Approximately how many trips do you take by bike per week?
- How often do you wear a helmet when riding a bike?
- For what reasons do you ride a bike? Select all that apply.
- What is your age?
- What is your race? You may select more than one option.
- What is your gender?

Other data was collected on the user's device characteristics, such as whether the survey was completed on mobile or on a desktop computer, along with operating system and screen size.

3.2 Study area: Eau Claire, Wisconsin

This study was implemented in Eau Claire, Wisconsin, located in the Upper Midwest of the United States. This city is the largest municipality in its county and metropolitan area, and it is home to a regional public university, the University of Wisconsin - Eau Claire, which has around 9500 students. While selected in part due to convenience and the authors' familiarity with the city, it is undeniably cycling-friendly compared to many other similarly sized US cities. The city possesses nearly 29 miles of separated bike trails, numerous bicycle lanes, and 8 car-free bridges (City of Eau Claire 2022). Despite this, like most other US cities, the vast majority of trips are taken by personal automobile, and much of the transportation infrastructure is not suitable for bicycles.

[1]:
```r
library(webshot2)

leaflet() %>%
  addTiles() %>%
  setView(lng = -90.99925, lat = 44.8090, zoom = 10) %>%
  ## add inset map
  addMiniMap(
    position = 'bottomright',
    width = 200,
    height = 200,
    toggleDisplay = FALSE,
    zoomLevelOffset = -8)
```

[4]:
```
Output in Figure 2
```

3.3 Survey Distribution

The survey was disseminated in the community through a combination of methods in August and September of 2021. Respondents were first recruited through simple word-of-mouth. Acquaintances of the research team who ride a bike were encouraged to complete

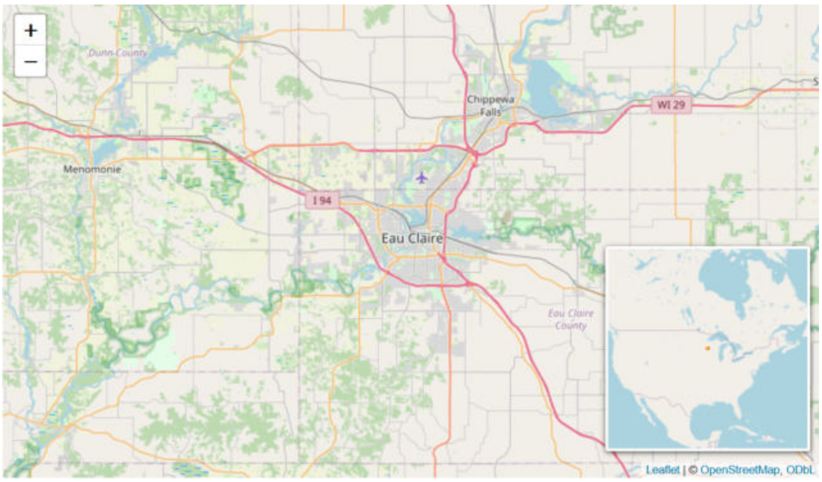

Figure 2: Location of Eau Claire, Wisconsin, USA

and share the survey. Fliers with QR codes and links to the survey were posted around the university campus, on social media sites such as Facebook, and distributed in local businesses. In an additional effort to reach the community, the research team on several occasions spent time intercepting cyclists in public parks and on commonly traveled bike trails. Additionally, approximately 300 fliers were taped to bicycles parked on bike racks at apartment buildings, near local businesses, and on campus. In total, 339 unsafe points were mapped by 99 unique individuals.

4 Results

Of the respondents, 43 are female, 52 are male, 3 respondents selected "Other" for gender, and 1 respondent neglected this response item. The percentage of female respondents is notably higher than those of other studies, likely explained by the female-heavy gender ratio of the university where many survey fliers were distributed. The largest age category, ages 18 – 23, had 63 responses, ages 25-34 had 13 responses, ages 35-44 had 10 responses, ages 45-54 had 8 responses, and the categories 55-64 and 65+ each had 2 responses.

The racial and ethnic makeup of the survey population roughly mimics the demographics of the city of Eau Claire and is thus relatively homogeneous. Specifically, 92 of the respondents selected a race of White, 4 selected Asian, 4 selected Hispanic, 3 selected Black, 2 selected Indian, 1 selected Hawaiian, and 1 selected Other (See Table 1 for a summary of demographic data and Table 2 for the first ten data points and eight variables.)

[2]:
```
df_race <- df %>%
  select(white, asian, hispanic, black, indian, hawaiian, other) %>%
  colSums() %>%
  data.frame() %>%
  add_rownames(var = "topic") %>%
  set_colnames(c("topic", "count")) %>%
  transmute(topic = str_to_title(topic), count=count)

df_gender <- df %>%
  group_by(gender) %>%
  count() %>%
  set_colnames(c("topic", "count"))

df$age <- as.factor(df$age)

df_age <- df %>%
  group_by(age) %>%
```

Table 1: Survey respondent demographics

Topic	Count
Race	
White	92
Asian	4
Hispanic	4
Black	3
Indian	2
Hawaiian	1
Other	1
Gender	
Female	43
Male	52
Other	3
NA	1
Age	
18-24	63
25-34	13
35-44	10
45-54	8
55-64	2
65+	2
NA	1

Table 2: Survey data

confidence	safety_influence	number_of_trips	helmet	age	gender	black	asian
5.7	4.0	8-12	Sometimes	18-24	Female	0	0
6.4	4.0	0-3	Never	18-24	Male	0	0
4.5	5.0	0-3	Always	18-24	Other	0	0
6.0	6.8	0-3	Never	18-24	Female	0	0
4.4	4.6	0-3	Never	18-24	Male	0	0
6.4	5.8	4-7	Always	18-24	Male	0	0
3.5	5.8	4-7	Never	18-24	Female	0	0
6.0	7.0	4-7	Always	18-24	Female	0	0
5.0	5.5	4-7	Always	18-24	Female	0	0
7.0	2.2	4-7	Always	NA	Female	0	0

```
  count() %>%
  set_colnames(c("topic", "count"))

df_demographics <- rbind(df_race, df_gender, df_age)

kbl(df_demographics,
  booktabs=TRUE, linesep = c(""),
  col.names = c("Topic", "Count")) %>%
  pack_rows("Race", 1, nrow(df_race)) %>%
  pack_rows("Gender", nrow(df_race)+1, nrow(df_race)+nrow(df_gender)) %>%
  pack_rows("Age", nrow(df_race)+nrow(df_gender)+1, nrow(df_demographics))
```

[2]:
```
Output in Table 1
```

[3]:
```
kbl(df[1:10,c(1:6,8:9)],
        align=rep('c',8),
        booktabs=TRUE, linesep = c(""))
```

[3]:
```
Output in Table 2
```

4.1 Non-spatial comparisons by gender

[4]:
```r
## get number of trips as a factor (for mann whitney u-test) and
## numeric (for density plot)
df$number_of_trips_factor <- df$number_of_trips %>%
  as.factor()

levels(df$number_of_trips_factor) <- c("0-3", "4-7", "8-12", "13-20", "20+")
df$number_of_trips_num <- df$number_of_trips_factor %>%
  as.numeric()

df_female <- df %>% filter(gender == "Female")
df_male <- df %>% filter(gender == "Male")

conf_by_gender <- wilcox.test(df_female$confidence, df_male$confidence)
infl_by_gender <- wilcox.test(df_female$safety_influence,
                              df_male$safety_influence)
trips_by_gender <- wilcox.test(df_female$number_of_trips_num,
                               df_male$number_of_trips_num)
```

To address the perceptual differences in cycling by gender, the authors compare responses to the following three survey questions:

- How confident do you feel in your cycling ability? Assume 7 is 'Very confident' and 1 is 'Not confident'.
- How much does safety influence where you ride? Assume 7 is 'Very much' and 1 is 'Not at all'.
- Approximately how many trips do you take by bike per week?

Further, the authors also compare the number of unsafe points mapped by each respondent by gender.

As shown in Figure 3, men visually have higher confidence levels than women. This is confirmed through a Mann-Whitney U-test ($p = 0.011$) which is used as an alternative to a two-sample t-test due to the non-normal shape of the two distributions (see Table 3). Similarly, a separate Mann-Whitney U-test, ($p = 0.008$) reveals a statistically significant difference in how safety influences riding locations, with safety influencing riding locations for women more than men (see Figure 4).

[5]:
```r
ggplot(df %>%
       select(gender, confidence) %>%
       filter(gender %in% c("Female", "Male")) %>%
       gather(gender, confidence) %>%
       transmute(Gender = gender, Confidence = confidence),
       aes(x = Confidence, fill = Gender)) +
  geom_density(alpha = 0.5) +
  xlab("Level of confidence in riding") +
  ylab("Density") +
  scale_fill_manual(values = c(female_color, male_color))
```

[5]: Output in Figure 3

[6]:
```r
ggplot(df %>%
       select(gender, safety_influence) %>%
       filter(gender %in% c("Female", "Male")) %>%
       gather(gender, safety_influence) %>%
       transmute(Gender = gender, `Safety influence` = safety_influence),
       aes(x = `Safety influence`, fill = Gender)) +
  geom_density(alpha = 0.5) +
  xlab("Influence of safety on riding locations") +
  ylab("Density") +
  scale_fill_manual(values = c(female_color, male_color))
```

[6]: Output in Figure 4

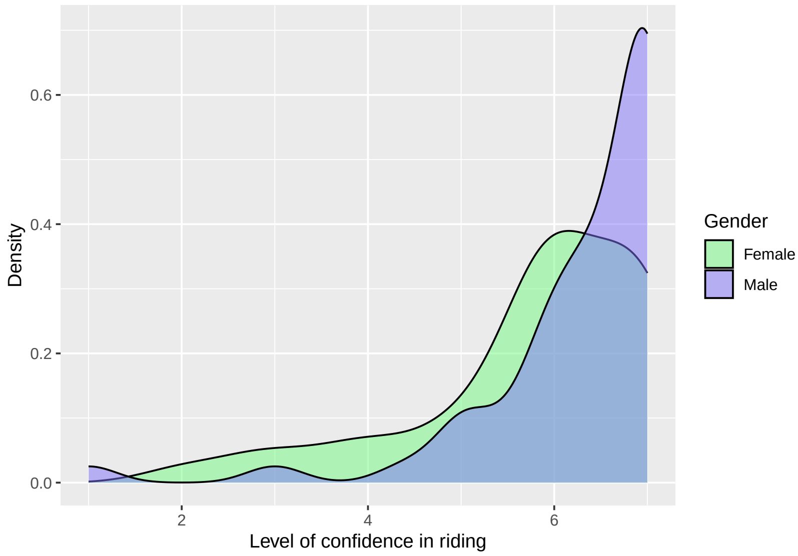

Figure 3: Level of cycling confidence by gender (1 = not confident, 7 = very confident)

[7]:
```
num_pts_female <- pts %>%
  filter(gender == "Female") %>%
  pull(user) %>%
  table() %>%
  as.numeric()

num_pts_male <- pts %>%
  filter(gender == "Male") %>%
  pull(user) %>%
  table() %>%
  as.numeric()

num_pts_df <- data.frame(num_points = c(num_pts_female, num_pts_male),
                 gender = c(rep("Female", length(num_pts_female)),
                            rep("Male", length(num_pts_male))))

num_pts_by_gender <- wilcox.test(num_pts_female, num_pts_male)
```

Statistically, there is no difference in the means of the number of points produced by women and men according to a Mann Whitney U-test ($p = 0.174$), which is perhaps surprising given the number of other gender differences. The means are 5.6 for women and 7.84 for men, respectively. The right skewed distributions indicate that women and men notably both exhibit the "long tail effect" – that is, the phenomenon that a small number of users produce a disproportionate amount of content (Elwood et al. 2013). Both women and men have one "power user", producing 47 points and 41 points, respectively.

[8]:
```
ggplot(num_pts_df %>% transmute(`Number of points` = num_points,
                        Gender = gender),
     aes(x = `Number of points`, fill = Gender)) +
  geom_density(alpha = 0.5) +
  xlab("") +
  ylab("Density") +
  scale_fill_manual(values = c(female_color, male_color))
```

[8]:
```
Output in Figure 5
```

Similar to the number of points produced by gender, there are not statistical differences in the number of trips taken per week according to a Mann-Whitney U-test ($p = 0.357$). This is perhaps surprising given the differences in level of confidence and the influence

Figure 4: Influence of safety on choice of riding locations by gender (1 = not at all, 7 = very much)

of safety on riding locations. However, the *distribution* of trips appears quite different by gender even if the mean number of trips is not. Whereas the distribution for men is roughly uniform, the distribution for women appears bimodal; women exceed men in both the 0-3 categories and the 13-20 categories (Figure 6). It appears as though women participating in this study are "all or nothing" cyclists; they either bike very little or quite a lot.

[9]:
```
## get number of trips as a factor (for mann whitney u-test) and
## numeric (for density plot)
df$number_of_trips_factor <- df$number_of_trips %>%
  as.factor()

levels(df$number_of_trips_factor) <- c("0-3", "4-7", "8-12", "13-20", "20+")
df$number_of_trips_num <- df$number_of_trips_factor %>%
  as.numeric()

df_num_trips <- df %>%
  group_by(gender) %>%
  count(number_of_trips_factor) %>%
  filter(gender %in% c("Female", "Male")) %>%
  na.omit(number_of_trips_factor) %>%
  mutate(Gender = gender)

ggplot(df_num_trips, aes(fill=Gender, y=n, x=number_of_trips_factor)) +
  geom_bar(position = "dodge",
           stat="identity",
           alpha = 0.5,
           color = "black") +
  scale_fill_manual(values = c(female_color, male_color)) +
  xlab("Number of trips") +
  ylab("Frequency")
```

[9]:
```
Output in Figure 6
```

[10]:
```
stat_results <- list(
  c(
    topic = "Level of confidence in cycling by gender",
```

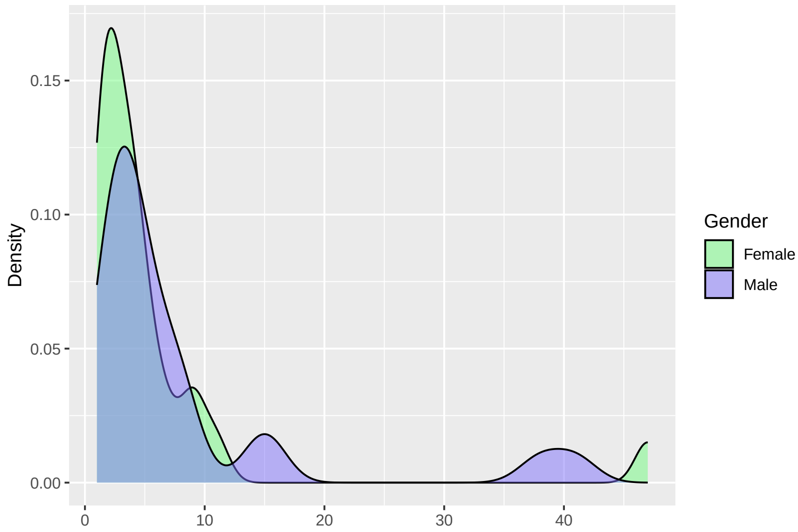

Figure 5: Number of unsafe points mapped

Table 3: Statistical test results

Topic	Test	p-value
Level of confidence in cycling by gender	Mann Whitney U-test	0.011
Influence of safety on choice of riding locations by gender	Mann Whitney U-test	0.008
Number of trips per week by gender	Mann Whitney U-test	0.357
Number of unsafe points mapped by gender	Mann Whitney U-test	0.174

```
    test = "Mann Whitney U-test",
    p_value = conf_by_gender$p.value %>% round(3)
  ),
  c(
    topic = "Influence of safety on choice of riding locations by gender",
    test = "Mann Whitney U-test",
    p_value = infl_by_gender$p.value %>% round(3)
  ),
  c(
    topic = "Number of trips per week by gender",
    test = "Mann Whitney U-test",
    p_value = trips_by_gender$p.value %>% round(3)
  ),
  c(
  topic = "Number of unsafe points mapped by gender",
  test = "Mann Whitney U-test",
  p_value = num_pts_by_gender$p.value %>% round(3)
))

stat_results_df <- map_df(stat_results, ~as.data.frame(t(.))) %>%
  tibble

kbl(stat_results_df,
             col.names = c("Topic",
                           "Test",
                           "p-value"),
             label = NA, booktabs = TRUE)
```

[10]:
```
Output in Table 3
```

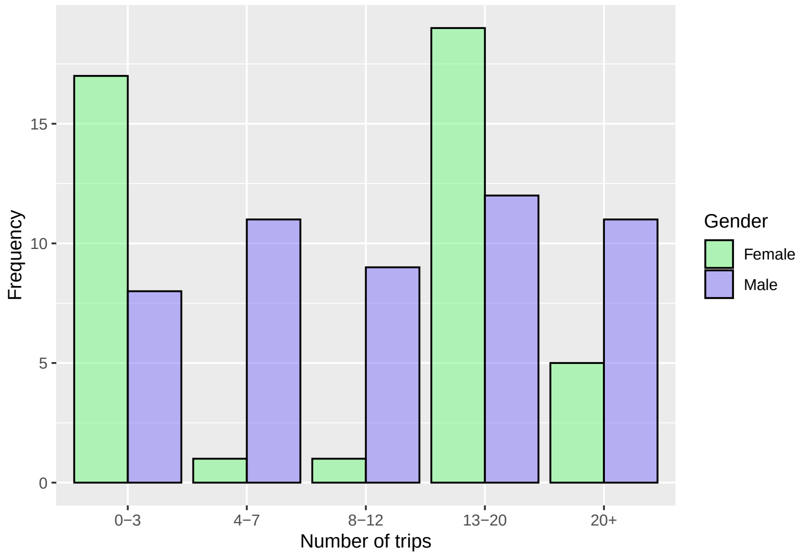

Figure 6: Number of trips per week

4.2 General spatial patterns of mapped unsafe locations

[11]:
```r
library(sf)
library(dplyr)
library(purrr)
library(magrittr)

pts_reasons <- pts %>% select(infrastructure,
                              traffic_proximity,
                              traffic_volume,
                              traffic_speed,
                              visibility,
                              pedestrians,
                              hills,
                              other.x) %>%
  st_set_geometry(NULL)

no_reasons_selected <- pts %>%
  filter(infrastructure == FALSE &
         traffic_proximity == FALSE &
         traffic_volume == FALSE &
         traffic_speed == FALSE &
         visibility == FALSE &
         pedestrians == FALSE &
         hills == FALSE &
         other.x == FALSE
         )

pts_reasons_sum <- pts_reasons %>%
  colSums() %>%
  data.frame() %>%
  mutate(reason = c("Lacking or poor infrastructure",
                    "Traffic proximity",
                    "Traffic volume",
                    "Traffic speed",
                    "Poor visibility from motorists",
                    "Potential conflicts with pedestrians",
                    "Steep hills",
                    "Other")) %>%
```

```
  `rownames<-`(NULL) %>%
  relocate("reason") %>%
  set_colnames(c("reason", "count")) %>%
  arrange(desc(count))
```

A few broad spatial patterns can be observed when examining the raw point data and the heat map (Figure 7). It is apparent that many points are located near busy intersections, major transportation corridors (with the exception of interstate highways), commercial centers, and mixed-use areas of Eau Claire. Very few points appear in residential neighborhoods, reflecting the relatively high feelings of safety in these areas compared to others.

[12]:
```
library(leaflet)
library(sf)
library(leaflet.extras)

pts_df <- pts %>%
  st_set_geometry(NULL)

leaflet(pts) %>%
  addProviderTiles("CartoDB.DarkMatter") %>%
  addHeatmap(radius = 25, blur = 30, max = 1,
             intensity = 60, group = "Heat Map") %>%
  addCircleMarkers(lng = pts_df$x,
                   lat = pts_df$y,
                   fillOpacity = 0.3,
                   color = "white",
                   stroke = FALSE,
                   radius = 5,
                   group = "Individual points")
```

[12]:
```
Output in Figure 7
```

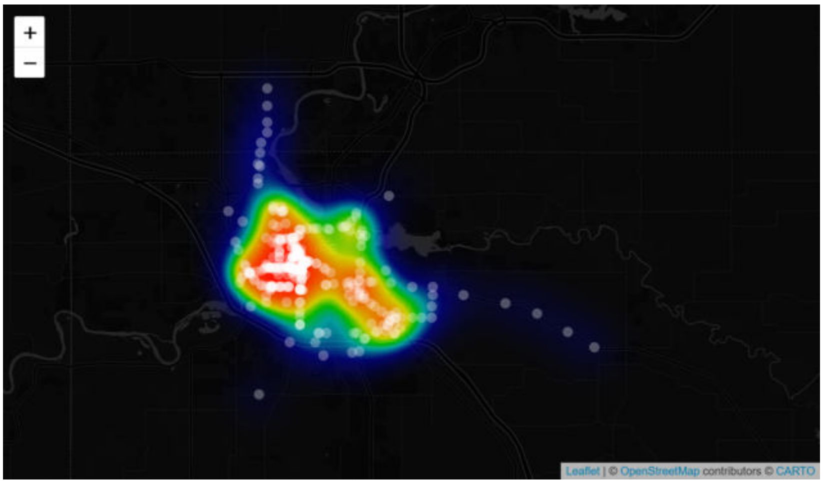

Figure 7: Raw data and heat map of unsafe points

[13]:
```
grd <- st_read(here("data/ec_grid.geojson"),
               quiet = TRUE) %>%
  st_set_crs(4326)

neigh_count_df <- df$grd_id %>%
  table %>%
  data.frame %>%
  setNames(c("id", "user_count"))
```

```r
neigh <- merge(grd, neigh_count_df, by = "id", all = TRUE) %>%
  replace_na(list(user_count=0))

tmap_mode("view")

user_count_by_neigh <- tm_shape(neigh) +
  tm_polygons(col = "user_count",
              palette = "YlGnBu",
              alpha = 0.8,
              title = "Number of respondents",
              popup.vars = c("Respondents:" = "user_count"),
              group = "Number of respondents")

neigh$pt_count <- st_intersects(neigh, pts) %>% lengths

pt_count_by_neigh <- tm_shape(neigh) +
  tm_polygons(col = "pt_count",
              palette = "YlOrRd",
              alpha = 0.8,
              title = "Number of unsafe points",
              id = "pt_count",
              popup.vars = c("Number of points: " = "pt_count"),
              group = "Number of points")

pt_count_by_neigh_lf <- tmap_leaflet(pt_count_by_neigh)
user_count_by_neigh_lf <- tmap_leaflet(user_count_by_neigh)

cor_results <- cor(neigh$pt_count, neigh$user_count, method = "spearman")
```

In general, there is a high degree of correlation between the number of respondents per grid cell (as determined through self-identified home locations) and the number of unsafe points plotted ($\rho = 0.65$; Figure 8 and Figure 9). This is unsurprising, since citizens are more likely to ride near their home. However, the spatial bias of respondents' home locations ought to be considered when making judgments about areas which are generally safe to ride. The unsafe locations identified in this study are certainly not exhaustive; these are locations which have a greater number of activity locations and are generally more accessible by bike. There are likely fewer points mapped on the outskirts of town not because these areas are safer but because the population is smaller there, and thus there are fewer cyclists. Additionally, cyclists who ride in areas with a dense concentration of unsafe points may indeed still feel safe most of the time by making minor route adjustments to avoid those precarious locations.

[14]:
```r
user_count_by_neigh_lf
```

[14]:
```
Output in Figure 8
```

[15]:
```r
pt_count_by_neigh_lf
```

[15]:
```
Output in Figure 9
```

Attached to each spatial response of unsafe locations is a set of reasons for why those locations are unsafe (Table 4). Despite the fact that for 142 of the 339 points no reasons were selected, the summaries are nevertheless informative since these are closely tied to the built environment. Of the options provided, "Traffic proximity" was identified as the most common reason followed by "Traffic speed". This gives credence to the idea that cyclists do not feel safe around motor vehicles and that motor vehicles are the biggest deterrent to cyclists. This was followed by "Lacking or poor infrastructure", indicating the importance of dedicated cycling infrastructure. "Potential conflicts with pedestrians" appears relatively often as the fourth most common reason for feeling unsafe, which is a bit unexpected given that cyclists are a greater threat to pedestrians than the other way around (Graw, König 2002). Nevertheless, conflicts with pedestrians can lead to crashes.

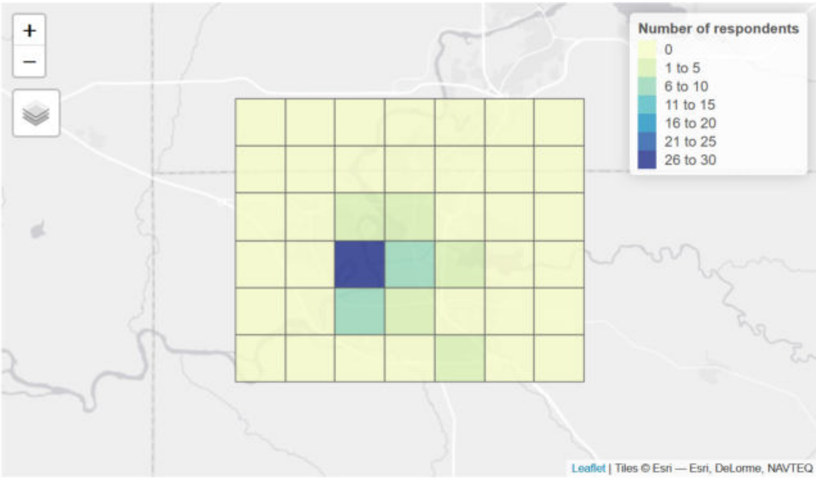

Figure 8: User-identified home locations

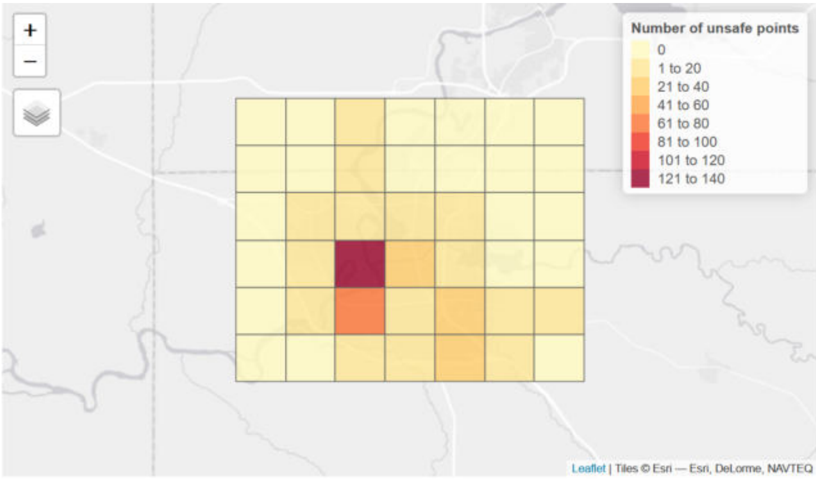

Figure 9: Locations of unsafe points

[16]:
```
kbl(pts_reasons_sum,
    booktabs = TRUE, linesep = c(""),
    col.names = c("Reason", "Count"),
    label = NA)
```

[16]:
```
Output in Table 4
```

4.3 Cluster analysis of mapped unsafe locations

[17]:
```
pts_3070 <- pts %>%
  st_transform(3070) %>%
  arrange(x)

remove_dups_within_dist <- function(pts_df, dist) {
  ## create empty holding tank for new point object, have to give it a crs
  new_pts <- st_sf(st_sfc()) %>%
    st_set_crs(st_crs(pts_df))

  ## create vector of rownames; will remove duplicated stuff from here
  pts_df$index <- 1:nrow(pts_df)

  ## create empty vector of duplicated indexes; will use this to skip
```

Table 4: Reasons for feeling unsafe on a bicycle

Reason	Count
Traffic proximity	129
Traffic speed	101
Lacking or poor infrastructure	98
Potential conflicts with pedestrians	76
Traffic volume	67
Poor visibility from motorists	49
Steep hills	11
Other	11

```
  ## over duplicates
  dup_indexes <- c()

  for (i in 1:nrow(pts_df)) {
    ## if the point's index has not been flagged as dup, don't skip over
    if (sum(dup_indexes %in% pts_df$index[i]) == 0) {
      tmp_pt <- pts_df[i,]

      ## put a buffer around it
      tmp_pt_buffer <- st_buffer(tmp_pt, dist)

      ## find points that intersect
      int_pts <- st_intersection(pts_df, tmp_pt_buffer)

      ## for all intersected points
      for (j in 1:nrow(int_pts)) {
        if (j == 1) {
          next
        } else {
          if (tmp_pt$user == int_pts$user[j]) {
            dup_indexes <- c(dup_indexes, int_pts$index[j])
          }
        }
      }
      new_pts <- rbind(new_pts, pts_df[i,])
    }
  }
  return(new_pts)
}

reduced_pts <- remove_dups_within_dist(pts_3070, 200)

clusters <- dbscan(reduced_pts %>% st_coordinates,
                   eps = 175,
                   minPts = 5)

reduced_pts$cluster <- clusters %>%
  pluck("cluster")

reduced_pts$cluster <- na_if(reduced_pts$cluster, 0)

cluster_pts_to_polygon <- function(pts, dist) {

  ## create placeholder for convex hull object
  c_hull <- st_sf(st_sfc()) %>%
    st_set_crs(st_crs(pts)) %>%
    st_as_sf() %>%
    mutate(cluster = NA)
```

```
  for (i in 1:length(na.omit(unique(pts$cluster)))) {

    ## filter by cluster number
    tmp_pts <- pts %>%
      filter(cluster == i)

    ## create convex hull object (returns geometry only)
    c_hull_geom_tmp <- st_convex_hull(st_union(tmp_pts))

    ## make in to sf object
    c_hull_sf_tmp <- st_as_sf(c_hull_geom_tmp)

    ## assign cluster number
    c_hull_sf_tmp$cluster <- i

    ## add to object
    c_hull <- rbind(c_hull, c_hull_sf_tmp)
  }

  ## buffer
  cluster_buff <- st_buffer(c_hull, dist)

  return(cluster_buff)
}

## use a small distance for cluster buffer
cluster_buff <- cluster_pts_to_polygon(reduced_pts, 20)

cluster_counts <- reduced_pts$cluster %>%
  table() %>%
  as.numeric()

cluster_buff$labels <- paste0(cluster_buff$cluster, " (n = ",
        cluster_counts, ")")
```

The DBSCAN algorithm is used to identify significant clusters of unsafe locations (Figure 10). However, inspections of the raw data revealed frequent occurrences of multiple points produced by a single user within a relatively small area, requiring some filtering before clustering. For example, around a few busy roundabouts (e.g., at the intersection of State St. and Patton St.) a single user produced several points at various places on the roundabout within distances of less than 50m. In theory, without any filtering, one individual could produce their own cluster, making such a location appear more significant than another cluster produced by many users who each mapped one point in the vicinity. So, multiple points produced by the same user within a distance of 200m were reduced to one. This resulted in a reduction of the total number of points from 339 to 287. The authors use 5 minimum points and a search distance of 175m in creating clusters. These parameters were selected through a process of experimentation and was deemed to strike a nice balance in cluster size and number. What follows is commentary on the characteristics of each individual cluster.

[18]:
```
cluster_map <- tm_shape(cluster_buff) +
  tm_fill(col = "cluster",
          palette = "Set2",
          alpha = 0.8,
          title = "Cluster",
          labels = cluster_buff$labels,
          group = "Clusters") +
  tm_borders(lwd = 5,
             col = "black") +
  tm_shape(reduced_pts %>% mutate(as.factor(gender))) +
  tm_dots(col = "gender",
```

```
        title = "Gender",
        alpha = 0.5,
        palette = c(Female = female_color, Male = male_color,
        Other = other_color), group = "Unsafe points") +
  tm_layout(legend.just = "left")

## use tmap_leaflet object to get web map to appear as figure
cluster_map_leaflet <- tmap_leaflet(cluster_map)
cluster_map_leaflet
```

[18]: Output in Figure 10

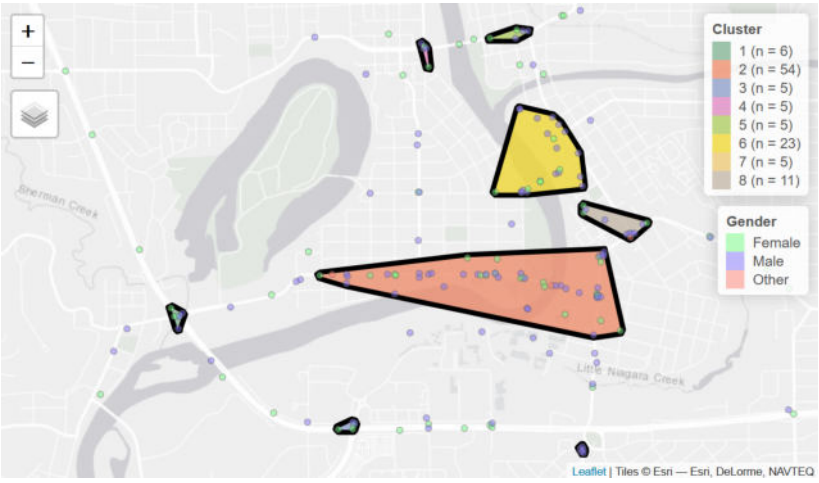

Figure 10: Clusters of points identified as unsafe for cycling using DBSCAN ($minPts = 5$, $eps = 175$m). Points produced by the same respondent within 200m are reduced to one.

Cluster 1 ($n = 6$): *Intersection of N. Clairemont Ave. and Menomonie St.* – this cluster lies at the confluence of a relatively busy intersection (seven lanes on one side of the street and four on the other side). Though there are crosswalks across each section of road, there is only one high-intensity activated crosswalk (HAWK) beacon (on the north side of Menomonie St.).

Cluster 2 ($n = 54$): *Water St., Summit Ave., and State St.* – the largest cluster in the analysis by a good margin in terms of area and number of points, this cluster covers a mixed-use and commercial corridor near the University of Wisconsin - Eau Claire. Points are well-distributed across both Water St. and Summit Ave.; these two roads are one connected segment as the name changes on the bridge crossing the Chippewa River. Though Summit Ave. has a bicycle lane, at both ends of the bridge on this road, motorists must cross the bike lane in order to use the right turn lane. Two "sub-clusters" appear at intersections on State St. between Summit Ave. and Washington Ave.

Cluster 3 ($n = 5$): *Intersection of N. Clairemont Ave. and State Highway 37* – this cluster lies at the confluence of a busy commercial corridor and several of the major medical facilities in Eau Claire. Unlike the intersection covered by Cluster 1, however, this intersection features four HAWK beacons. Users marked similar intersections to the East as unsafe, though these other intersections did not have enough points to form a cluster.

Cluster 4 ($n = 5$): *Intersection of Madison St. and Oxford Ave.* – while there is now a bicycle underpass beneath Madison St., this area can still pose problems for cyclists needing to cross Oxford Ave. Further, one user marked the area just south of this intersection as unsafe – at this point the Chippewa River Trail temporarily stops and empties into the road; those traveling south seeking the trail connection are forced onto the road.

Cluster 5 ($n = 5$): *Madison St. east of the Chippewa River* – this is a section of road bounded by a large hill to the East and a relatively wide bridge to the West. Though there is a dedicated bicycle trail near this road, there are no bicycle lanes on Madison St. at this cluster.

Cluster 6 ($n = 23$): *Eau Claire Central Business District (CBD)* – the second largest cluster in terms of area and number of points, this is a dense, mixed-use corridor covering the CBD and is similar in land use to Cluster 2. Points are well distributed across Farwell St., Barstow St., and Lake St. Lake St. contains a bike lane, but like on Summit Ave., right turning traffic must cross the bike lane both at the intersection of Lake St. and Barstow St. and at the intersection of Lake St. and Farwell St. The speed limit on Farwell St. is 30 mph but is 4-5 lanes with no bike lane. While traffic moves slower on Barstow St., the downtown core of Eau Claire, due to many stop signs, significant amounts of on-street parking can reduce visibility from motorists.

Cluster 7 ($n = 5$): *The Roundabout at State St. and Lexington Blvd.* – this cluster lies at the southern end of a newly constructed – and relatively complex – roundabout at the top of a steep hill. Though there is a bicycle lane north of this roundabout, there is not one to the South, where most of the points are congregated.

Cluster 8 ($n = 11$): *Washington St. and Farwell St.* – this cluster partially lies between Clusters 2 and 6, marking a transition zone between the historic Third Ward neighborhood and the downtown core of the city. A large "sub-cluster" of points appears at the intersection of Washington St. and Farwell St. The "sub-cluster" just to the Northeast lies at the base of a steep hill, and the road just to the East widens from two lanes to three.

In general, clusters can be found around intersections with heavy car traffic (clusters 1, 3, 4, 5, 7, and 8) and in mixed use areas where cars are also common (clusters 2 and 6). It is telling that unsafe points are marked at wide intersections – such as clusters 1 and 3 along Clairemont Ave. – as this indicates that despite the apparent impenetrability of wide thoroughfares and the lack of any cycling-based infrastructure, cyclists are nevertheless riding in these locations. The four southernmost clusters (clusters 1-3 and 7) are also notably located in a ring surrounding the local university campus. Despite the high amount of survey distribution in this area – which obviously impacts results – it should be noted that a reasonable share of students does not own or use a car yet still need to commute in and around this area for a variety of trip purposes. Further, all clusters show a reasonable mix of points produced by women and men, with the exception of Cluster 7, which is made up of points produced exclusively by men. This warrants inspection of gender-based clusters.

4.4 Gendered spatial patterns of mapped unsafe locations

[19]:
```
eps_gender <- 200
min_pts_gender <- 4

## female only
reduced_pts_female <- reduced_pts %>% filter(gender == "Female")
clusters_female <- dbscan(reduced_pts_female %>% st_coordinates,
                          eps = eps_gender,
                          minPts = min_pts_gender)
reduced_pts_female$cluster <- clusters_female %>%
  pluck("cluster")

reduced_pts_female$cluster <- na_if(reduced_pts_female$cluster, 0)

cluster_buff_female <- cluster_pts_to_polygon(reduced_pts_female, 20)

cluster_counts_female <- reduced_pts_female$cluster %>%
  table() %>%
  as.numeric()

cluster_buff_female$labels <- paste0(cluster_buff_female$cluster,
```

```
                                     " (n = ",
                                     cluster_counts_female,
                                     ")")


## male only
reduced_pts_male <- reduced_pts %>% filter(gender == "Male")
clusters_male <- dbscan(reduced_pts_male %>% st_coordinates,
                        eps = eps_gender,
                        minPts = min_pts_gender)
reduced_pts_male$cluster <- clusters_male %>%
  pluck("cluster")

reduced_pts_male$cluster <- na_if(reduced_pts_male$cluster, 0)

cluster_buff_male <- cluster_pts_to_polygon(reduced_pts_male, 20)

cluster_counts_male <- reduced_pts_male$cluster %>%
  table()%>%
  as.numeric()

cluster_buff_male$labels <- paste0(cluster_buff_male$cluster,
                                   " (n = ",
                                   cluster_counts_male,
                                   ")")

gender_cluster_map <- tm_shape(cluster_buff_female) +
  tm_fill(col = "cluster",
          palette = female_color,
          alpha = 0.5,
          title = "Female clusters",
          labels = cluster_buff_female$labels,
          group = "Female clusters") +
  tm_borders(lwd = 5,
             col = "black") +
    tm_shape(cluster_buff_male) +
    tm_fill(col = "cluster",
            palette = male_color,
            alpha = 0.5,
            title = "Male clusters",
            labels = cluster_buff_male$labels,
            group = "Male clusters") +
    tm_borders(lwd = 5,
               col = "black") +
  tm_shape(reduced_pts %>% mutate(as.factor(gender))) +
  tm_dots(col = "gender",
          title = "Gender",
          alpha = 0.5,
          palette = c(Female = female_color, Male = male_color,
          Other = other_color), group = "Unsafe points") +
  tm_layout(legend.just = "left")

gender_cluster_map_center <- cluster_buff_male %>%
  st_union() %>%
  st_centroid() %>%
  st_transform(4326)

gender_cluster_map_center$lng <- gender_cluster_map_center %>%
 st_coordinates() %>%
 data.frame() %>%
 pull(X)
```

```
gender_cluster_map_center$lat <- gender_cluster_map_center %>%
 st_coordinates() %>%
 data.frame() %>%
 pull(Y)

gender_cluster_map_leaflet <- tmap_leaflet(gender_cluster_map)
gender_cluster_map_leaflet %>%
  setView(zoom = 14, lng = gender_cluster_map_center$lng,
  lat = gender_cluster_map_center$lat)
```

[19]:
```
Output in Figure 11
```

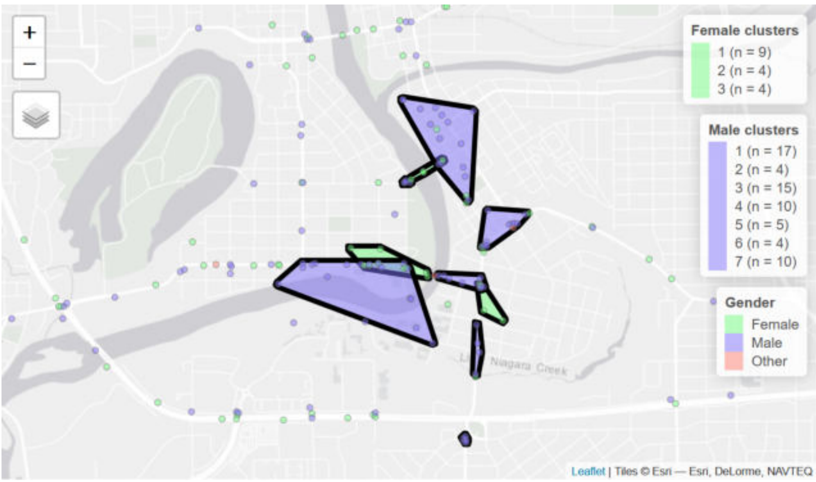

Figure 11: Clusters of points identified as unsafe for cycling by gender using DBSCAN ($minPts = 4$, $eps = 200$m); Points produced by the same respondent within 200m are reduced to one.

Gender-based clusters use slightly modified DBSCAN parameters – four minimum points and a search distance of 200m – to account for the fewer data points available for clustering as a result of grouping by gender (Figure 11). Clusters for both women and men are generally located toward the center of study area with clusters for both genders located around the mixed-use areas of Eau Claire. However, there are only three clusters created for women and seven for men. Keeping the original parameters results in an even starker picture with one cluster for women and seven for men. The clusters for men are also larger in terms of area, and they extend farther from the city center.

Investigating all points of unsafe locations by gender reveals several intriguing trends (Figure 12). The outskirts of the city are dominated by points produced by men. At first glance, it would appear as though a single "power user" may have produced all of these points, which would perhaps warrant their removal from analysis. However, inspection of individual data points demonstrates that each of the points placed farthest north, east, south, and west were indeed produced by four unique users. As a result, all are worth keeping, and the convex hulls created by gender are thus highly disparate in terms of area.

[20]:
```
pts_female <- pts %>% filter(gender == "Female")
pts_male <- pts %>% filter(gender == "Male")
pts_other <- pts %>% filter(gender == "Other")

gender_map <- leaflet() %>%
  addProviderTiles("CartoDB.Positron") %>%
  addCircleMarkers(lng = pts_female$x,
                   lat = pts_female$y,
                   radius = 4,
                   stroke = TRUE,
```

```
                    color = "black",
                    weight = .5,
                    opacity = 1,
                    fill = TRUE,
                    fillColor = female_color,
                    fillOpacity = 0.6) %>%
  addCircleMarkers(lng = pts_male$x,
                    lat = pts_male$y,
                    radius = 4,
                    stroke = TRUE,
                    color = "black",
                    weight = .5,
                    opacity = 1,
                    fill = TRUE,
                    fillColor = male_color,
                    fillOpacity = 0.6) %>%
  addCircleMarkers(lng = pts_other$x,
                    lat = pts_other$y,
                    radius = 4,
                    stroke = TRUE,
                    color = "black",
                    weight = .5,
                    opacity = 1,
                    fill = TRUE,
                    fillColor = other_color,
                    fillOpacity = 0.6) %>%
  addLegend("bottomright",
             colors = c(female_color,
                        male_color,
                        other_color),
             labels = c("Female",
                        "Male",
                        "Other"),
             opacity = 1)

gender_map
```

[20]: Output in Figure 12

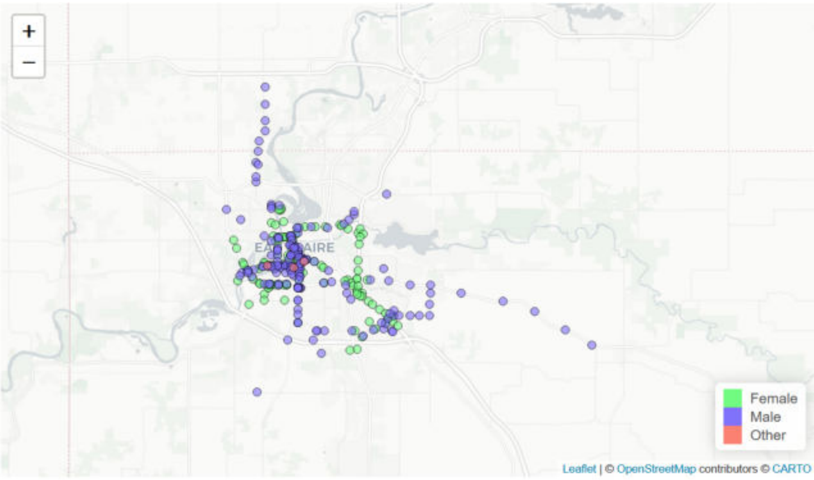

Figure 12: Locations identified as unsafe for cycling by gender

[21]:
```
## convex hull female
ch_f <- st_union(pts_female) %>%
  st_convex_hull %>%
```

```
  st_as_sf %>%
  mutate(info = "Female convex hull",
         gender = "female")

## convex hull male
ch_m <- st_union(pts_male) %>%
  st_convex_hull %>%
  st_as_sf %>%
  mutate(info = "Male convex hull",
         gender = "male")

ch_f$area <- ch_f %>%
  st_area %>%
  set_units("km^2") %>%
  as.numeric %>%
  round(0)

ch_m$area <- ch_m %>%
  st_area %>%
  set_units("km^2") %>%
  as.numeric %>%
  round(0)
```

The convex hull for women is almost completely encompassed by the convex hull for men and is about a fourth of the area (Figure 13). Specifically, the areas for women and men are 43 km2 vs. 159 km2, respectively. While the survey in this study did not ask about mobility and cycling extent per se, due to the way the survey question was framed – pertaining to feelings of being unsafe *where* respondents actually ride – this result may be indicative of gendered differences in mobility. Put more plainly, the cycling infrastructure in Eau Claire, notwithstanding broader cultural factors, may offer more locational freedom to men. While future research could confirm or deny this hypothesis, it is in line with broader research on mobility in the United States.

[22]:
```
pts$user_short <- str_sub(pts$user, start = -3) %>%
  toupper()
pts$info <- "Unsafe location (click for detailed data)"

chull_map <- tm_shape(ch_m) +
  tm_fill(col = male_color,
          alpha = 0.5,
          popup.vars = FALSE,
          id = "info",
          group = "Convex hull (male)") +
  tm_shape(ch_f) +
  tm_fill(alpha = 0.5,
          col = female_color,
          popup.vars = FALSE,
          id = "info",
          group = "Convex hull (female)") +
  tm_shape(pts) +
  tm_dots(col = NA,
          id = "info",
          palette = c("#fffdfb"),
          legend.show = FALSE,
          popup.vars = c("Gender: " = "gender",
                         "Age: " = "age",
                         "Helmet usage: " = "helmet",
                         "User id: " = "user_short"
                         ),
          size = 0.075,
          alpha = 0.8,
          group = "Unsafe points") +
```

```
  tm_view(set.view = 12)

chull_map_leaflet <- tmap_leaflet(chull_map)
chull_map_leaflet %>%
  setView(zoom = 11, lng = mean(pts$x), lat = mean(pts$y))
```

[22]: Output in Figure 13

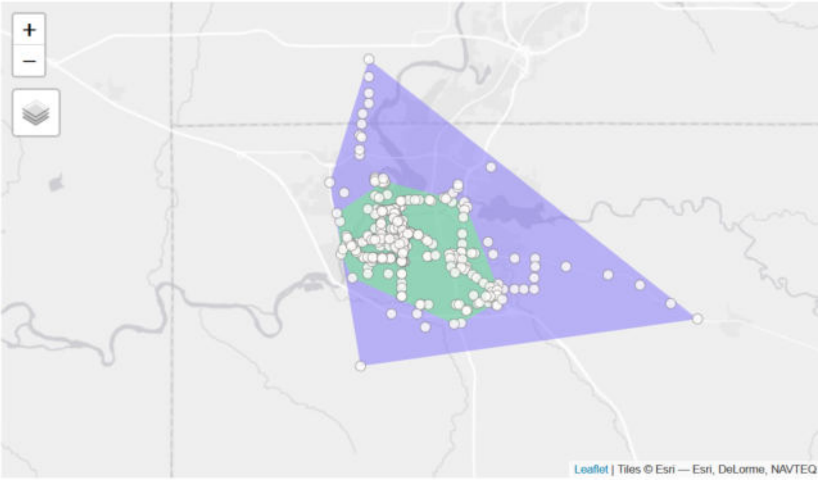

Figure 13: Convex hull of responses by gender

5 Discussion, Limitations, and Future Work

The results of this study are consistent with previous literature on cycling perception in some ways but markedly different in others. Women and men are significantly different in terms of overall cycling confidence and how concerns of safety influence riding locations. While this study did not ask participants open-ended questions about perception, other works suggest that inadequate infrastructure is shown to have greater influence on the cycling rates of women than men (Manton et al. 2016, Misra, Watkins 2018, Hood et al. 2011).

The convex hulls revealed in this study are emblematic of the general trends in gender cycling behavior. The spatial extent of where men mapped points – and thus, likely where they ride more generally – exceeds the extent of points mapped by women, at least at the extremes. Individuals who feel more unsafe cycling are less likely to travel farther distances. Other research indeed confirms that men are more likely to travel further when cycling (Misra, Watkins 2018). All this said, it is notable that even though perceptions of safety and confidence differ, there is not a significant difference in the number of trips taken per week by gender.

It follows from this that despite the fact that women have more negative perceptions about cycling, it does not appear to reduce their number of trips. Though cycling is largely dominated by men in the United States currently, this finding of relative parity in terms of the number of trips is a departure from other studies in this country. This finding suggests a desire of women to participate in cycling which should encourage policy makers to not consider it purely an activity for men. With the political will to do so, the creation of a safe cycling environment is attainable – as demonstrated in other countries (Pucher, Buehler 2008) – which can lead to greater gender equity.

Even though there is a greater concentration of points near the city center, it is notable that points are indeed scattered throughout the city, even at the city's edges. While these peripheral locations have little dedicated cycling infrastructure – and, to the casual observer, would not be utilized by bicycle at all – the presence of points indicate cycling relevance. Cyclists are still riding in these locations and may desire to ride there more but presently feel unsafe doing so.

In addition to the analysis of unsafe points as a whole, the analysis of the clusters reveals several common themes. Clusters are generally located in commercial and mixed-use areas rather than quiet residential neighborhoods. While respondents perceive mixed-use areas as more unsafe, this does not necessarily mean that mixed-use areas are detrimental to commuter cycling in general. In fact, the converse has been demonstrated other cases, both within (Hull, O'Holleran 2014) and outside of the United States (Cervero 1996). In this study however, this result is likely the product of car dependency creating traffic in commercial and mixed-use areas, leading to a greater potential for conflict between cyclists and motor vehicles.

Unsurprisingly, many of the clusters are located at intersections: spaces where cyclists are likely to encounter vehicular traffic. This is further corroborated by the top two cited reasons for feeling unsafe being related to traffic and aligns with other literature (Wang, Akar 2018, DiGioia et al. 2017). Bridges also appear to be a common site for clusters, yet it is unclear if these can be explained purely by the cyclists being forced into close proximity with vehicles, or if the structural elements of the bridges themselves create relative feelings of being unsafe. Additionally, places where motor vehicles must cross a bike lane are common locations perceived to be unsafe.

There are several limitations to this study that cannot be ignored. First, the study did not utilize random sampling, as this would be difficult to achieve given the target population. Additionally, since fliers were distributed in late summer 2021, the results cannot be applied to cycling in the winter months. Indeed, the significant amount of snowfall combined with an inadequate handling of snow in bike lanes and trails make the study inapplicable to winter cycling. The number of respondents was also relatively small ($n = 99$), and the survey did not include an exhaustive list of all reasons why cyclists may feel unsafe; fear of crime, for instance was not included. Additionally, a study such as this does rely on respondents' capability of accurately placing locations on a map. Though web maps are increasingly utilized by the general population, this capacity is at times less than perfect. Finally, the city of Eau Claire is largely white, and the lack of responses from people of color is a significant disadvantage to a study concerned with equity. Future work could deliver a similar survey in other municipalities, perhaps ones which are more diverse, to include the voices of historically marginalized populations.

Future work could also compare the locations of where respondents feel unsafe with where crashes have actually happened. While it would be expected that the two would have a strong correlation, differences may be illuminating. Moreover, it would be telling to compare the locations where respondents feel unsafe with land use data and characteristics of the built environment: street width; slope; and the presence or absence of traffic signals, bicycle lanes, and intersections. In addition to these possibilities for study expansion, the data collected in this study possesses many variables and relationships which remain to be studied. These include differences in the reasons *why* locations were identified as unsafe for cycling by demographic groups, differences in convex hulls by demographic groups other than gender, and other age/race related comparisons.

6 Conclusion

This study aimed to investigate both the spatial and non-spatial patterns in perceived cycling safety in Eau Claire, Wisconsin. To accomplish this, the authors created a survey instrument for identifying locations perceived to be unsafe for cycling and conducted a survey of local residents. The survey observations were then analyzed for statistical differences in cycling ridership through Mann-Whitney U-tests, demonstrated where infrastructure improvements could be focused through cluster analysis, and compared the spatial distribution of ridership points through convex hulls.

While a growing body of literature has investigated cycling safety perceptions, three aspects of this study are particularly unique. First, the authors implemented an interactive open-source web application to collect public survey responses. Second, the study used spatial analysis on where respondents feel unsafe, rather than simply where cyclists ride, or what non-spatial infrastructure characteristics are undesirable for cycling. Third, this study is the first, to the authors' knowledge, that analyzed the gendered spatial patterns in cycling safety perceptions.

The study findings align with previous literature on cycling safety perception in some aspects but diverge in others. Gender differences in overall cycling confidence and safety concerns' impact on riding locations are consistent with previous work, however, while men tend to exhibit greater spatial extent in cycling patterns compared to women, there's no significant gender gap in the number of weekly trips. Despite women's more negative perceptions, their trip frequency remains comparable, challenging the notion of cycling as solely male-dominated in the US. This suggests a desire for gender-inclusive cycling environments, emphasizing the need for policymakers to prioritize safety infrastructure. While unsafe points are clustered in areas with mixed land use and intersections, it's important to recognize that these locations remain relevant for cycling, albeit hindered by traffic-related safety concerns.

Some results are quite encouraging, such as the relative parity in the number of trips taken by gender, but significant progress is still needed to make cycling more equitable. Public policy and infrastructure design have indeed been successful in creating urban areas that are safer for cycling. These can be used to calm traffic, improve public transport integration, support bike sharing programs, and promote cycling through promotional events (Pucher et al. 2011). These techniques can make cycling safer, and as suggested in this study, perhaps more equitable as well. Such transportation improvements produce tangible community benefits which deserve consideration from planners and public officials.

Acknowledgments

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