Europe, we have a problem!
The Economic Effects of Border Controls during COVID-19

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Abstract

The first wave of COVID-19 temporarily suspended free movement in the Schengen Area, creating a natural experiment on border closures' economic impact. Using monthly nighttime lights data, we find that cross-border municipalities experienced greater economic declines than interior municipalities. The negative border effect was stronger in new EU member states than in old EU member states. Moreover, the severity of the decline depended on municipality size and cross-border mobility purpose. Small municipalities were the most vulnerable during the lockdown, experiencing greater economic declines due to their reliance on cross-border economic activity. Municipalities reliant on economic-oriented cross-border mobility (shopping, business, and leisure) experienced significant reductions in luminosity, indicating weak local substitution effects, such as a limited capacity to offset lost cross-border economic activity with domestic alternatives. In contrast, those dependent on social-oriented mobility (visits to family, friends, and public services), showed weaker or negligible effects, suggesting the presence of strong local substitution. If policymakers acknowledge that substitution potential varies across regions, they can design more effective, region-specific interventions to support local economies during future disruptions.

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Keywords: Schengen Area, COVID-19, border controls, Nightlights (NTL), municipalities

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1 Introduction

"This virus has no passport. We must unify our forces, coordinate responses and cooperate. I sincerely believe that closing borders are bad decisions within Europe..."

-Emmanuel Macron, May 2020

It has been nearly three decades since the Schengen Area was established in 1995, creating a borderless Europe with free movement of people, goods, services, and capital. However, the COVID-19 pandemic triggered the most severe restrictions on internal Schengen borders in history, reversing decades of economic and social integration. Governments, unprepared for the sudden shock, swiftly imposed border controls as a public health measure to contain the spread of the virus. While these restrictions were intended to protect public health, they also disrupted economic activity, particularly in border regions that depend on cross-border mobility.

The economic impact of these policies was unevenly distributed across Europe. While national-level studies have examined the broader macroeconomic effects of lockdowns and travel restrictions, there is limited research on the regional dimension, particularly at the municipality level. Our analysis shows that the severity of economic decline varied based on several factors, including proximity to international borders, city size, degree of integration into international markets, and reliance on cross-border mobility.

This paper makes several contributions to the literature. It provides a detailed empirical analysis of the economic impact of border restrictions using NASA's Black Marble nighttime lights (NTL) data at the municipal (LAU-2) level, allowing for precise measurement of economic disruptions near borders. Unlike studies relying on national or regional data, this approach captures localized effects with high spatial and temporal resolution. The use of high-frequency NTL data enables real-time tracking of economic activity across multiple European countries, offering a cross-country perspective that has been largely missing from the literature. While most research focuses on pandemic lockdowns within cities, little attention has been given to how border closures affected cross-border economic interactions and regional disparities. By addressing this gap, this study offers insights for policymakers to identify vulnerable regions and design adaptive border policies that balance public health measures with economic stability.

Second, by exploiting the sudden reintroduction of border controls as a natural experiment, we find that border municipalities experienced sharper declines in economic activity than interior municipalities, with the impact being particularly severe in small border cities. These areas faced greater economic disruptions due to their limited local market size. Unlike larger cities that could rely on more diversified economic structures, small border municipalities lacked the internal market strength to buffer the impact of mobility restrictions. The negative effect was further exacerbated in new EU member states compared to old member states, reflecting differences in economic integration and cross-border labor dependencies.

Third, municipalities reliant on economic-oriented cross-border mobility, such as shopping, business, and leisure, experienced significant NTL reductions, indicating a strong dependence on cross-border economic flows that could not be easily replaced. In contrast, those dependent on social-oriented mobility, such as visiting family or accessing public services, were less affected or unaffected, suggesting the presence of local substitution effects. This implies that municipalities with stronger domestic alternatives for essential services and social interactions were more resilient to border closures, whereas those heavily integrated into cross-border markets faced greater economic disruptions due to limited substitution options.

The remainder of this paper is organized as follows. The next section describes the theoretical framework, data sources, and methodology. This is followed by an empirical analysis of the main results and additional robustness checks. The final section discusses policy implications and provides concluding remarks.

2 Theoretical Framework

The theoretical framework is based on a multiregion version of the market-access-based New Economic Geography (NEG) model, similar to Redding and Sturm (2008). Unlike traditional studies that focus on economic integration, our framework is adapted to analyze the effects of temporary but severe restrictions on mobility and trade, such as COVID-19 border closures. The model captures how negative market access shocks affect municipal economic activity, with a focus on border municipalities compared to interior municipalities.

As in standard NEG models (Krugman, 1991; Fujita, Krugman, and Venables, 1999), the combination of increasing returns to scale and transport costs leads to agglomeration forces, where firms tend to concentrate near large markets with better access to consumers. In parallel, spreading forces (such as congestion effects and competition) provide counterbalancing incentives for firms and workers to relocate to lower-cost areas. Under normal conditions, border municipalities benefit from cross-border interactions, allowing them to sustain higher levels of economic activity due to trade, commuting, and market spillovers.

However, border closures introduce a sharp, asymmetric increase in trade costs, particularly affecting border regions where Firm Market Access (FMA) and Consumer Market Access (CMA) depend heavily on cross-border interactions. The model predicts that such restrictions cause a decline in economic activity, which we measure through nightlight intensity. While interior municipalities also experience economic slowdowns, they remain less affected due to their greater reliance on domestic markets and lower dependence on cross-border labor mobility.

The economy consists of a set of locations indexed by $a \in 1, \ldots, A$, where each location corresponds to municipalities. Each municipality has an exogenous stock of nontradable services H_a, capturing local infrastructure and amenities. The number of consumers (or workers) L is mobile across locations and spends a fraction $\mu \in (0, 1)$ of income, while the remaining share $1 - \mu$ is allocated to nontradable services. Firms operate under increasing returns to scale, engaging in monopolistic competition with a constant elasticity of substitution $\epsilon > 1$ (Dixit and Stiglitz, 1977). Trade between municipalities is subject to iceberg trade costs $T_{ai} > 1$, meaning that more units must be produced in region i for one unit to reach region a. Lockdowns increase T_{ai} significantly for border municipalities, leading to a stronger economic contraction in these areas.

The equilibrium allocation of economic activity across municipalities is determined by migration and firm location decisions, ensuring that the same real economic conditions hold across populated regions in the long-run equilibrium. If we let w_a denote the nominal wage rate, L_a the number of workers, P_a^M the Dixit-Stiglitz price index for varieties, n_a the number of firms, and p_a the local free-on-board price of a variety, then the equilibrium real wage can be reformulated as an equilibrium level of nightlight intensity NTL_a:

$$NTL_a = \Omega \left(\sum \left(\frac{w_i L_i P_i^M}{T_{ai}^{\epsilon-1}} \right) \right)^{\frac{\mu}{(1-\mu)(\epsilon-1)}} \left(\sum \left(n_j \frac{p_j P_j^M}{T_{ja}^{\epsilon}} \right) \right)^{\frac{1}{(1-\mu)(\epsilon-1)}} \frac{1}{H_a} \tag{1}$$

where Ω is a function of structural parameters and the common real wage. The two key components of the equation are Firm Market Access (FMA) and Consumer Market Access (CMA).

Firm Market Access (FMA) measures how easily firms in municipality a can access demand in other municipalities, depending on trade costs T_{ai}. During lockdowns, cross-border restrictions sharply increase T_{ai}, disproportionately reducing FMA for border municipalities. Consumer Market Access (CMA) reflects how easily consumers in region a can purchase goods from other municipalities. In border areas, where consumers often rely on cross-border shopping, increased trade costs T_{ja} significantly reduce CMA during lockdowns.

The impact of lockdowns is thus asymmetric. While both border and interior municipalities experience economic contractions, the model predicts that border municipalities suffer a larger and more persistent reduction in economic activity due to the disproportionate decline in market access. This is observable in nightlight intensity data, where a sharper decline in NTL_a is expected for border regions compared to interior ones. If the lockdown effects are long-lasting, border regions may experience permanent economic scarring, with firms and workers relocating to interior municipalities.

2.1 Theoretical Model Extension: Lockdown and Substitution Effects

The reintroduction of border controls during the COVID-19 pandemic imposed significant constraints on cross-border economic interactions, particularly in border municipalities where economic activity is highly dependent on mobility. These restrictions altered FMA and CMA by increasing the costs of cross-border trade and mobility, which in turn affected local economic performance. To capture these effects, we extend the theoretical model to incorporate border control restrictions (δ) and the substitution effect (σ), which determines the extent to which municipalities can replace lost cross-border activity with domestic alternatives.

During the COVID-19 lockdowns, governments reintroduced border controls (δ), which significantly increased trade frictions and mobility costs, disproportionately affecting border municipalities reliant on cross-border employment, shopping, and services. To capture this effect, we introduce a border control cost δ, which raises trade costs:

$$T_{ai}^{\text{lockdown}} = T_{ai}(1 + \delta) \tag{2}$$

$$T_{ja}^{\text{lockdown}} = T_{ja}(1 + \delta) \tag{3}$$

where higher δ values indicate stricter border restrictions and increased economic frictions.

However, not all municipalities were equally affected. Some border regions were able to mitigate these disruptions by substituting lost cross-border economic activity with local alternatives (e.g., shifting from cross-border shopping to domestic consumption, adapting business operations, or increasing reliance on local labor markets). We introduce the substitution factor (σ), which offsets some of the increased trade costs:

$$T_{ai}^{\text{lockdown}} = T_{ai}(1 + \delta - \sigma) \tag{4}$$

$$T_{ja}^{\text{lockdown}} = T_{ja}(1 + \delta - \sigma) \tag{5}$$

where σ represents the degree of local substitution potential; If $\sigma = 0$, municipalities experience full economic losses from border closures; If $\sigma = \delta$, the municipality fully substitutes for lost cross-border activity, resulting in no net impact on economic activity.

Incorporating these extensions, the equilibrium model for nighttime light intensity becomes:

$$NTL_a = \Omega\left(\sum\left(w_i L_i P_i^M\right)\left(\frac{1}{T_{ai}^{\text{lockdown}}}\right)^{\frac{\mu}{(1-\mu)(\epsilon-1)}}\right)\times\left(\sum\left(n_j \frac{p_j P_j^M}{T_{ja}^{\text{lockdown}}}\right)^{\frac{1}{(1-\mu)(\epsilon-1)}}\right)\frac{1}{H_a} \tag{6}$$

where T_{ai}^{lockdown} and T_{ja}^{lockdown} now incorporate the border restriction (δ) and substitution potential (σ).

The extended model provides a framework to understand the heterogeneous economic effects of border controls. Border municipalities with low substitution potential ($\sigma \ll \delta$) experienced severe economic declines, as firms and consumers could not replace lost cross-border activity. Municipalities with high substitution potential ($\sigma \approx \delta$) were more resilient, mitigating the negative effects of border closures. Interior municipalities ($\delta = 0$) remained largely unaffected, as they relied more on domestic markets.

This framework allows for empirical validation using nighttime lights data by analyzing differences in economic shocks across border and interior municipalities and measuring how substitution capacity influenced economic resilience.

When we apply model in Equation (6) to two types of territorial units, border municipalities and interior municipalities. We predict that luminosity decline significantly in border municipalities due to trade and commuting disruptions.

$$NTL_B = \Omega \cdot (FMA_B)^{\frac{\mu}{(1-\mu)(\epsilon-1)}} \cdot (CMA_B)^{\frac{1}{(1-\mu)(\epsilon-1)}} \tag{7}$$

Lockdown increases trade costs (T_{Bi}), reducing FMA_B and CMA_B:

$$NTL_B^{\text{lockdown}} < NTL_B^{\text{pre-lockdown}}$$

However, since interior regions rely mostly on domestic trade, the increase in T_{Ii} is smaller. Interior municipalities experience a much smaller decline in nightlights.

$$NTL_I = \Omega \cdot (FMA_I)^{\frac{\mu}{(1-\mu)(\epsilon-1)}} \cdot (CMA_I)^{\frac{1}{(1-\mu)(\epsilon-1)}} \tag{8}$$

$$NTL_I^{\text{lockdown}} \approx NTL_I^{\text{pre-lockdown}}$$

Using this theoretical framework, we formulate following empirically testable hypotheses:

H: Municipalities that are close to an closed border as a result of COVID-19 shock experience a relative luminosity decline. We compare nightlight reductions in border vs. interior municipalities.

$$\Delta NTL_B < \Delta NTL_I$$

Based on the discussion above, we further extend this into the following sub-hypotheses:

H.1: The impact of border closures differs between new and old EU member states.

H.2: The effect of border closures varies between large and small border municipalities.

H.3: The extent of the impact of border closures depends on the purpose of cross-border mobility, e.g. the role of substitution effects.

These hypotheses provide a structured approach to examining the heterogeneous effects of border restrictions. By analyzing the differences across regions, municipality sizes, and mobility purposes, we gain deeper insights into how border closures shaped local economic activity.

This distinction is particularly important because border municipalities are not a homogeneous group—while some depend heavily on cross-border economic interactions, others have more diversified local economies that are less sensitive to mobility restrictions.

3 Data

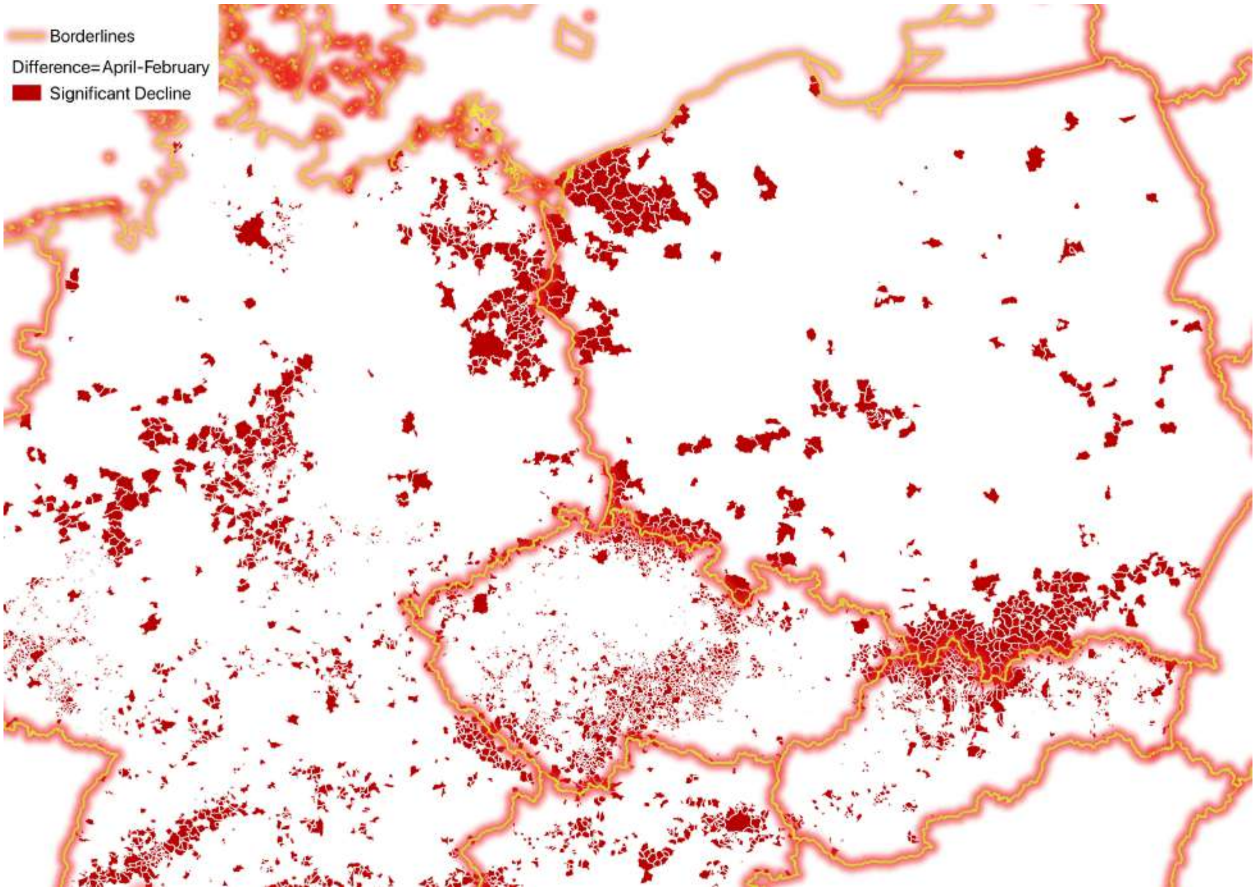
3.1 NASA's Black Marble Nighttime Lights

Remotely sensed nighttime lights are increasingly used in economics as a typical proxy, a typical proxy for human and economic activity (Gibson et al., 2021). The vast majority of studies have used the Defense Meteorological Satellite Program (DMSP-OLS) to monitor lights from space and study long-term relationships between human activity and socioeconomic variables since 1992[1]. However, the spatial and radiometric resolution is a course of the DMSP-OLS, which makes the sensor saturate, bloom, and over-glow. In addition, it has the disadvantage of having no onboard calibration, which is the basis for deriving a reliable remote sensing record over time. Generally speaking, DMSP-OLS is an ideal and without an alternative when looking at long-term, large-scale changes in human and economic activities - the data from this source has been beneficial in understanding long-term historical trends. However, it is less used in remote sensing literature when examining more recent nighttime dynamics.

The satellite generation Visible Infrared Imaging Radiometer Suite (VIIRS) is the latest and the best version of nighttime light sensors. The day-night band on the VIIRS is ultra-sensitive even in low-light conditions. It allows researchers to observe the dynamics of the nighttime lights with better spatial and temporal resolutions than DMSP-OLS. The VIIRS day-night band presents a significant improvement over the DMSP-OLS sensor for several reasons. First, it has a higher spatial resolution of $\approx$ 750 meters instead of $\approx$ 2.7 km for the DMSP-OLS. The VIIRS day-night

[1]in African cities (Michalopoulos and Papaioannou, 2014; Storeygard, 2016; Eberhard-Ruiz and Moradi, 2019; Dreher et al., 2019); in world cities (Hodler and Raschky, 2014; Düben and Krause, 2021; Kocornik-Mina et al., 2020; Mamo et al., 2019; Lessmann and Seidel, 2017); in Indian cities (Gibson et al., 2015; Castelló-Climent et al., 2018); Prakash et al., 2019); in Barbados beaches (Corral and Schling, 2017); in OECD countries (Smith and Wills, 2018); in North Korea (Lee, 2018); in Indonesian sub-districts (Heger and Neumayer, 2019); in European twin cities (Kapanadze, 2023).

Figure 3.1: Change in NTL: where West meets East



Notes: Author's own elaboration in QGIS based on NASA's Black Marble Nightlights in Germany, Poland, Czechia.

band is sensitive to lower light levels than the DMSP-OLS. It has a 14-bit radiometric quantization, which means it is 256 times more sensitive to radiometric differences in nighttime lights than DMSP-OLS. Second, VIIRS sensors do not saturate and have little blooming and over-glow effect. Third, VIIRS has onboard radiometric calibration, which allows the time series data to be corrected and stable over time. Surprisingly, even though the quality of VIIRS is way better than DMSP-OLS, VIIRS is rarely used in economics (Gibson et al., 2021). The use of VIIRS in economics research might be limited due to economists' and social scientists' lack of awareness[2].

NASA developed the Black Marble products, the first daily calibrated and corrected product suite

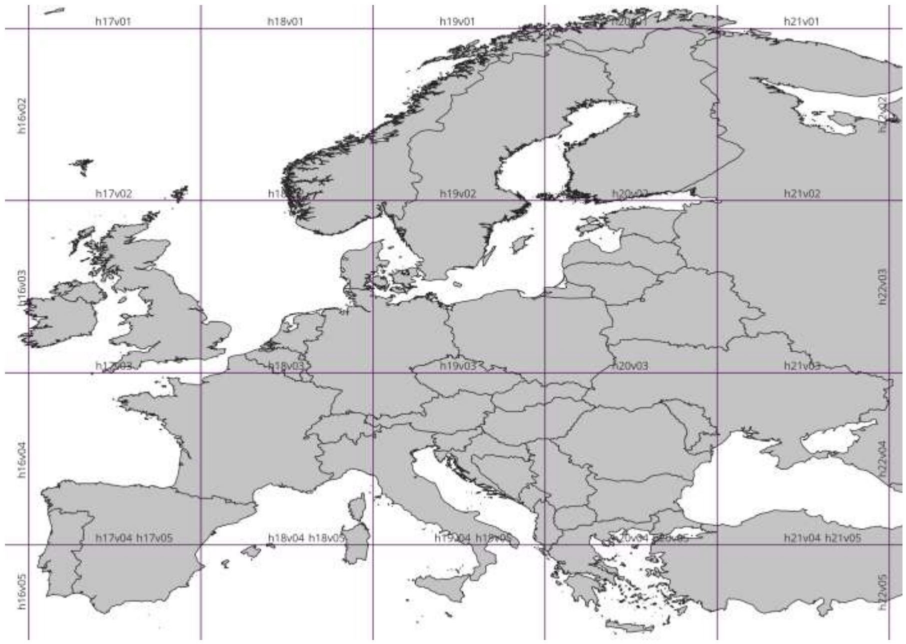
[2]The interdisciplinary nature of using remote sensing data in economic analysis requires researchers to understand satellite imagery, data processing techniques, and relevant statistical methodologies.

of VIIRS nighttime lights in 2020. The data was significantly improved and can be used effectively in all scientific areas. NASA released Black Marble's VNP46A2 - VIIRS/NPP Lunar BRDF-Adjusted Daily Nighttime Lights in July 2020. It is the first database of improved remotely-sensed lights at night, available daily. In April 2021, NASA released VNP46A3 Lunar BRDF-Adjusted Monthly Nighttime Lights and VNP46A4 Lunar BRDF-Adjusted Yearly Nighttime Lights. The Black Marble has low resolution and allows me to build a dataset of economic and human activities at the finest spatial level.

To obtain administrative data at the municipality level in Europe is challenging due to variations in requirements and bureaucratic systems across countries. Data unavailability is always a barrier for researchers studying economic dynamics in European cities. The statistical office of the EU (Eurostat) maintains a territorial disaggregation at the LAU-2 or municipality level. This stands for local administrative units and is part of the nomenclature of territorial units for statistics (NUTS) classification system, i.e., $LAU2 \approx NUTS5$. Each EU member state divides its territory into LAU-2 units, corresponding to municipalities, cities, or towns.

The availability and accessibility of data at the LAU2 level can vary depending on the country and the specific datasets. However, obtaining comprehensive information at such a granular spatial level is challenging. Statistical agencies often prioritize collecting data periodically, such as once every few years or less frequently, depending on the country and the specific data set. This gives another argument why it is timely and necessary to use non-traditional data in this study. Unconventional data sources can address the main limitations and provide a dynamic and comprehensive understanding of the characteristics and changes across LAU2 areas. Figure 3.A.6 shows the spatial distribution of LAU2 entity area (km2). Having identical-sized spatial units makes it easier to ensure comparability across/within countries and draw valid statistical inferences. However, it is important to note that there can still be some variation in the size of LAU-2 units due to historical boundaries and population distribution.

Figure 3.2: Black Marble Tiles in the Schengen Area



Source: Author's own elaboration in QGIS based on Black Marble tiles.

Notes: Selected Schengen countries are - Austria (AT), Belgium (BE), Czechia (CZ), Estonia (EE), France (FR), Germany (DE), Hungary (HU), Italy (IT), Latvia (LV), Lithuania (LT), Netherlands (NL), Poland (PL), Portugal (PT), Slovakia (SK), Slovenia (SI), Switzerland (CHE) and Spain (ES).

Black Marble products consist of 460 non-overlapping worldwide land tiles, which measure the whole world approximately into a 10 degrees by 10 degrees grid[3]. Continental Europe covers 16 land tiles. we retrieved the spatial layers of the 16 tiles in shape-file format from the Black Marble server to create the raster map of the Schengen area. In Figure 3.2 , tiles corresponding to Europe are h17v02, h18v02, h19v02, h20v02, h17v03, h18v03, h19v03, h20v03, h17v04, h18v04, h19v04, h20v04, h17v05, h18v05, h19v05, h20v05 and they were extracted from the archives.

The initial Black Marble products are in Hierarchical Data Format (HDF5) version. This provides a flexible and efficient way to manage and access data, particularly in numerical applications. To work with the data in geographical statistical software such as ArcGIS & QGIS, we converted all data into TIFF file format through the Black Marble server tools. Converting the data to TIFF format ensures compatibility with the Geographic Information System (GIS) and enables

[3]To calculate the area of a grid cell, we use the following formula: Area of a grid cell = (latitude) * (longitude) * (cosine of the average latitude). Then the formula becomes the approximate area of 10 degrees by 10 degrees grid cell = (10 degrees) * (10 degrees) * 1 = 100 square degrees

me to leverage the rich set of geospatial analysis tools available in the GIS software applications[4]. Then finally, we retrieved the VNP46A3 database. The data provides moonlight and atmosphere-corrected composites of nighttime lights captured by the VIIRS satellite. The VNP46A3 dataset is specifically designed to address the challenges of observing nighttime lights in the presence of moonlight and atmospheric effects. It applies a lunar bidirectional reflectance distribution function (BRDF) correction to account for the variations in lunar illumination and incorporates atmospheric correction algorithms to remove atmospheric interferences. Thus the final data, the moonlight and atmosphere-corrected NTL composites from the VNP46A3 dataset, can be used for socioeconomic studies. The corrected composites provide a much more accurate representation of the distribution and intensity of artificial lights on the Earth's surface.

The final composites consist of 28 layers containing information on the radiance, the quality, categories of the different angles (i.e., near-nadir, off-nadir, and all angles), and snow status (snow-covered and snow-free). we retrieved and worked on two layers from the VNP46A3 composite product. The first layer is All Angle Composite Snow Free, which represents the temporal radiance composite using all observations during the snow-free period. The second layer corresponds to quality flags. The quality flags are associated with each pixel in a raster graphic image and provide information about the quality or reliability of the data captured by the sensor. These flags indicate certain characteristics that may affect the pixel's accuracy for further analysis. A quality indicator is a dummy variable that takes the value of one if pixels are good quality and zero if pixels suffer cloud contamination, sensor saturation, or missing data. After examining the aggregated quality flags, we found no significant pattern where certain quality flags are abnormal. This suggests that the pixels captured by the sensor are, on average, of good quality and do not exhibit consistent issues[5]. All data work is outlined in the Figure 3.A.1; the process has a graphical and textual representation.

And finally, we calculated NTL radiance in 89,849 municipalities in 17 Schengen countries. Raw (text) data of the NTL radiance at LAU-2 level is available upon request. we included in the sample countries that implemented the Schengen treaty in 1995: Austria, Belgium, France, Germany, Italy,

[4]The total size of TIFF files during the Q1 of 2020 is $\approx 64GB$.

[5]However, it is important to note that the absence of significant patterns could also be influenced by factors such as the sensor's calibration and data processing techniques. These factors ensure high-quality data and minimize systematic errors.

Netherlands, Portugal, and Spain - Old Member States. Countries that became members of the free zone in 2008 are Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, and Switzerland - New Member States. we excluded from the analysis small-sized Schengen member states, i.e., European microstates (less than a million population) - Liechtenstein, Luxembourg, Malta; Island countries (no land borders) - Iceland, Greece; Scandinavian countries (half-island states) - Finland, Sweden, Norway, Denmark. Considering the highly distinctive Covid management approaches undertaken by the latter countries, we exclude them from the dataset.

3.2 Interreg-A Cross Border Cooperation (CBC) Programs

After reviewing the initial analysis, we used additional data sources to examine mechanisms and channels. European Cross-Border Cooperation (CBC) programs, known as Interreg A, support cross-border initiatives such as sharing resources, developing infrastructure, and increasing collaboration across internal borders. The first ever CBC survey was conducted in 2015 among residents of border regions to gain insights into their lives and to understand the local community better. Approximately 40,000 respondents were classified into 56 CBC program units. By categorizing the respondents into CBC program units at the NUTS3 level, the survey aimed to identify regional variations in socioeconomic conditions, infrastructure development, resource sharing, and collaboration opportunities. The survey revealed interesting results, and in 2020, the second survey was conducted to get even more accurate information on cross-border areas [6].

[6] The survey was conducted between February and April 2020. The interviewers in the survey were highly trained so that all of the respondents' answers applied to a *COVID-free* situation, thus minimizing the measurements errors due to the pandemic.

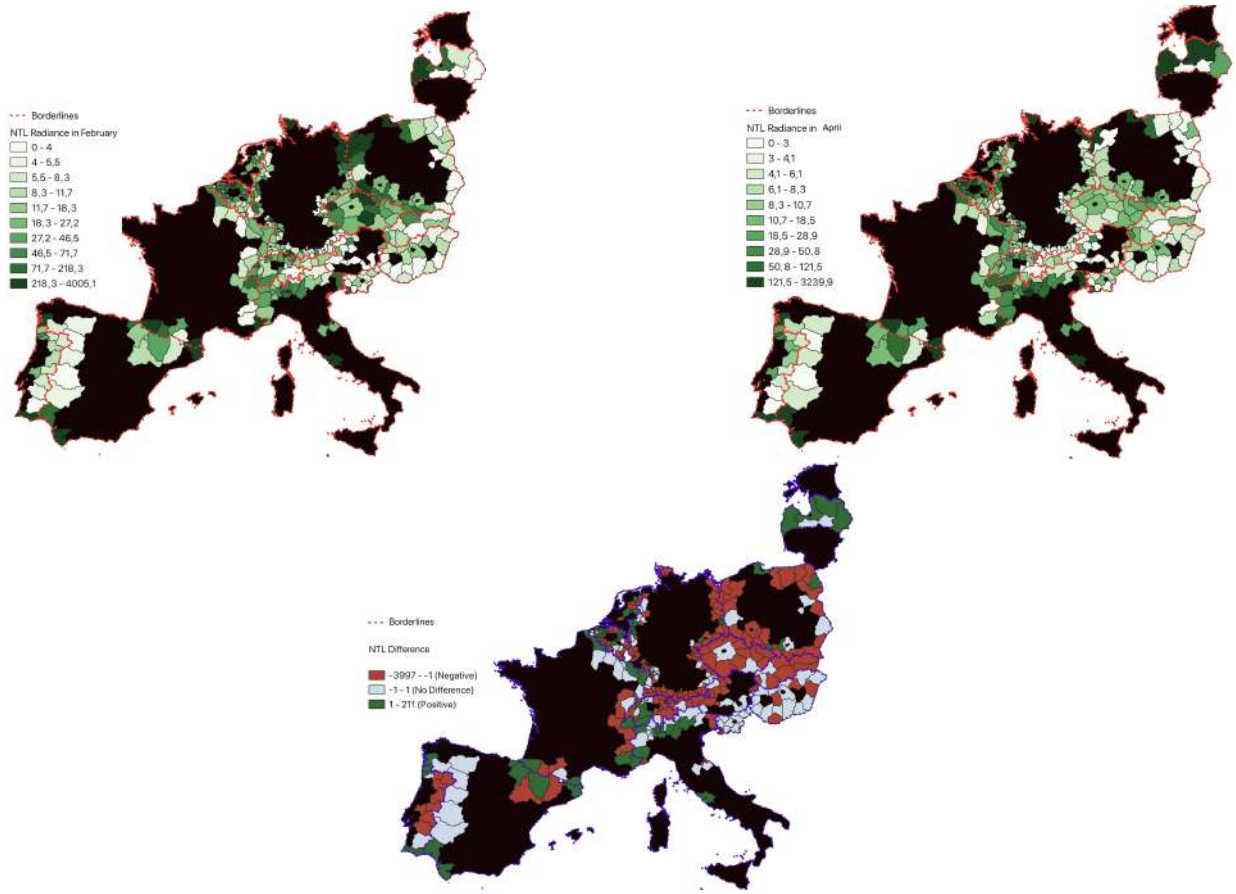
Table 3.1: The Interreg-A CBC Programs and Neighbouring Country Pairs

Interreg CBC Program/Country Pair	Border Enactment	Interreg CBC Program/Country Pair	Border Enactment
CB001 BE-DE-NL	March 14	CB029 Slovenia-Croatia	March 14
CB002 Austria-Czech Republic	March 12	**CB030 Slovakia-Czech Republic**	March 14
CB003 Slovakia-Austria	March 14	**CB031 Lithuania-Poland**	March 14
CB004 Austria-DE/Bavaria	March 11	CB032 SE-FI-NO	March 16
CB005 Spain-Portugal	March 16	**CB033 Italy-France**	March 14
CB006 ES-FR-AND	external border	**CB034 France-Italy**	March 14
CB008 Hungary-Croatia	March 12	**CB035 Italy-Switzerland**	March 13
CB009 DE/Bavaria-Czech Republic	March 14	**CB036 Italy-Slovenia**	March 14
CB010 Austria-Hungary	March 12	CB037 Italy-Malta	March 14
CB011 DE/Brandenburg-Poland	March 15	CB038 FR-BE-NL-UK	external border
CB012 Poland-Slovakia	March 16	**CB039 FR-DE-CHE**	March 14
CB013 PL-DN-DE-LI-SE	March 16	CB040 France-United Kingdom	external border
CB014 FI-EST-LV-SE	Marrch 16	**CB041 France-Switzerland**	March 13
CB015 Slovakia-Hungary	March 12	CB042 Italy-Croatia	March 12
CB016 Sweden-Norway	March 16	**CB044 Belgium-France**	March 20
CB017 DE/Saxony-Czech Republic	March 14	CB045 FR-BE-DE-LUX	March 16
CB018 Poland-DE/Saxony	March 15	**CB046 Belgium-The Netherlands**	March 20
CB019 Germany-Poland	March 15	CB047 United Kingdom-Ireland	external border
CB020 Greece-Italy	March 12	CB048 United Kingdom-Ireland	external border
CB021 Romania-Bulgaria	external border	CB049 Hungary-Romania	external border
CB022 Greece-Bulgaria	external border	**CB050 Estonia-Latvia**	March 14
CB023 Germany-The Netherlands	March 14	**CB052 Italy-Austria**	March 11
CB024 DE-AT-CHE-LI	March 14	**CB053 Slovenia-Hungary**	March 12
CB025 Czech Republic-Poland	March 16	**CB054 Slovenia-Austria**	March 11
CB026 SE-DE-NO	March 16	CB055 Greece-Cyprus	external border
CB027 Latvia-Lithuania	March 16	CB056 Germany-Denmark	March 12
CB028 SE-FI-NO	March 16	PC001 Ireland-United Kingdom	external border

Notes: Author's own elaboration based on cross-border cooperation programs and information about member states' notifications of the temporary reintroduction of border control at internal borders pursuant to Article 25 and 28 et seq. of the Schengen Borders Code (Europeia, 2022). This study covers internal border areas along Schengen countries: Austria, Belgium, Czechia, Estonia, France, Germany, Hungary, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Slovakia, Slovenia, Switzerland, and Spain.

Although the 2015 CBC survey has a mass of information, it has a salient drawback that can hamper researchers from analyzing respondents' answers deeply (Decoville and Durand, 2019). The first is the need for granularity. While respondents were classified into CBC program units, the program-level classification does not provide enough spatial granularity. Researchers could not examine localized variations and characteristics (e.g. it was possible only at the program level).

Figure 3.3: Spatial Distributions of Monthly Averaged NTL Luminosity



Notes: Author's own elaboration based on remotely sensed VIIRS nightlights data and GISCO shapefiles.

Map (a) shows NTL radiance in cross-border NUTS3 regions before the border control.

Map (b) depicts the NTL after the border controls.

Map (c) illustrates the monthly difference (i.e., $\triangle NTL_i = NTL_{i,after} - NTL_{i,before}$) in the luminosity.

The second limitation was the limited scope of questions available in the survey. The survey had two ways in which questionnaires had improved: enhanced granularity and expanded scope of questions. In the 2020 survey, information on the respondents' regional identifiers at the NUTS3 level became available. This allows me to have information on respondents' attitudes and activities in cross-border sub-regions. The second extension was to have information on territorial typologies, i.e., if respondents lived in villages, small cities, or large cities. By incorporating information about respondents' settlement types, the CBC survey gained an additional layer of analysis about cross-border dynamics.

During the first wave of the pandemic in 2020, one country's border controls were followed by border restrictions in another country. Table 3.1 gives detailed information about the dates of border controls along 56 CBC areas, including the internal and external European borders. For example, if country A's border had been closed and A's neighboring country B had not enacted border restrictions yet, we still count this as a border enactment. For example, Austria closed the border officially on March 12th and then Slovakia on March 14th, so we count that on March 12th, the border between the two countries had been closed in response to the pandemic. As the virus spread around Europe, countries introduced border controls in a domino effect mode.

For the initial descriptive and motivational purpose, we merged the CBC survey to the NTL dataset and calculated the spatial distribution of monthly averaged NTL radiance before and after the enactment of border controls across CBC cooperation areas. we conducted the raster calculation to generate monthly differences, which are defined as follows:

$$\triangle NTL_i = NTL_{i,after} - NTL_{i,before}$$

Where $\triangle NTL_i$ is the monthly difference in luminosity in the cross-border region i, $NTL_{i,after}$ is the monthly averaged luminosity after the border controls in area i, and $NTL_{i,before}$ is the monthly averaged luminosity before the border controls in region i.

Graphical inspection in Figure 3.3 clearly shows that NTL luminosity decreased in cross-border areas after the border controls came into force in March. The sole plausible justification for such outcomes is decreased economic activities. An explanation based on people's movement is invalid due to data-related constraints. First, the approximate time Suomi NPP VIIRS satellite nightly overpass is ca. 1:30 am local time. The Suomi NPP VIIRS sensor can capture stable lights, such as those produced by cities, towns, and other permanent artificial lighting sources. It can detect the intensity of light emitted by streetlights, buildings, industrial regions, and other infrastructure that contribute to the consistent illumination of the nighttime. However, if a movement of people does not result in significant changes in the intensity of artificial lighting in an area, it may not be captured by satellite sensors. These sensors are suited to capturing and monitoring stable sources of artificial lighting[7]. Second, it is true that car lights, including headlights and taillights, can be captured by VIIRS, but only if they are bright enough to be detected from space and *not in motion*.

[7]Otherwise, the monitoring of human movements and displacements is complex and often requires multiple sources of data, such as surveys, census data, mobile data, and other types of data collection and analysis.

Third, displacement is more likely to occur during the day or earlier in the evening than 1:30 am. And fourth, during the late-night hours, most people are typically asleep, and the presence of lights captured in satellite imagery can only indicate ongoing economic activity; if lights are still visible at that time, it suggests that there is likely an active and operating economy.

4 Empirical Strategy and Results

To investigate the hypotheses discussed in the previous section, we use a difference-in-differences methodology by comparing the economic performance of border municipalities (treatment group) to interior municipalities (control group)[8] before, during, and after lockdowns. Consequently, we focus on the differential impact of lockdowns on economic activity, measured through nightlight intensity. Let NTL_{it} be the nightlight intensity in region i at time t, and our baseline empirical specification is as follows:

$$NTL_{it} = \alpha + \beta Border_i + \gamma(Border_i \times Lockdown_t) + d_t + D_C + \epsilon_{it}, \tag{9}$$

where NTL_{it} represents nightlight intensity in municipality i at time t, $Border_i$ is a dummy variable equal to 1 if unit i is a border municipality and 0 otherwise, and $Lockdown_t$ is a dummy equal to 1 if a lockdown is in effect at time t. The interaction term $(Border_i \times Lockdown_t)$ captures the differential effect of lockdowns on border municipalities relative to interior municipalities. If the coefficient γ is significantly negative, it would confirm that border municipalities suffered a disproportionately higher reduction in economic activity during lockdowns. The term d_t represents a set of time fixed effects, D_C is a set of country dummies, and ϵ_{it} is the error term.

In Table 1, our results show that nightlight luminosity declined by approximately 12% in border municipalities relative to interior municipalities during the initial COVID-19 border restrictions. we conduct a comparative analysis to gain a deeper understanding of the differences between Eastern and Western border regions after implementing border restrictions. The results in Table 1 show that

[8]Oftentimes, border regions are defined as treated and interiors as a control group in the European integration and border studies - primarily at NUTS3 level (Mitze and Breidenbach, 2018; Niebuhr, 2008; Braakmann and Vogel, 2011) and at NUTS2 level (Wassmann, 2016), and hardly ever at the cities' level (Brakman et al., 2012; Heider, 2019; Brülhart et al., 2018)

there is a substantial decline in NTL in Eastern border municipalities relative to interiors, and it is roughly 30%. However, the decline in Western border municipalities is just 6%. This implies that the negative externalities due to border controls in Eastern border municipalities were much larger than in Western border municipalities. Moreover, the disparity remains notably adverse even when combining both categories of municipalities within a single regression analysis. It is important to highlight that the negative difference cannot be attributed to municipalities located near the borders of non-European countries such as Russia, Belarus, and Russia, as these borderlines were closed after World War II, making them unaffected by the Covid-related border restrictions.

An important potential mechanism influencing the impact of border restrictions is agglomeration size, which has been extensively examined in the context of border easing but remains underexplored in the context of border closures. Previous studies, such as Redding and Sturm (2008) and Brülhart et al. (2018), have shown that small towns tend to be more responsive to integration processes, such as the fall of the Iron Curtain, compared to larger municipalities. In contrast, Brakman et al. (2012) suggests that larger European cities play a more dominant role in the long-term process of economic integration. If municipality size significantly shapes the dynamics of integration, it is reasonable to expect that it also influences the effects of temporary border closures.

While larger municipalities may face substantial disruptions due to their higher population densities and economic interdependencies, our findings, as presented in Table 1, indicate that smaller border towns were disproportionately affected by border restrictions during the pandemic. Specifically, small border municipalities experienced an approximately 7% greater decline in nighttime luminosity compared to large non-border municipalities. Several factors could explain why smaller towns were more severely impacted.

Table 2: The effects of border controls on VIIRS NTL luminosity

	(1)	(2)	(3)	(4)
	Log(NTL)	Log (NTL)	Log (NTL)	Log(NTL)
Lockdown	-0.155***	-0.161***	-0.0597***	-0.0126***
	(0.002)	(0.002)	(0.011)	(0.00310)
Lockdown× Border	-0.121***	-0.066***	-0.287***	
	(0.0029)	(0.003)	(0.011)	
Lockdown × Border × Small municipality				-0.0755***
				(0.00634)
Month Fixed Effects (Q1)	✓	✓	✓	✓
Municipality Fixed Effects	✓	✓	✓	✓
Constant	✓	✓	✓	✓
N	338,404	274,852	63,552	338,404
Adjusted R^2_{within}	0.116	0.125	0.117	0.133
Countries	All	Old Members	New Members	All

Notes: Fixed-Effects model. Robust standard errors are presented in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

First, small towns often rely heavily on tourism and cross-border trade, both of which were severely disrupted by border restrictions. Many of these towns serve as regional commercial hubs where economic activity depends on daily or frequent movement across the border. The closure of borders significantly curtailed visitor inflows, disrupted supply chains, and reduced demand for local services, leading to sharper economic downturns. Unlike larger municipalities with more diversified economies, small towns have fewer alternative industries to cushion the impact of such shocks. Second, transportation constraints further exacerbated the effects of border closures on small towns. Unlike major metropolitan areas, which have well-developed transportation networks, small towns often have limited connectivity, fewer international flights, and fewer direct transportation routes. When travel restrictions were imposed, these towns became even more isolated, making it more difficult for residents and businesses to adapt to new economic conditions. Third, many small towns located near international borders have historically strong cross-border linkages, often functioning as twin municipalities or historically unified communities (e.g., Gubin, Poland & Guben, Germany). These towns depend heavily on cross-border labor mobility, shopping, and economic exchanges. The abrupt imposition of border controls disrupted long-standing economic and social ties, disproportionately affecting local businesses and households that depend on cross-border interactions. In sum, while larger municipalities may have faced significant challenges due to their dense populations and complex economic structures, the disproportionate economic impact on small border towns highlights the importance of considering agglomeration size when analyzing the consequences of temporary border restrictions.

5 Additional Analysis and Discussion

The estimation results outlined in the previous section suggest that border restrictions negatively impacted the night-time lights (NTL) of border municipalities, particularly in smaller border municipalities. Our analysis demonstrates that the effects of border restrictions on municipalities are heterogeneous within the treated group, with variations depending on municipality size and geographical proximity to the border.

In this section, we take a closer look at border areas to provide a more detailed understanding of these effects and explore additional reasons why their impact may be even more heterogeneous[9]. Given that our previous findings identified small municipalities as the most vulnerable, this section is dedicated to analyzing them in greater detail. In the Appendix, Figure 3.B.1 illustrates that approximately 80% of respondents in the 2020 CBC survey lived in rural or small municipalities, while only 20% resided in urban or large municipalities. Moreover, the CBC survey is particularly relevant for this analysis because it primarily focuses on small municipalities.

[9]By focusing on border areas, we capture the unique challenges these regions faced due to border restrictions. This localized analysis offers a more nuanced perspective on the impacts and enables targeted policy interventions to address the specific needs of border communities during the pandemic.

Table 2: The effects of border controls on VIIRS NTL: cross-border mobility

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lockdown	-0.498***	-0.332***	-0.351***	-0.319***	-0.241***	-0.281***	-0.538***
	(0.0132)	(0.00600)	(0.00693)	(0.00429)	(0.00724)	(0.00551)	(0.0123)
Lockdown × Visit Family	-0.00319	0.241***					
	(0.0374)	(0.0316)					
Lockdown × Visit Friends	0.151***		0.266***				
	(0.0338)		(0.0272)				
Lockdown × Use Public Service	0.0318			0.237***			
	(0.0374)			(0.0320)			
Lockdown × Shopping	-0.286***				-0.128***		
	(0.0194)				(0.0165)		
Lockdown × Business Purposes	-0.0729*					-0.0692*	
	(0.0309)					(0.0305)	
Lockdown × Leisure Activities	-0.486						-0.406***
	(0.0222)						(0.0196)
Month Fixed Effects (Q1)	✓	✓	✓	✓	✓	✓	✓
Municipality Fixed Effects	✓	✓	✓	✓	✓	✓	✓
Constant	✓	✓	✓	✓	✓	✓	✓
N	128872	128872	128872	128872	128872	128872	128872
Adjusted $R^2{}_{within}$	0.131	0.125	0.125	0.124	0.124	0.124	0.128

Notes: Fixed-Effects model. Robust standard errors are presented in parenthesis
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Studying the factors behind the cross-border movement of people from border regions to foreign countries is crucial for understanding why one particular border municipality may be affected less than another. Therefore we construct and define variables to reflect why people travel to border regions. The CBC survey question is worded as follows: How often do you go to a foreign area (sharing the same borderline) for each of the following reasons? (i) To visit family (ii) To visit friends (iii) To use public services (e.g., health or education services) (iv) To shop for goods or services (e.g., buying clothes or visiting a hairdresser) (v) For work or business purposes (vi) For leisure activities including tourist visits[10].

[10]CBC survey is conducted at the NUTS3 level, and we have constructed sub-groups based on respondents' responses. It is reasonable to assume that these sub-categories can also correspond to the municipality level within the NUTS3

In Table 2, our findings indicate that when the primary reasons for cross-border mobility are visiting family and friends or accessing public services, border restrictions had little to no economic impact. There are several possible explanations for this. First, cross-border travel for personal visits or public services does not typically involve significant economic spending. For instance, visiting family and friends is largely a personal expense rather than an economic transaction that would be reflected in NTL luminosity or other economic indicators. Second, in regions where essential public services such as healthcare, education, or government facilities are readily available, the restrictions on cross-border mobility may have had minimal economic consequences. When individuals can access similar services within their own country, the economic loss due to border restrictions is likely to be negligible.

By contrast, our analysis demonstrates that restrictions on cross-border mobility negatively affected economic indicators, including NTL luminosity, particularly when mobility was driven by leisure and tourism, shopping, or work and business purposes. First, cross-border restrictions significantly disrupted the tourism and leisure industry, which depends on international visitors. Tourism supports local economies through spending on accommodations, restaurants, transportation, attractions, and related services. A decline in tourist arrivals due to border closures led to reduced economic activity and lower NTL luminosity in regions reliant on tourism. Second, some areas heavily depend on cross-border shopping, where consumers travel to a neighboring country for better prices, tax advantages, or product availability. Restricting cross-border movement disrupted this consumer behavior, leading to a decline in retail spending and affecting local businesses. As a result, economic activity fell, leading to a decrease in NTL luminosity in regions with strong cross-border shopping flows. Third, cross-border mobility is essential for employment and business activities, including commuting, business transactions, and work-related travel. Restrictions on mobility disrupted these economic interactions, reducing productivity and business activity. In regions where cross-border economic interactions play a crucial role, the decline in work and business-related mobility contributed to lower NTL luminosity, reflecting broader economic downturns.

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regions. This assumption allows for a more granular analysis and understanding of the factors influencing migration within specific municipalities. Each sub-group was constructed independently based on respondents' responses. we have calculated the share in each group at the NUTS3 level.

6 Conclusion

Since the expansion of the Schengen Area, the border restrictions imposed during the COVID-19 pandemic were the most severe ever experienced, temporarily reversing decades of economic integration. Using NASA's Black Marble Nighttime Lights data, this paper evaluates the economic cost of these restrictions at a granular level. Several key findings emerge from the analysis.

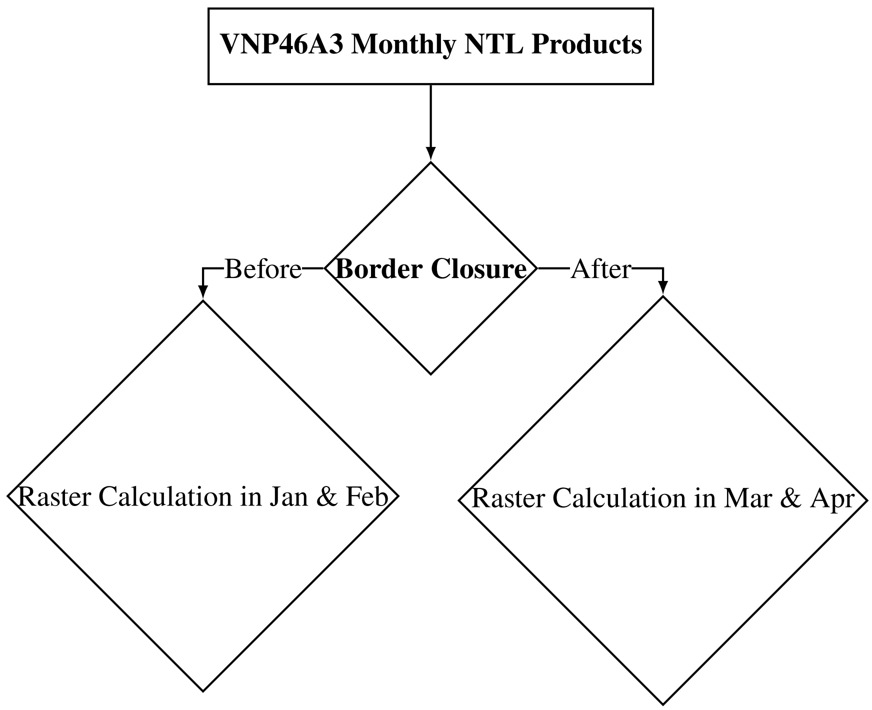
First, the impact of border controls was highly uneven across municipalities. Border municipalities, particularly small ones, suffered greater economic losses compared to interior municipalities. Moreover, the decline in NTL radiance was significantly larger in the border municipalities of New Member States than in those of Old Member States, reflecting differences in economic resilience and integration levels.

Second, municipalities dependent on economic-oriented cross-border mobility, such as shopping, business, and leisure activities, experienced the most severe economic losses. In these areas, border closures directly restricted consumer access to foreign markets, particularly in regions where price differences, product availability, or tax advantages made cross-border shopping a key economic driver. The lack of viable domestic substitutes led to significant reductions in nighttime lights (NTL), reflecting a sharp decline in retail activity, tourism, and business transactions. The impact was especially pronounced in municipalities where local economies were heavily integrated with foreign consumer markets, demonstrating their vulnerability to external shocks. In contrast, municipalities reliant on social-oriented cross-border mobility, such as visits to family, friends, and public services, were less affected. These activities often had stronger local substitutes, such as domestic healthcare, education, and social networks, allowing residents to adapt without substantial economic losses. The weaker or negligible NTL reductions in these areas suggest that border closures primarily disrupted social interactions rather than essential economic transactions. Overall, this study demonstrates that even short-term border closures can have significant economic consequences for border municipalities. The disproportionately larger impact on New Member States suggests important policy implications, highlighting the need for targeted policies to support economic recovery in border regions, particularly in countries where the integration process is still evolving. Policies aimed at strengthening cross-border economic resilience and facilitating deeper regional integration should be prioritized.

This paper also opens avenues for future research. As border restrictions were temporary, further studies could explore which municipalities recovered quickly and which faced prolonged economic setbacks. Additionally, other dimensions of border control policies, such as their effects on housing prices, business dynamism, and spatial shifts in economic activity between residential and commercial areas, worth for further investigation.

7 Appendix A: NASA Black Marble Processing

Figure 3.A.1: Data Processing



Notes: The overall workflow of NTL data before and after the border controls during the COVID-19 pandemic using NASA's Black Marble monthly products. The data retrieval process, as described below, involves several steps:

- *Downloading h5 Files:* The first step involves downloading h5 files for the 16 land tiles. These files were downloaded for the months of January, February, March, and April.
- *File Format Conversion:* In the second step, the 64 product files' format are converted to TIFF format. This conversion allows for compatibility and ease of processing in subsequent steps.
- *Merging Tiles:* The third step involves merging the individual land tiles into a single layer that represents the entire region of Europe. This merged layer combines the data from the previously converted TIFF files.
- *Adding Shape Files and Zonal Statistics:* In the fourth step, shape files of the LAU-2 spatial level are added to the merged layer.

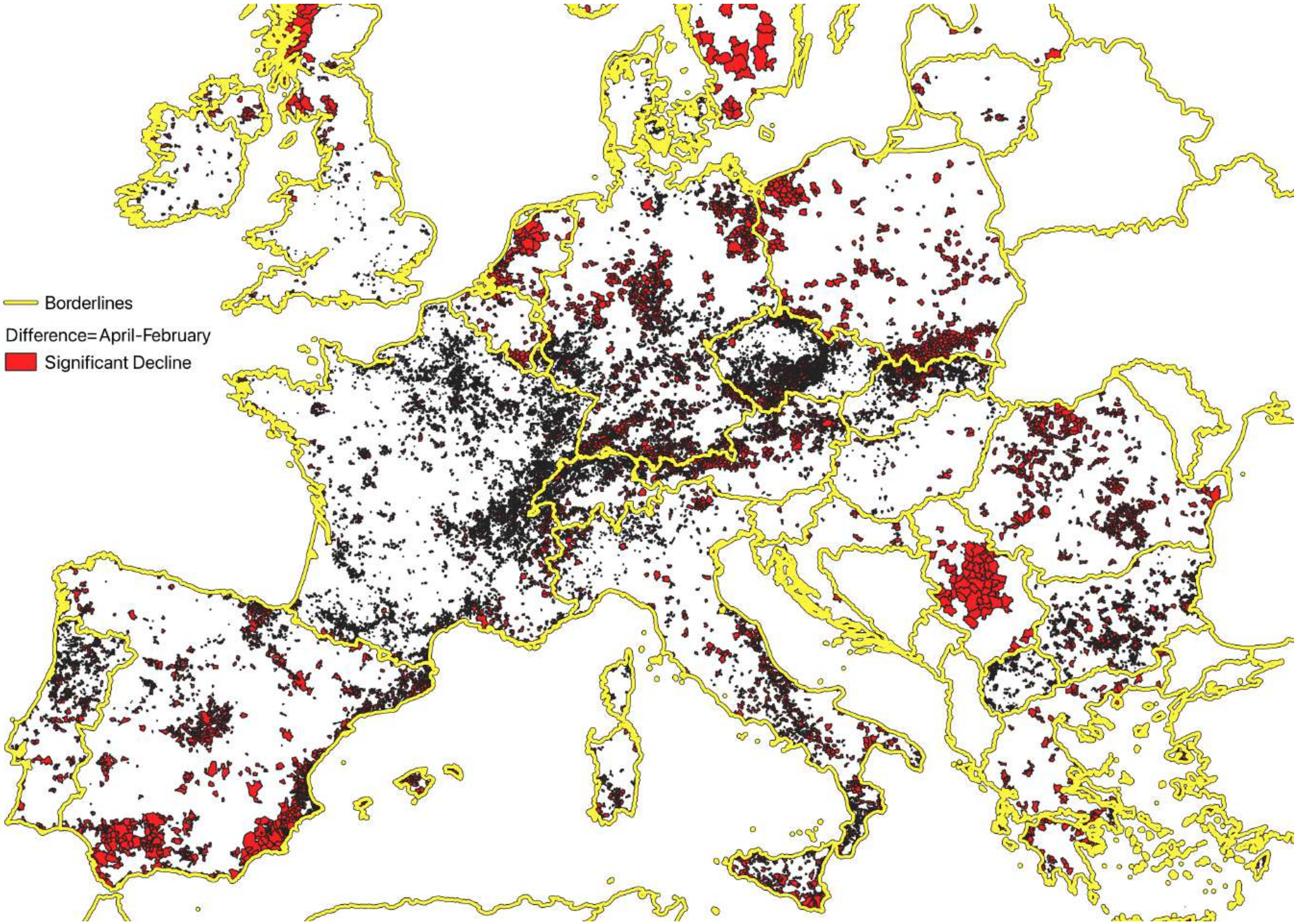
Table 3.A.1: Descriptive Statistics of log[NTL+($\approx$ 0.001)] in February, 2020

Countries	LAU-2	Mean	SD	Min	Max
OMS - West					
AT	2100	1.764462	1.1219	0	7.143505
DE	11160	1.735669	1.281327	0	10.3973
ES	7991	1.781889	1.473215	0	8.00765
FR	35775	1.446495	1.394471	0	9.298748
IT	8003	3.13918	1.24129	.059157	9.301953
PT	2882	2.921992	1.423006	0	9.715172
BE	589	3.714317	1.107357	1.322403	7.117976
LU	105	3.399937	.9657596	2.014249	7.295933
NL	390	4.065071	1.917735	.2911244	10.95112
NMS - East					
CZ	6258	1.940798	1.482806	0	10.8453
PL	2478	2.115067	1.677914	0	9.746455
SK	2927	1.357514	1.106135	0	8.694381
HU	3155	1.073345	.8801249	0	7.202508
SI	212	1.72807	.9074985	0	5.046938
EE	213	1.198067	1.522058	0	6.1257
LT	527	1.082879	1.622757	0	7.920162
LV	119	1.150955	1.472138	.0045958	5.716861
Total	84884	1.800253	1.485371	0	10.95112

Table 3.A.2: Descriptive Statistics of log[NTL+($\approx$ 0.001)] in April, 2020

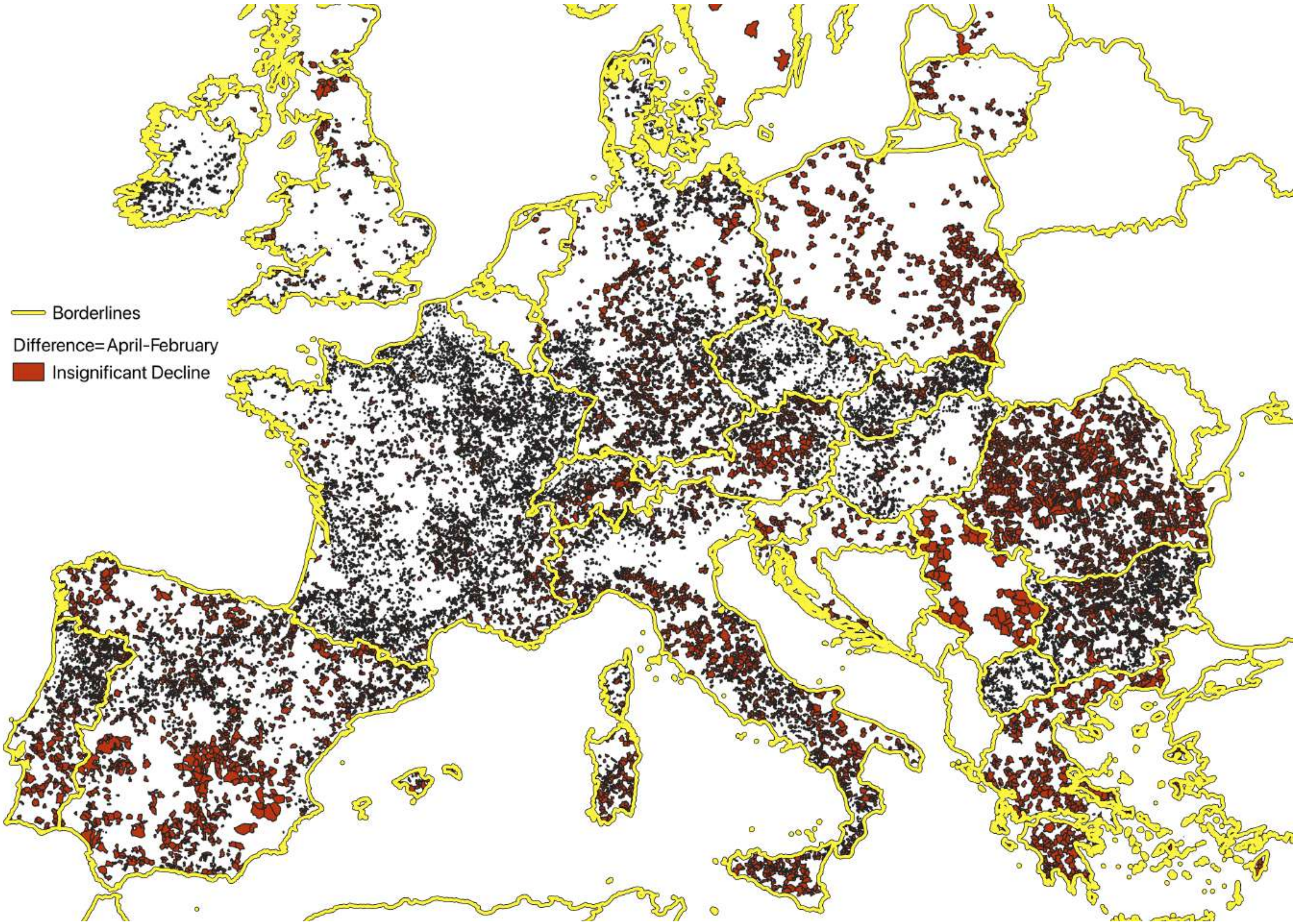
Countries	LAU-2	Mean	SD	Min	Max
OMS - West					
AT	2100	1.517459	1.15729	0	6.345119
DE	11160	1.439356	1.163355	0	7.776486
ES	7991	1.68191	1.530335	0	8.16815
FR	35775	1.290988	1.487559	0	9.298672
IT	8003	3.115321	1.303362	.0273241	9.341333
PT	2882	2.857564	1.500629	0	9.886707
BE	589	3.785746	1.095681	.5319132	7.027092
LU	105	3.334347	.9840552	1.878582	5.871408
NL	390	4.024683	1.830927	.2409158	10.94152
NMS - East					
CZ	6258	1.45786	1.092941	0	5.783825
PL	2478	1.845369	1.429313	0	8.11095
SK	2927	1.008953	1.083937	0	6.748408
HU	3155	1.005199	.8927955	0	5.598272
SI	212	1.716657	.9361971	0	4.868653
LT	527	1.014831	1.651084	0	6.678394
LV	119	1.718844	2.014665	.014045	7.895646
Total	84884	1.621624	1.514629	0	10.94152

Figure 3.A.2: Spatial Distribution of Negative Significant Changes



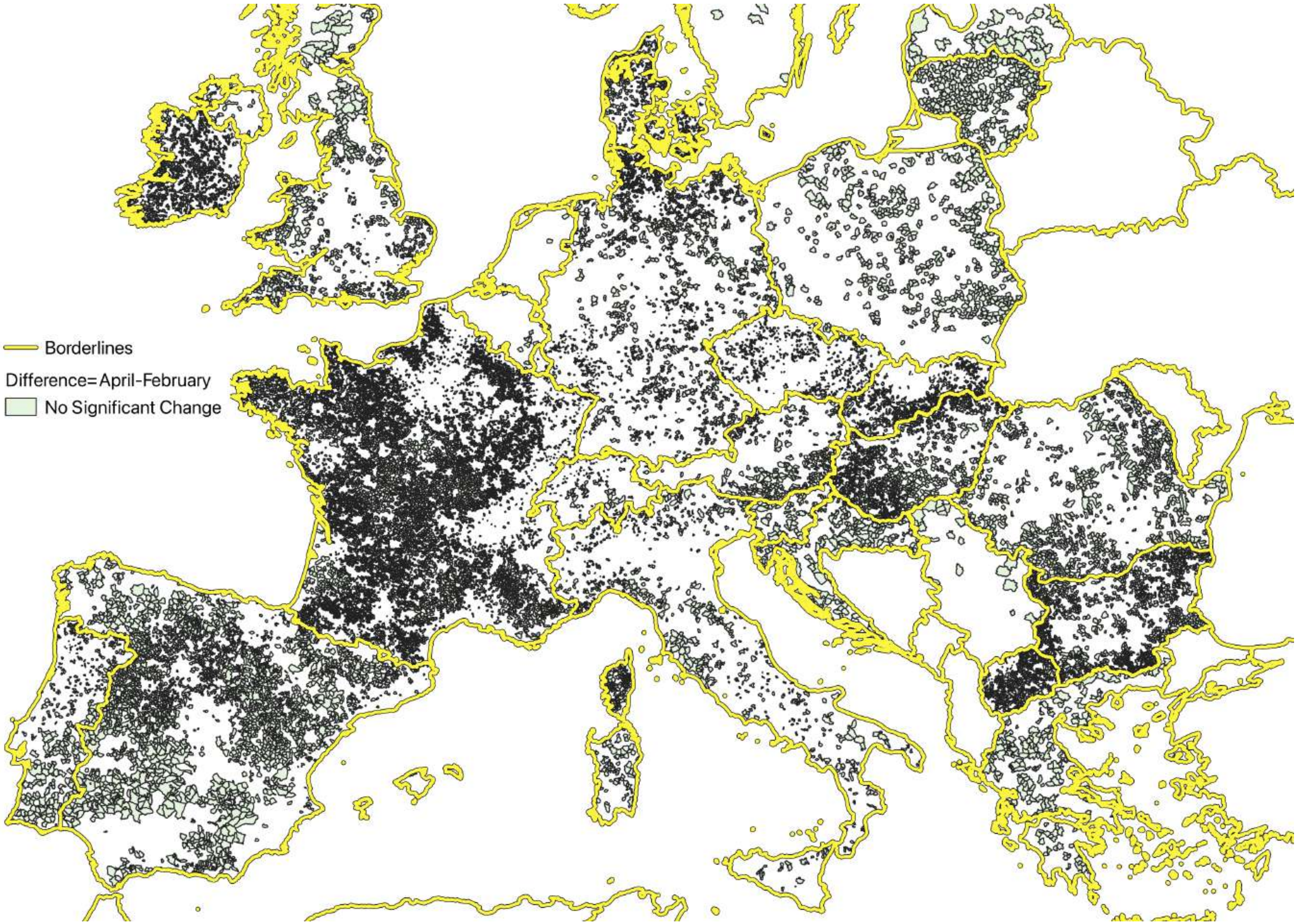
Notes: Author's own elaboration in QGIS based on Eurostat statistics and the GISCO shapefiles.

Figure 3.A.3: Spatial Distribution of Insignificant Negative Changes



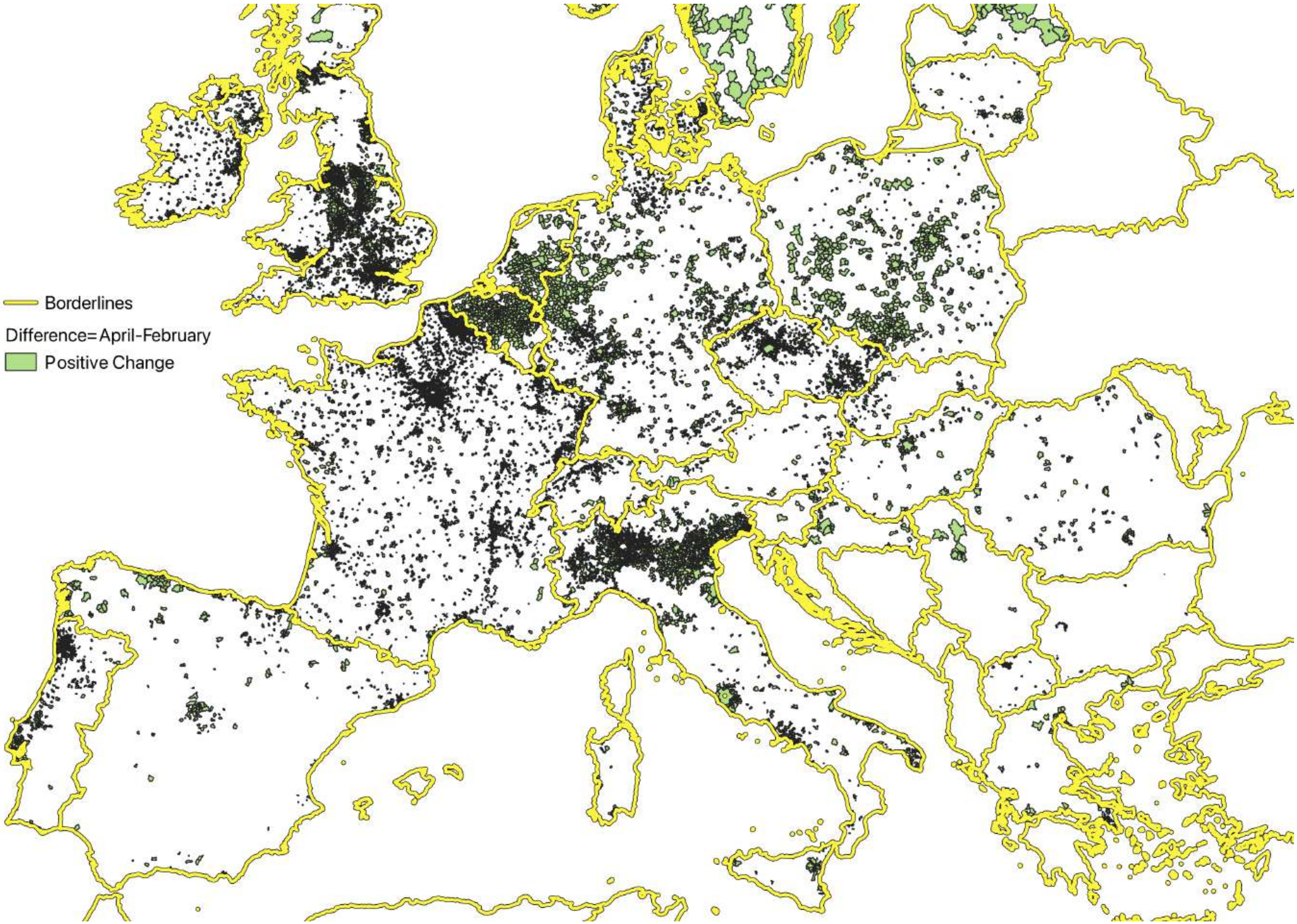
Notes: Author's own elaboration in QGIS based on Eurostat statistics and the GISCO shapefiles.

Figure 3.A.4: Spatial Distribution of Insignificant Changes



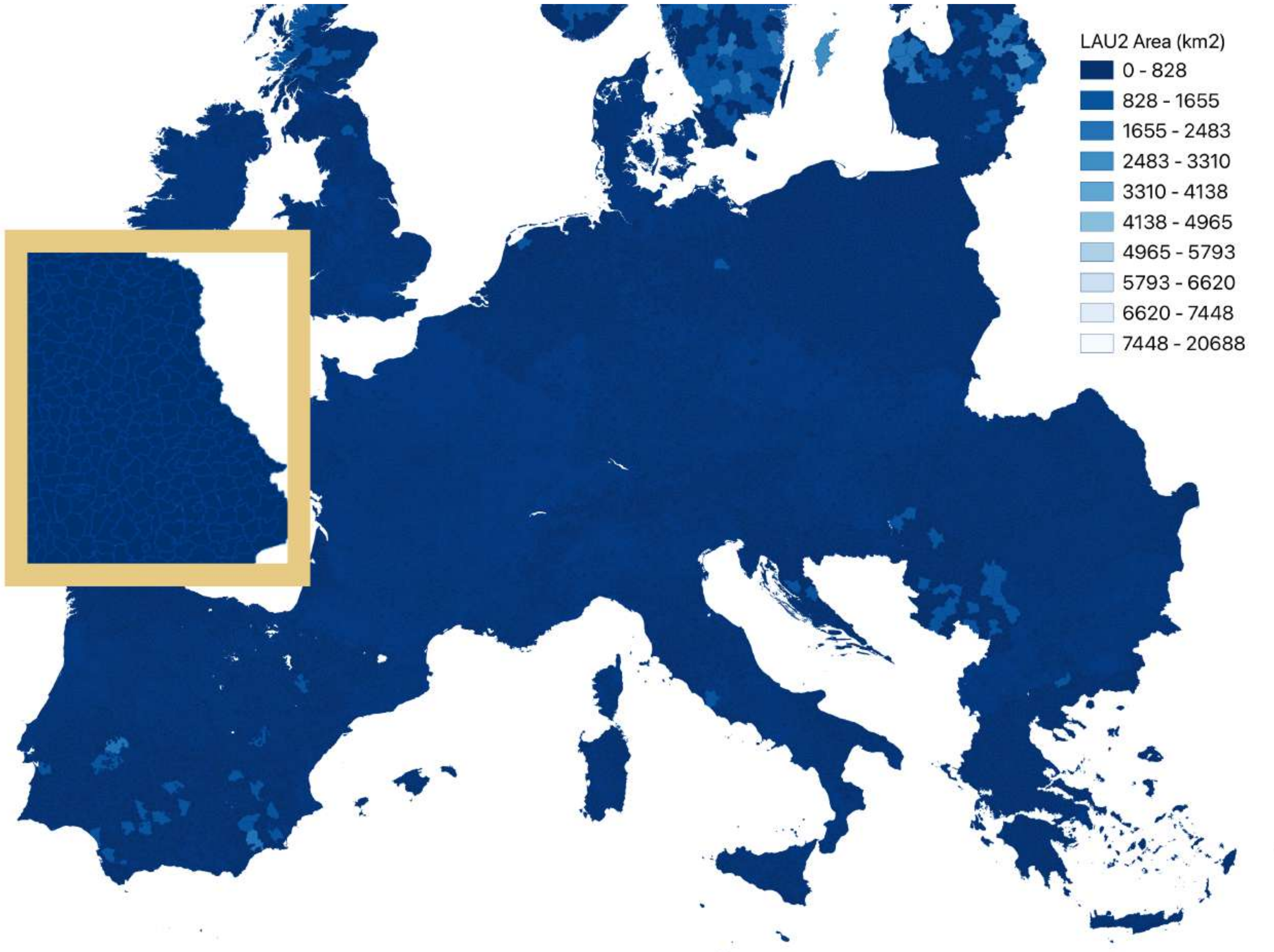
Notes: Author's own elaboration in QGIS based on Eurostat statistics and the GISCO shapefiles.

Figure 3.A.5: Spatial Distribution of Positive Changes



Notes: Author's own elaboration in QGIS based on Eurostat statistics and the GISCO shapefiles.

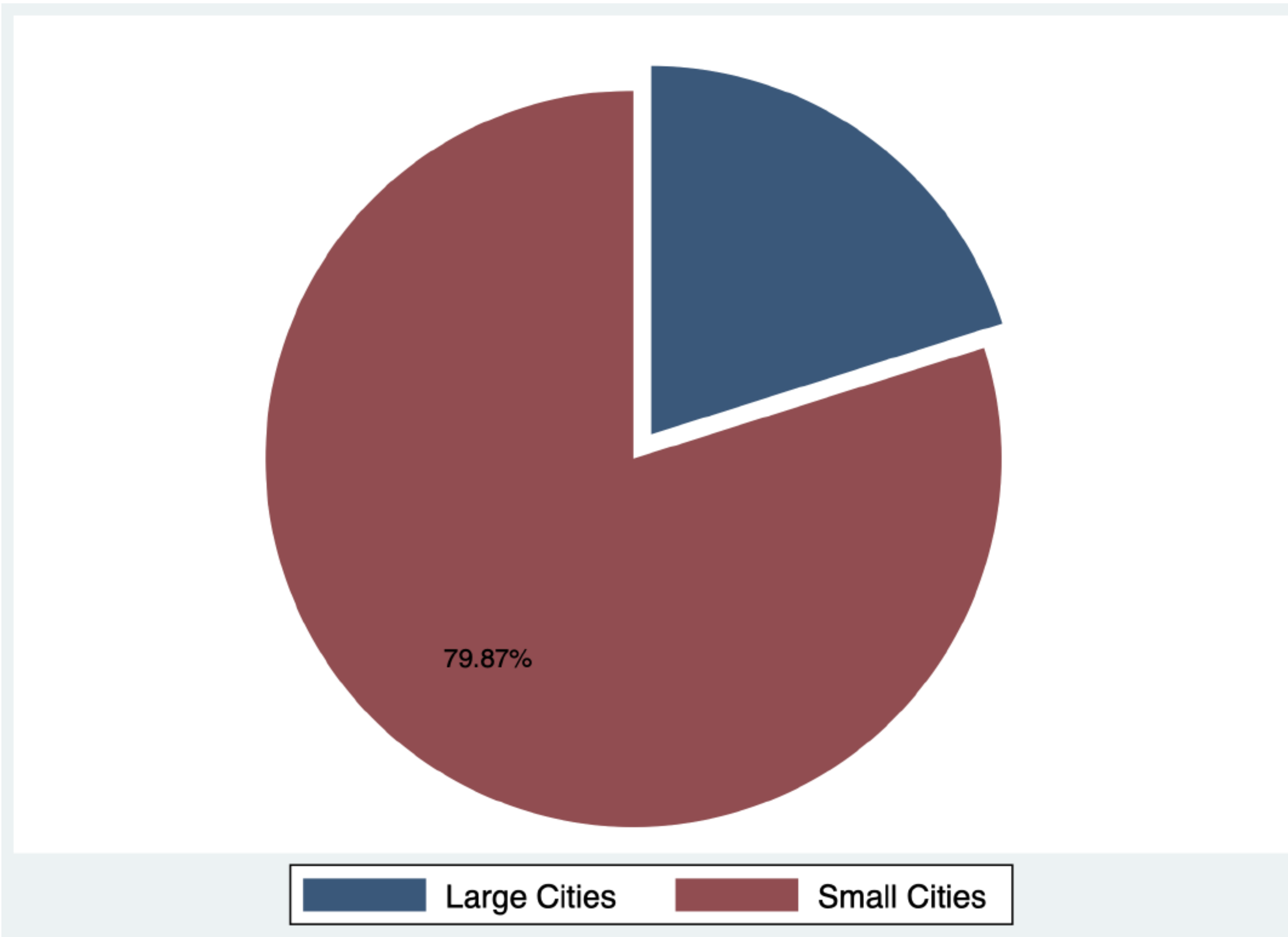
Figure 3.A.6: Spatial Distribution of Geographical Area (km2)



Notes: Author's own elaboration in QGIS based on Eurostat statistics and the GISCO shapefiles.

7.1 Appendix B: Cross Border Cooperation survey

Figure 3.B.1: Respondents living in large and small cities according to the CBC survey



Notes: Author's own elaboration based CBC survey in 2020.

Table 3.B.1: **Cross Border Mobility**[a]

How often?					
		Once a month or more often	Several times a year	Once a year or less often	Never
1	To visit family	1	2	3	4
2	To visit friends	1	2	3	4
3	To use services	1	2	3	4
4	To shop	1	2	3	4
5	To work	1	2	3	4
6	To leisure	1	2	3	4

[a] Q2 How often do you go to [COUNTRY FROM PROGRAMME] for each of the following reasons?

7.2 Appendix C: Supplementary

Figure 3.C.1: A temporary border barrier in France

Source: Photo by Thierry Thorel

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