Effect of COVID-19 Border Closures on Domestic Trade Patterns

A Spatial Autoregressive Approach to Estimate the Response of Colombian Trucking Flows

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Abstract

In this paper, I analyze and quantify the effects of exposure to international trade by considering the response in trade flow dynamics that took place within the Colombian domestic trucking network following the spread of COVID-19 and the implementation of spread-mitigation policies. This research topic is important because studying the effects of a transition to relative autarky (a no-trade-situation) for an entire country is one that is traditionally difficult to analyze, as most countries that engage in trade continue to do so in perpetuity. Using data on Colombian trucking for 2019 and 2020 along with geospatial trade exposure characteristics data, I implement a panel-data spatial autoregressive (SAR) model estimation to study how trade exposure affected the response of Colombian domestic trucking flows, measured as the value of goods traded between municipalities, to COVID-19 spread mitigation policies. Overall, the results indicate that accounting for spatial autocorrelations is important when conducting trade flow analyses. Additionally, the results indicate that the trading role of the municipality prior to COVID-19 did influence how a municipality was affected by COVID-19 and the spread-mitigating policies.

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Contents

1 Introduction

The socioeconomic impacts of the COVID-19 pandemic on countries around the world has been immense. To slow the propagation of global contagion, many national governments imposed strict border closures, in addition to other measures. This provides a unique opportunity to analyze the structure and response of domestic society and markets to sudden and complete disconnection from international markets. Using a novel dataset containing granular information on truck-based trade in Colombia, I look at how trans-municipal trade flows changed following the abrupt shift to autarky by observing trucking behavior before and after Colombia's implementation of border closures and other national-level COVID-19 spread-mitigating policies in March 2020. Colombia has a diverse and rugged geographic profile across its 1123 municipalities, which influence the structure of its domestic trade network, including snow-capped volcanoes of the Andes mountains, tropical beaches along both the Gulf of Mexico and the Pacific Ocean, arable croplands, to dense forests and wetlands surrounding the Amazon River basin. While these geospatial factors likely affected Colombia's domestic trade flows before COVID-19, the sudden shift to near-autarky[1] increased the importance of domestic trade and, by direct extension, the salience of geospatial factors' effects on trade patterns.

In this paper, I investigate the connection between geospatial factors and trade exposure on the trade patterns of Colombian municipalities following the implementation of COVID-19 spread-mitigation measures in March 2020. I construct a trade exposure measure that inte-

[1] Though Colombia did close its borders, limited trade of emergency and medical necessities continued as the country relied on imported PPE goods to address the pandemic.

grates key geospatial characteristics of Colombian municipalities and compare them across observed changes in freight trucking patterns. Trucking is representative of the internal dynamics of Colombia's domestic trade as it accounts for approximately 81% of all cargo trade in Colombia, with rail and inland river transport accounting for the rest of domestic freight transport (Arellana et al., 2020).[2] Table A.1 contains a breakdown of relevant trends in Colombia's domestic cargo from 2017 to 2019.

This paper makes three contributions to the literature. First, given the interconnectedness of countries and the magnitude of the COVID-19 pandemic, modeling the impact of sharp disconnections from international markets aids in identifying features that may amplify or suppress the general trade-reducing impact of a global pandemic. Second, by comparing domestic trade flows between Colombian municipalities across the border closure, it is possible to parse out the impact of various geospatial features of countries on localized trade behaviors; in this paper, I focus on interregional trade, but I do not rule out the possibility of extending this approach to examine similar effects on a global scale. Third, to my knowledge, incorporating geospatial characteristics that correspond to municipal-level trade exposure has not been formally considered in the literature, particularly using micro-level freight transportation panel data.

In addition to its prime geographic location, connecting two oceans as well as two continents, Colombia's administrative structure makes it a unique case study. While it is classified as a developing country (UN DESA et al., 2020), the degree of data collection conducted by Colombian governmental entities is extensive and laudable. The strong regulations and

[2]Both Arellana et al. (2020) and Ministerio de Transporte de Colombia (2020) report data and calculations using millions of tons, rather than on the value of goods shipped.

transparency concerning data collection, coupled with the openness and availability of the resulting data sets, motivated my decision to consider Colombia as my area of interest for my analysis. Formed in 1953, the primary statistical agency in Colombia is National Administrative Department of Statistics (DANE). This is the agency tasked with the strategy, collection, and dissemination of the data and related statistical information for Colombia.[3] Having a centralized agency for data collection in Colombia combined with a wave of data transparency regulations in recent decades has positioned Colombia as prime for economic analysis.

We must also consider the nature and implementation of COVID-19 spread-mitigation policies in Colombia and, thus, also the structure of its legislative process. Colombia is "a state with a decentralized government at regional (departments) and a local (municipalities) scale" and is "a unitary republic with partial autonomy of regional authorities" (Arellana et al., 2020). Each department and municipality maintains limited control over the policies implemented that affect them, however the president of Colombia retains the power to impose measures at a national level, which included the closure of land, sea, and river borders on March 17th, 2020 to protect against further spread of COVID-19 (Arellana et al., 2020).

To conduct my analysis, I obtained data on the locations of factors that are likely to affect the trade exposure of municipalities. For example, I include proximity to airports, availability of roads, and contiguity with neighboring countries via national borders. Using publicly available GIS data, I generate six geospatial variables relating to trade exposure for each Colombian municipality: border contiguity, seaport contiguity, airport buffers, road toll buffers, road density, and river coverage. I then implement a spatial autoregressive

[3] Additionally, DANE conducts the national census in Colombia.

estimation on panel data to estimate trade flows within Colombia as measured by value of goods imported and exported by municipality and compare the results to the baseline estimation results from a standard pooled OLS analysis. I find that the effects of COVID-19 border closure were heterogeneous across municipalities, varying by net balance of trade status. Municipalities that were net exporters prior to COVID-19 are found to have both higher trade inflows and overall trade flows across the entire time frame considered, including the post-COVID-19 period.

2 Literature Review

In this section, I discuss the literature that has been put forth recently regarding the interregional trade responses to COVID-19. There are three areas of research discussed below that motivated my analysis: domestic trade in Colombia, effect of COVID-19 on trade behaviors, and interregional trade. These three areas share some degree of thematic overlap, but the nature of their approaches differ given their region(s) and subject(s) of interest. I begin by going over how trade in Colombia has been modeled or analyzed by the literature. I then proceed by presenting a brief summary of the direction of COVID-19-related research in trade. Finally, I provide an overview of literature related to the study of interregional trade patterns.

The nascent literature on domestic trade in Colombia is growing, potentially linked to the relative scale, scope, quality, and availability of its economic data. As an illustration of some of this work, I highlight four influential papers that have used aspects of Colombian trucking data to analyze domestic trade. Prato et al. (2021) present a comprehensive overview of the role of freight transportation within the economy of Colombia. Additionally, the authors describe how the National Registry of Cargo Dispatches (RNDC) is compiled, which directly informs the trucking data used in my analysis. Gonzalez-Calderon et al. (2018) fortify existing trucking data through the implementation of a survey in order to analyze freight generation patterns. The authors highlight the value of survey collection as a means of characterizing freight movements, which would allow for more comprehensive freight demand models. Vasco Correa (2012) compares the allocative efficiencies of rail and truck transport systems in Colombia, identifying rail as the relatively-efficient method for resource allocation. Duranton (2015) estimates the relationship between the presence of major roads within and between cities in Colombia and both the level and composition of trade. This paper also considers both the weight and value of goods traded, which provides support for using value-measures in the analysis of interregional trade. Duranton (2015) determines that municipalities with denser intra-municipal roads networks are more likely to export a greater value and weight of goods, while the value and volume[4] of traded goods are negatively related with travel distance; these findings promote the notion that greater road connectivity would significantly affect trade and welfare.

As time passes and more data concerning socioeconomic factors from the time-frame of the pandemic become available, the scope of research concerning the effects of pandemic on said economic and social factors will undoubtedly increase. Therefore, I highlight contemporaneous papers that have analyzed the early impacts of COVID-19 on trade flows in a variety of countries and settings. In particular, I direct my attention to the literature highlighting trade impacts in South America and present a selection of these papers below; the majority of the papers that analyzed the impacts of COVID-19 trade focused their analysis on Colombia.

Arellana et al. (2020) studied the short-run impacts of Colombian COVID-19 mitigation policies implementation air, freight, and urban transportation behavior. This paper provides motivation for considering transportation, as well as an overview of Colombia's transport systems as they relate to trade, as well as a comprehensive overview of the government's response to COVID-19. In particular, the authors corroborate findings that trade frequency

[4]Volume measured by weight.

declined as a result of COVID-19. Haddad et al. (2020) present a methodology for measuring daily economic costs of the COVID-19 spread-mitigation policies. The regional and national governments of Brazil and Colombia implemented this methodology to analyze the potential costs of different lockdown measure strategies.

Bonet-Morón et al. (2020) also construct a measure capturing the economic implications of pandemic-related lockdown in Colombia by using an input-output model to estimate related economic losses. The authors use this method to identify sectors and regions in Colombia that are most-likely to experience significant economic losses. Haddad et al. (2021) take a similar approach to assess the daily economic costs of Brazil's COVID-19 spread-mitigation policies, using a similar input-output approach to estimate potential responses to various simulated top-down policy approaches. Chen et al. (2020) also estimate the economic impact of COVID-19 containment policies, but considers those implemented in China. This particular paper provided motivation for my analysis, as it uses truck flow data to investigate the impact of national COVID-19 response policies on regional-level incomes effects, highlighting the economic relevance of analyzing the geospatial patterns of trade.

Finally, I highlight papers that analyzed interregional trade, some of which consider trade via freight trucks. The intent of this section is to highlight the variety of approaches that have been implemented in this area of study.

Liu et al. (2015) estimate interprovincial trade flows in China using a sector-specific model developed from the gravity model and location quotient techniques; they find that their proposed sector-specific model can increase the credibility of interregional trade flows in the sectors considered (food and tobacco, metal smelting and processing, and electrical equipment). Joshi and Mahmud (2021) identify the factors in theoretical framework that incentivize interconnected market formation between heterogeneous regions: risk alleviation and gains from trade. This motivated my analysis of trade across heterogeneous municipalities. Tsekeris (2017) propose a dynamic spatial panel model to understand channels through which changes in transportation conditions of a region affect its own ability to trade, as well as spillover effects affecting the abilities of neighboring regions.

Adam et al. (2021) use GPS data on Belgian freight trucking at the national-level-specifically location and movement data-to conduct a community detection analysis. The authors find that trucks registered locally in Belgium form contiguous chains of communities, while trucks registered in foreign countries tended to cluster in the economic hubs of Belgium. This highlights potential links between geospatial and behavioral factors related to micro-level economic transportation data. Paul Lesage and Polasek (2008) present a spatial econometric extension of the gravity model by modeling commodity flows; the authors incorporate the highway network into the network connectivity structure of the spatial autoregressive econometric model. They observe the strongest spatial autoregressive effects in origin-destination pairing that have neighboring regions located on the highway region. Jin et al. (2021) quantify the border effects of three border types (natural, infrastructural, and administrative borders) on intra-urban travel connections in China, using a spatial interaction model.

This paper merges elements from the three strains of literature presented to analyze the behavioral response of markets in Colombia, through shifts in interregional trade following a sudden change shift to economic autarky caused by the implementation of national-level COVID-19 spread-mitigating policies. I use novel micro-level trucking data to analyze how the composition of trade flows between the 1123 Colombian municipalities changed following the sudden closure of international borders.

3 Data

The data used in this analysis are publicly available from various agencies of the Colombian government, which I identify in this section. For lucidity, I group the types of data used into three categories by theme: data concerning truck flow (Section 3.1), data related to the trade exposure variable (Section 3.2), and additional data (Section 3.3). All geospatial data used in this paper are presented using the MAGNA-SIRGAS projection, following Resolution 471 of 2020 of the Agustín Codazzi Geographical Institute (IGAC) enacted on May 14th, 2020.[5] In this paper, I rely on administrative boundary geospatial data provided by DANE for municipality, departmental, and national boundaries.

3.1 Trucking Data

The primary trucking flow data set for my analysis is taken from Registro Nacional Despacho de Carga (RNDC) of Colombia (Ministerio de Transporte, 2021) and provides information on the frequency and value of goods transported in the cargo shipments by trucks between pairs of population centers in Colombia.[6] Specifically, the data consists of transaction-level information on the origin municipality, destination municipality, date, shipment weight,

[5] As of the writing of this article, a copy of the official declaration from the Government of Colombia (in Spanish) can be found at this web address: https://igac.gov.co/sites/igac.gov.co/files/normograma/resolucion_471_de_2020.pdf

[6] While RNDC requires freight truck drivers to maintain and report GPS routing data of all shipments as of February 2019, this data is not publicly available. In this analysis, I use the generalized origin-destination data.

number of trips taken, number of zero-value trips taken[7], and value of shipments. I make use of the data from October 2018 to December 2020.[8] Trucking data are aggregated at the quarter-by-municipality level to control for naturally-occurring short-term idiosyncratic trade fluctuations (reducing "lumpiness" in the data Manova and Zhang (2012)).

The operationalized data set used in this analysis data includes both the components of the original data and a few transformations. First, observations are aggregated upward from the day-shipment level to the quarter-by-municipality level. The value of shipments into-and out of-each municipality are taken to be the total value of municipal exports and imports. Third, I use the municipalities of origin and destination to construct trade outflow, trade inflow, and net trade flow values. Fourth, the pre-pandemic municipality-level balance of trade status is calculated from the net municipal trade flow during the period prior to 2020 Q2. This measure is used to classify municipalities as domestic exporters or importers using a dummy-indicator variable. A municipality that exported more than they imported for the period considered is classified as a net exporter.

In Table 1, I present descriptive statistics of the quarterly outflows and inflows for origin-destination municipality pairs; this includes weight, value, and distance of orders shipped. From the table, we see that outflows generally tend to be heavier, higher valued, and require more trips on average. We also see that, based on number of observations, there are more municipalities importing domestically than exporting. For reference, in total there are 1,122 municipalities in Colombia and 32 departments along with a capital district; in this analy-

[7]The term "zero-value trips" refers to trips taken by trucks carrying no value of freight. This may or may not correspond directly to empty loads in all cases, but operating under this assumption is unlikely to hinder this analysis.

[8]I truncate the scope of my analysis at December 2020 because as this was the time period in which COVID-19 spread-mitigating policies were more stringent.

sis, I consider 1,035 municipalities representing the capital district (Bogotá) along with 31 departments.[9]

3.2 Trade Exposure

There are two components of the trade exposure measure that I incorporate into my model. The first set of components capture the exposure of municipalities to international trade; this set of components is designed to capture how exposed municipalities are to international trade. The set is constructed using the proximity of municipalities to international airports and sea trade ports and geographical contiguity of a municipality.

The second set of components capture the exposure to interregional trade; this set of components is designed to capture the exposure of a municipality to interregional trade within Colombia. The set is constructed using data on the presence of tolls as well as computed river coverages and road densities within municipalities.[10] Figure 1 highlights the points of interest used in the computation of the trade exposure measure, while Figures **??** and **??** present the map of the road densities and river coverages, respectively.[11] These indicators capture trade frictions between municipalities. For instance, during the pandemic, Colombia suspended the collection of tolls for domestic freight vehicles moving within the national territory in order to reduce barriers to interregional trade, compensating for increased barriers to international trade (Arellana et al., 2020). Road density within a municipality captures how accessible a municipality is both internally and between regions, and the use of such

[9] I exclude island municipalities, known as San Andrés and Providencia, which define the department I exclude, from my analysis.

[10] I considered incorporating elevation, but the likely correlation to other factors (placement of airports, seaports, roads, and administrative boundaries) motivated me to exclude this consideration.

[11] For context, I provide maps of the road and river networks in Colombia in Figures B.3 and B.4, respectively, found in the Appendix.

a measure has been accepted in the literature as a measure for freight trade barriers (Duranton, 2015); we may apply similar logic to the use of river coverage as an indicator of a municipality's river network access.

The data used to capture trade exposure came from multiple Colombian governmental agency sources. I obtain airport concession and road toll geodata from the National Comprehensive Highway Information System (SINC) which contains public data from the Ministerio de Transporte de Colombia (Ministry of Transport of Colombia) as of 2017 (Ministerio de Transporte de Colombia, 2020). SINC provides data for 46 airport concessions in Colombia.[12] The road toll data consists of 110 road toll concessions in Colombia. I identify seaports by the port concession data made available in ESRI from the National Infrastructure Agency of Colombia (ANI). In total, there are 61 seaport concessions in Colombia, which are clustered in nine areas of mainland Colombia. This data captures seaport data but not river port data, as the two are subject to different regulations regarding Public-Private Partnerships (PPP).

SINC also provides data on road concessions in Colombia. There are multiple tiers of road concession types; I focus my analysis on two types: national and departmental road networks. There are 988 municipalities in the departmental road network and 645 municipalities in the national road network. With this data, I construct a road density measure for each municipality, which is computed as the ratio of total road lengths in a municipality to the total area of the respective municipality. World Bank Group (2017) provides polyline data on river outlines for Colombia. I generated polygons from this data. I obtain a total of 713

[12]For context, according to the U.S. Department of Commerce's International Trade Administration, all of Colombia's major airports are "operated via concession agreements" (Colombia - Infrastructure)

river polygons, from which I compute river coverage for each municipality by computing the ratio of square kilometers of river in each municipality to the square kilometer size of each municipality.

In order to account for edge effects, I generate buffers for trade exposure features, setting the buffer distances based on standards set by the literature. The administrative boundary data allowed for the generation of contiguity data and contiguity buffers. For the airport locations, I implemented a 30 km buffer (Li and Liang, 2018). For road tolls, following Asborno et al. (2021), I set the buffer size to 10 miles; this source was also the basis for setting a 50-mile buffer around the seaports. For the border contiguity buffer, I set the buffer to 10 kilometers per Simmons (2019). Figure 5 illustrates the resulting buffers. Using the buffers generated, I constructed municipality-level variables consisting of dummy and count variables for each feature buffered. I generated buffer dummy variables for all four buffer types (airport, road tolls, seaports, and border contiguity) as well as count variables for the airport buffers and road toll buffers which capture the number of airports and road tolls service areas that are within each municipality.

For my analysis, I incorporate the count variables for the airport and road toll buffers instead of the dummy variables, relying on the larger variability to improve the explanatory power of the estimation techniques. Table 1 includes the summary statistics of the geospatial characteristics corresponding to trade exposure.

3.3 Nightlights Data

In order to account for the variations in economic activity and populations between municipalities, I rely on annual nightlight's data as a proxy for an economic size measure within each municipality. The intent is to use nightlights as a proxy for economic activity, as has been traditionally done in the literature. Based on the reasoning presented in Gibson et al. (2021), I use VIIRS Annual VNL V2 data for 2019 and 2020 (Elvidge et al., 2021) in my study as opposed to DMSP. I aggregate the data to the municipality level to allow for comparisons across municipalities.

GDP data at the municipality level for 2019[13] is available from DANE. I began by considering the validity of using nightlights data to estimate the changes in economic activity in Colombia. Using the VIIRS Annual VNL V2 data for 2019, I examined the relationship between GDP and nightlights by municipality. In Figure 2, I present an overview of the nightlights and GDP data for 2019 by municipality. As would be expected, we see that GDP and nightlights are both higher in areas with higher population densities. For context to the effects of COVID-19, in Figure 3, I present a map that highlights the changes in nightlights from 2019 to 2020 at the annual level by municipality. We can see that in most cases, the regions with higher economic activity experienced a decline in nightlights, whereas the less populated neighboring regions experienced an increase in nightlights. A simple linear regression estimation, which is not included in this paper, verified the relationship between GDP and nightlights in 2019.

[13] 2020 GDP data at the municipality-level was not available at the time of writing.

4 Theory

I begin by estimating the effect of COVID-19 on net exporting and importing municipalities in Colombia by running a difference-in-difference estimation. The differences used are (1) pre- and post-COVID-19 measured as beginning in the second fiscal quarter of 2020 in Colombia and (2) net exporting municipalities versus municipalities that were net importers in the year prior to the onset of COVID-19 and the spread mitigations that were implemented in response to its spread. I determine municipalities as net exporters if the total value trucked out of the municipality is greater than the total value trucked into the municipality in the four quarters prior to the onset of COVID-19 in Colombia.

While the estimation strategy does provide insight to the effect of COVID-19 on the trade behaviors of municipalities in Colombia, it does not incorporate the nuances of the geospatial variations that would capture the variation not explained in the econometric model. This paper proposes an approach to incorporate geospatial characteristics into the analysis of domestic trade patterns by introducing a means of incorporating a geospatial trade exposure measure.

Duranton (2015) presents evidence supporting the notion that greater connectivity via road infrastructure within a city is correlated with an increase in the exports from that city. Based on Duranton (2015), one would expect that the international border closure that followed the spread of COVID-19 would have the following impact on domestic trade patterns. I expand on this finding by postulating that, while trade exposure led to greater exports, the closure of the international borders led to an increase in trade flows for previously net exporting municipalities and a decline in trade flows for previously net importing municipalities.

We may consider each case individually to identify why this hypothesis is viable. First, in an open trade scenario, municipalities with greater access to international trade may be net domestic importers or exporters, which they are is likely to depend on their population size as that is a driver of demand; therefore, densely populated municipalities with higher international trade exposure, they are likely to be net importers in the international market as demand is likely to exceed domestic production.[14] With the closure of international borders, municipalities that were net importers in the international market as likely to increase their domestic imports to supplement the consumption needs that were previously met by foreign suppliers. They are also likely to export less domestically as their supply of goods (likely to have been foreign goods) declined with border closures. Conversely, municipalities that were less exposed to international trade and/or were less populated were likely to increase their own production or potentially experience population growth stemming from lockdowns that would increase their demand for domestic goods. This increased production, as well as heightened demand, results in a relative increase in domestic exports and imports.

In the next section, I discuss my estimation approach, discussing the baseline pooled OLS estimation followed by the SARS approach.

[14] This assumption is based on the information that Colombia has historically maintained a trade deficit (WITS).

5 Estimation

5.1 Baseline Estimation

The central question of this analysis concerns how pre-pandemic municipality-level net trade-flow status informs municipal economic response to COVID-19 spread-mitigation policies through changes in their domestic trade patterns, conditioned for various geospatial factors linked to international trade exposure. To motivate the analysis, I first consider a standard economic baseline model: pooled ordinary least squares (POLS).

For my baseline model, I examine correlations between pre-COVID-19 municipality-level domestic trade patterns and post-COVID-19 trade flows by implementing a pooled OLS estimation procedure, similar to a difference-in-differences (DiD) modeling approach.[15] In this case, pooled OLS (POLS) methodology is preferable to DiD methodology, as the stable unit treatment valuation assumption (SUTVA) of the latter is unlikely to hold. Two of the motivating facets of this analysis invalidate DiD methodology by construction. First, in this case, SUTVA requires that municipalities' net trade status remain consistent across time. Due to the fact that municipalities are sorted into net trade status groups using pre-pandemic trade flow measures only, there is no guarantee that this element of SUTVA will be satisfied. Second, SUTVA requires the absence of spillover effects. This is unlikely to hold due to the presence of common geospatial factors related to international trade exposure, and due to the nested structure of Colombian municipalities within departments, which retain some authority to redistribute resources across municipalities within its domain.

[15]This analysis could be done using a difference-in-differences approach. However, I define net exporters as municipalities by their pre-COVID-19 net trade status, partially due to data limitations.

Using POLS, I estimate three quarterly dependent variables: log total outflow value, total inflow value, and net trade flows. I use log-transformed outflow and inflow values to reduce the impact of extreme values and impose a degree of normality. The distribution of raw outflow and inflow values is shown in figure B.1. I conduct the baseline empirical estimation using the following POLS model:

$$\begin{aligned} Value_{it} = \beta_1 + \beta_2\, VIIRS_{it} + \beta_3\, Net\ Exporter_i + \beta_4\, COVID_t \\ + \beta_5\,(Net\ Exporter_i \cdot COVID_t) + \beta_6 X_i + \varepsilon_{it} \end{aligned} \tag{1}$$

where i indexes the municipality and t indexes the quarter. $VIIRS_{it}$ captures the average annual nightlight intensity by municipality measured in radiance (nW/cm2/sr). The dummy indicator $Net\ Exporter_i$ takes value one if municipality i was a net domestic exporter prior to COVID-19, while another indicator variable, $COVID_t$, is equal to one if the observation is in a post-COVID-19 quarter. The vector X_i captures the trade characteristic measures: border contiguity, seaport contiguity, airport buffer, road density, and river coverage.

Table 2 shows the pair-wise correlations between all independent variables considered. The intended full set of explanatory variables contained a road toll buffer variable. However, I found that the presence of road tolls was highly correlated with two other independent variables considered: VIIRS and airport buffers. This strong correlation is intuitive, as funded roads and/or paid expressways are likely to be located near areas with higher relative economic activity, which includes airports and likely corresponds to larger and more-densely populated areas; this is reinforced by the minor positive correlation between VIIRS and airport buffers.[16] For this reason, I do not incorporate the road toll variable as a regressor

[16]The relationship between VIIRS nightlight intensity and airport buffers is potentially an interesting one for future study, airports are more commonly observed on the periphery of large cities as opposed to inside

in my analysis.

The results of the pooled OLS estimation for all three of the dependent variables considered are presented in Table 3. First, all explanatory variables capturing trade exposure, with the notable exception of road density, are positively correlated with trade flows across all three dependent variables. Unexpectedly, road density appears to have no impact on either outflows or inflows. Second, we see that the economic activity of a municipality is directly related to their domestic trade activity. Third, we also see that COVID-19 had a negative effect on the traded values as well as net trade flows, which is what we expected based on the reported decline in freight activity in Colombia. Being a net exporter pre-COVID-19 is correlated with higher values of trade, both exports and imports. Finally, the interaction of COVID-19 and net exporters which captures the effect of COVID-19 on those municipalities that were net exporters prior to COVID-19 is not significantly correlated with outflows or net trade flows, but it is negatively related with inflows. This result signals that the driving force for net exporters to import domestically prior to COVID-19 was from those municipalities that were suppliers to markets abroad.

5.2 Spatial Estimation

As Tobler's first law of geography states: "Everything interacts with everything, but two nearby objects are more likely to do so than two distant objects." This points to a potential limitation introduced by POLS in this situation. POLS assumes that the residual variation in the model that is not captured by the regressors is not spatially autocorrelated; such

the urban core. It is possible that airport buffers and VIIRS have a stronger correlation, but the distance between the airport and the most-dense urban cores exceed my buffer radius.

residual spatial autocorrelated would introduce bias into the results and justify the use of models that are unbiased under such conditions.

I use Moran's I test of spatial autocorrelation[17] and find that, for all three dependent variables and time periods considered, I cannot reject the null hypothesis that spatial autocorrelation was not present. For my analysis, I implement a spatial autoregressive model for panel data. This modeling approach incorporates the geospatial autocorrelations that are present in the world.

$$\boldsymbol{y}_{it} = \rho \boldsymbol{W} \boldsymbol{y}_{it} + \boldsymbol{X}_{it}\boldsymbol{\beta} + \boldsymbol{\varepsilon}_{it} \qquad t = 1, 2, \ldots, T \tag{2}$$

where $\boldsymbol{y}_{it}$ is an i-dimensional vector of dependent variables, which are log(outflows), log(inflows), and net trade flows in my estimation. $\boldsymbol{W}$ is the spatial weighting matrix. The spatial weight matrix $\boldsymbol{W}$ captures the spatial linkages between pairs of municipalities, i and j (with $i, j = 1, \ldots, N$), and is generated by computing the inverse-distance between the two municipalities.[18] When $i = j$, the weight is 0 as we do not consider municipalities to be their own neighbors, and non-zero weights between two municipalities indicates that there is a spatial link between the two. $\boldsymbol{X}_{it}$ is the matrix of regressors, consisting of the same variables as in Section 5.1. $\boldsymbol{\varepsilon}_{it}$ is the error term. For this random effects SAR estimation, we make the standard assumptions that $\boldsymbol{\varepsilon}_{it} \sim N(0, \sigma_e^2)$ and $\mathbb{E}[\varepsilon_{ij}\varepsilon_{js}] = 0$ for $i \neq j$ or $t \neq s$ (Belotti et al., 2017).

[17]This measure tests the degree of correlation across spacetime by comparing the results against a null hypothesis that correlations are perfectly random.

[18]Row-normalization is applied in the construction of the spatial weighting matrix.

5.3 Results

Table 4 presents the results of the SAR estimation approach presented in Equation 2. The results indicate that there is spatial autocorrelation in the trucking dynamics. From the table, we see that the results for nightlights (VIIRS) are similar to those found under the POLS estimation. Once spatial autocorrelation is accounted for in the estimation approach, the direct impact of COVID-19 and the subsequent spread-mitigation policies were estimated to be less significantly related to net trade flows.

The sign of the net exporter status effect changed for inflows, switching from positive under POLS to negative under the SAR specification. More rigorous testing will need to be done to identify a root-cause for this result; however, as a preliminary explanation from conjecture and economic theory, the role of the net exporter prior to COVID-19 could have been dictated by its relative geographic position in the country as well as the production portfolios of each municipality. In specific, it is possible that certain municipalities, such as those located on the political boundary of Colombia, may have benefited internally from having a comparative advantage as a trade hub.

The results for the interaction terms are approximately similar for the three dependent variables. The coefficient for outflows increased and is more statistically significant under the SAR specification. Of the proposed trade exposure characteristics, only airport buffers were statistically significant across all three dependent variables.[19] Overall, the results support the assertion that spatial autocorrelation matters for trade flow analyses. The trading status of a municipality prior to COVID-19 had a deterministic impact on the changes in regional

[19]It is possible that a significant proportion of the impact was felt by a small subset of municipalities, as many are sparsely populated or remote relative to Colombia's primary economic hubs.

economic behavior after the shift to near-autarky following the implementation of COVID-19 spread-mitigating policies.

6 Discussions

The results of this analysis are promising and present opportunities for future considerations of the role geospatial factors have in influencing trade. As with any study, this analysis has limitations that should be taken into consideration in order to interpret results within the correct context. The set of limitations listed consists simply of the ones that I have found along the way; it is by no means exhaustive.

Two important limitations to this paper concern contemporaneous factors related to the COVID-19 pandemic itself. First, I assume for this analysis that the impact of the COVID-19 spread-mitigation policies is constant across municipalities. Second, I assume that the period before and after the implementation of COVID-19 spread-mitigation policies is otherwise comparable across all metrics. While this might be true using a localized reference frame, it is possible that another systematic shift in trade behavior attributable to the pandemic itself, prior to any shutdowns, could render the entire incomparable with time periods outside the pandemic. While this natural experiment to capture a shift from a globalized marketplace to near-autarky in an instant is unique, the fact remains that there exists the potential for a common underlying trend in the economy associated with the time period of the pandemic that may make it systematically "abnormal."

To address issues caused by the common municipal shock-response assumption, data could be aggregated to quarterly-levels which is likely to smooths the heterogeneity of policy responses in Colombia as spread-mitigating policies and measures are likely to have taken effect in the first three months of COVID-19's onset in Colombia. As discussed in Arellana et al. (2020), the spread-mitigation measures imposed on freight transport were also heterogeneous across sectors. As I consider aggregate trends, the homogeneity assumption may be appropriate, but I believe my analysis may be strengthened by analyzing the distribution of the sectors in which municipalities trade. As one possible extension, I hope to expand the analysis to account for the heterogeneity in the timing of COVID-19 spread mitigation within Colombia. In this paper, the analysis simplified the COVID-19 effect by aggregating it at the national level, considering differences in trade characteristics between municipalities. To push this analysis, I would pursue incorporating departmental-level COVID-19 spread mitigation data. I would do this by compiling a dataset on municipality-level (or departmental-level) COVID-19 policy measures.

Individual elements from the various geospatial characteristics are treated equal in this analysis, meaning I do not control for variations in the size of airports or seaports, nor variations in the length of borders shared with foreign countries; by doing so, each instance of specific classes of geospatial characteristics are considered homogeneous. While this may affect the predictive capability of the estimation by, for example, underestimating the impact of a municipality having access to an airport with a runway capable of handling large cargo aircraft or a seaport with deep-water berths to handle large ocean-going container ships, the inclusion of such geospatial elements still more accurately depicts factors that are relevant for domestic and international trade than previous works. Additionally, while disconnected from international markets, it is not readily apparent that larger trading ports or borders would benefit municipalities as much in autarky as the marginal benefit is likely to decrease faster than the marginal costs associated with upkeep. This is not a factor explored in this analysis, however, and could be examined in the future.

The data provided in the RNDC contains data regarding zero-valued trucking fright trips, which leaves the possibility open to extend my analysis to examine differences in patterns of zero-valued trade in a closed border scenario. However, for the paper at hand, I do not separate zero-value trips and thus included in this analysis. Additionally, there were ten municipalities that did not trade domestically the year prior to COVID-19, but did engage in interregional trade post-COVID-19.

7 Conclusion

In this paper, I proposed a method of estimating the effects of COVID-19 spread mitigating measures on the domestic trade patterns in Colombia. Based on the results obtained in this paper, I found that there was a redistribution of trade flows that was likely due to the closure of external markets in Colombia. I would like to reiterate the notion I presented in the discussion section that, while this project still has more work to be done, the experience of combining GIS techniques and econometric methods has been insightful and motivating. The methods and results presented here highlight the importance of approaching standard areas of research (such as international trade) from an interdisciplinary perspective by incorporating a geospatial analysis approach.

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Tables

Table 1: Quarter-Municipality Level Summary Statistics

Variables	Mean	SD	Min	Max	N
Municipality Outflows					
Total Kilograms	27,371,563	152,233,006	0	3,234,919,756	7,245
Total Gallons	877,074	5,718,903	0	116,102,386	7,245
Total Zero-Value Trips	368	1,949	0	38,535	7,245
Total Kilometers	233,918	2,079,142	0	64,166,872	7,245
Avg. Trip Distance	68	99	0	950	7,245
Total Value (in Millions)	2,475	15,182	0	295,598	7,245
Total Number of Trips	2,045	11,037	0	226,673	7,245
Avg. Trip Value	1,124,341	842,008	0	9,600,000	7,245
Municipality Inflows					
Total Kilograms	27,368,710	141,793,946	0	3,170,820,351	7,245
Total Gallons	876,657	6,257,578	0	169,054,219	7,245
Total Zero-Value Trips	368	2,036	0	49,083	7,245
Total Kilometers	233,913	1,921,920	0	71,747,796	7,245
Avg. Trip Distance	95	96	0	776	7,245
Total Value (in Millions)	2,474	13,366.10	0	328,668	7,245
Total Number of Trips	2,044	10,636	0	265,380	7,245
Avg. Trip Value	1,172,682	569,915	0	7,250,000	7,245
Trade Exposure					
Border Contiguity	0.06	0.24	0	1	7,245
Seaport Contiguity	0.15	0.36	0	1	7,245
Airport Buffer[a]	0.51	0.66	0	3	7,245
Road Toll Buffer[a]	0.74	1.11	0	7	7,245
Road Density	0.19	0.17	0	1.40	7,245
River Coverage	0.01	0.01	0	0.16	7,245

Notes: Values are in Colombian pesos. Coverage consists of 2018 Q4 through 2020 Q4 for contiguous Colombia.

[a] These measures consist of number of instances of buffer intersecting municipality.

Table 2: Cross-correlation table

Variables	VIIRS	COVID-19	Net Exporter	Border	Seaport	Airport	Road Density	River Coverage	Department	Road Toll
VIIRS	1.000									
COVID-19	0.01	1.00								
Net Exporter	0.16	-0.01	1.00							
Border Contiguity	-0.03	-0.00	-0.04	1.00						
Seaport Contiguity	0.11	0.00	0.06	0.07	1.00					
Airport Buffer	0.29	-0.00	0.13	0.03	0.02	1.00				
Road Density	0.15	-0.00	0.01	-0.14	-0.16	0.15	1.00			
River Coverage	0.08	-0.00	0.05	0.10	0.05	-0.03	-0.14	1.00		
Department	-0.10	0.00	0.08	0.18	-0.03	0.12	-0.15	0.01	1.00	
Road Toll Buffer	0.45	0.00	0.22	-0.07	0.20	0.55	0.20	0.02	-0.05	1.00

Table 3: Baseline pooled OLS estimation

	(1) log(Outflows)	(2) log(Inflows)	(3) Net Flows
VIIRS	0.36***	0.30***	0.01***
	(0.03)	(0.01)	(0.00)
COVID-19	-0.81***	-0.08	-0.03***
	(0.16)	(0.05)	(0.01)
NET Exporter	5.53***	0.65***	1.11***
	(0.21)	(0.07)	(0.01)
COVID-19 × NET Exporter	0.58	-0.31*	0.03
	(0.39)	(0.13)	(0.02)
Border Contiguity	0.48	0.76***	-0.00
	(0.36)	(0.13)	(0.02)
Seaport Contiguity	0.79**	0.45***	0.02
	(0.28)	(0.10)	(0.01)
Airport Buffer	1.24***	0.53***	0.04***
	(0.12)	(0.04)	(0.01)
Road Density	-0.04	0.10	-0.05*
	(0.49)	(0.17)	(0.02)
River Coverage	10.76	5.98*	0.55
	(6.79)	(2.35)	(0.33)
Constant	16.11***	19.04***	-0.71***
	(0.23)	(0.08)	(0.01)
Adj. R^2	0.312	0.314	0.727
AIC	45,444.57	30,077.94	1,525.89
BIC	45,726.98	30,360.35	1,808.30
Observations	7,245	7,245	7,245

Standard errors in parentheses. Departmental fixed effects are included in all three estimations. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: SAR estimation

	(1) log(Outflows)	(2) log(Inflows)	(3) Net Flows
MAIN			
VIIRS	0.35***	0.21***	0.01***
	(0.06)	(0.02)	(0.00)
COVID-19	-0.41***	-0.01	-0.01*
	(0.12)	(0.02)	(0.01)
Net Exporter	3.40***	-0.59***	0.83***
	(0.22)	(0.04)	(0.01)
COVID-19 × Net Exporter	0.81**	-0.16**	0.02
	(0.25)	(0.05)	(0.01)
Border Contiguity	0.32	0.63	-0.02
	(0.79)	(0.32)	(0.04)
Seaport Contiguity	0.96	0.60*	0.04
	(0.61)	(0.25)	(0.03)
Airport Buffer	1.30***	0.67***	0.06***
	(0.26)	(0.10)	(0.01)
Road Density	0.15	0.34	-0.04
	(1.06)	(0.44)	(0.05)
River Coverage	13.40	8.75	0.95
	(14.65)	(6.04)	(0.76)
Constant	6.65***	3.90***	-0.40***
	(1.48)	(0.91)	(0.06)
SPATIAL			
ρ	0.59***	0.79***	0.55***
	(0.09)	(0.05)	(0.10)
VARIANCE			
θ_{t-1}	-0.89***	-1.85***	-0.94***
	(0.03)	(0.03)	(0.04)
σ_e^2	12.24***	0.45***	0.03***
	(0.22)	(0.01)	(0.00)
R^2	0.30	0.27	0.72
R^2_{within}	0.04	0.05	0.42
$R^2_{between}$	0.39	0.29	0.80
AIC	41,353.96	19,042.09	-2,092.18
BIC	41,657.04	19,345.17	-1,789.10
Observations	7,245	7,245	7,245

Standard errors in parentheses. Departmental fixed effects are included in all three estimations. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figures

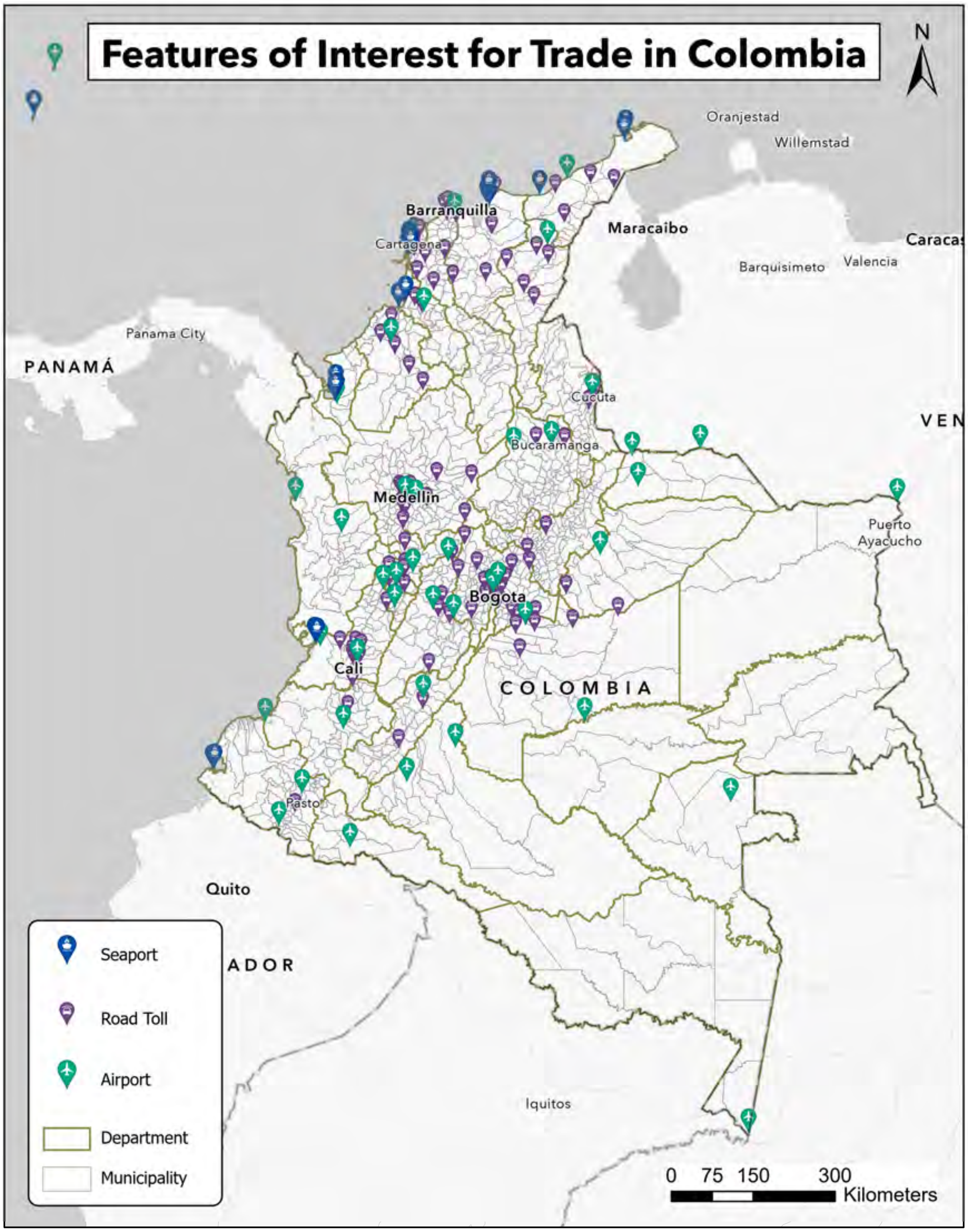

Figure 1: Map of point features used in the construction of the trade exposure measure.

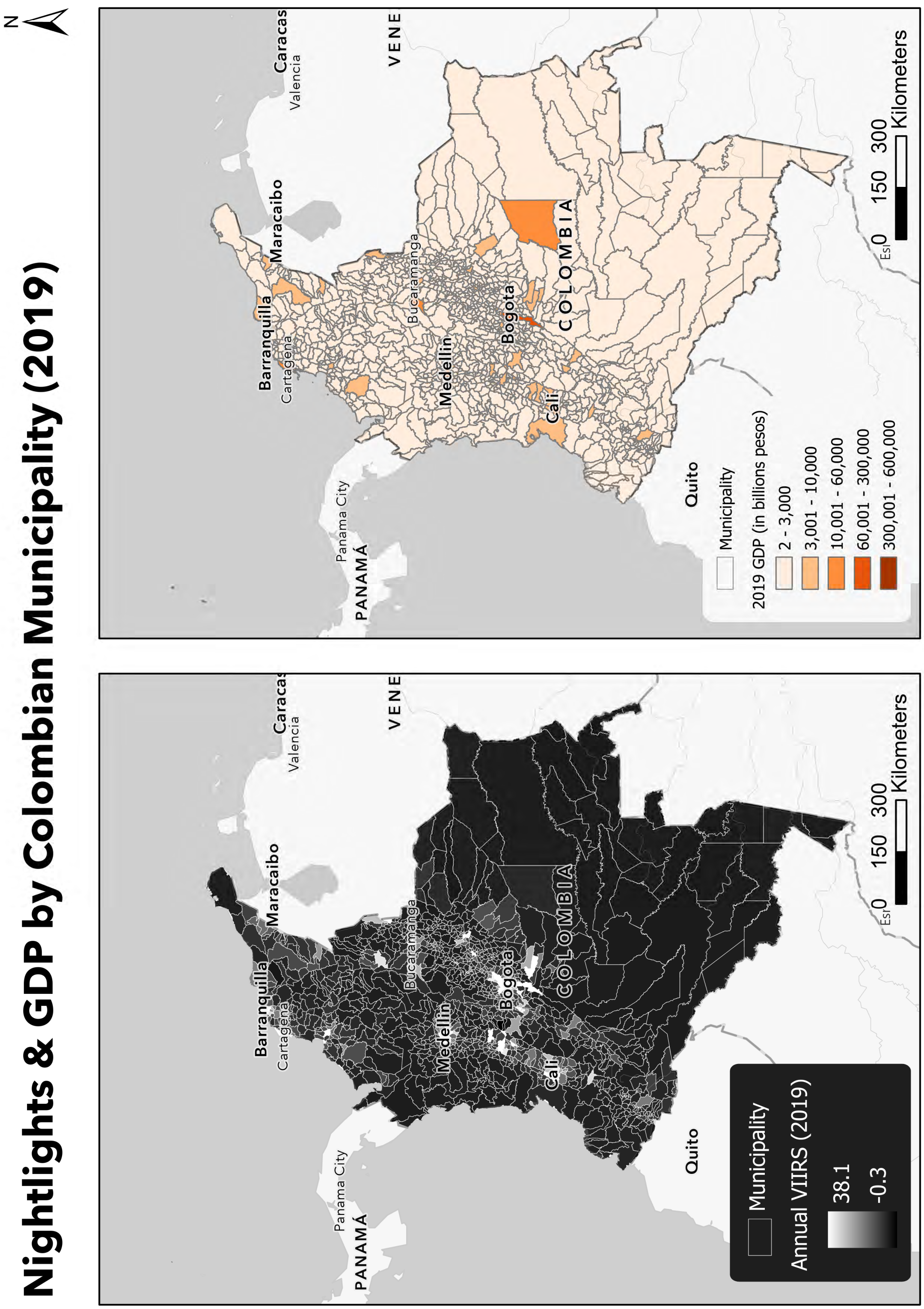

Figure 2: Map of the 2019 annual nightlights and GDP in Colombia by municipality.

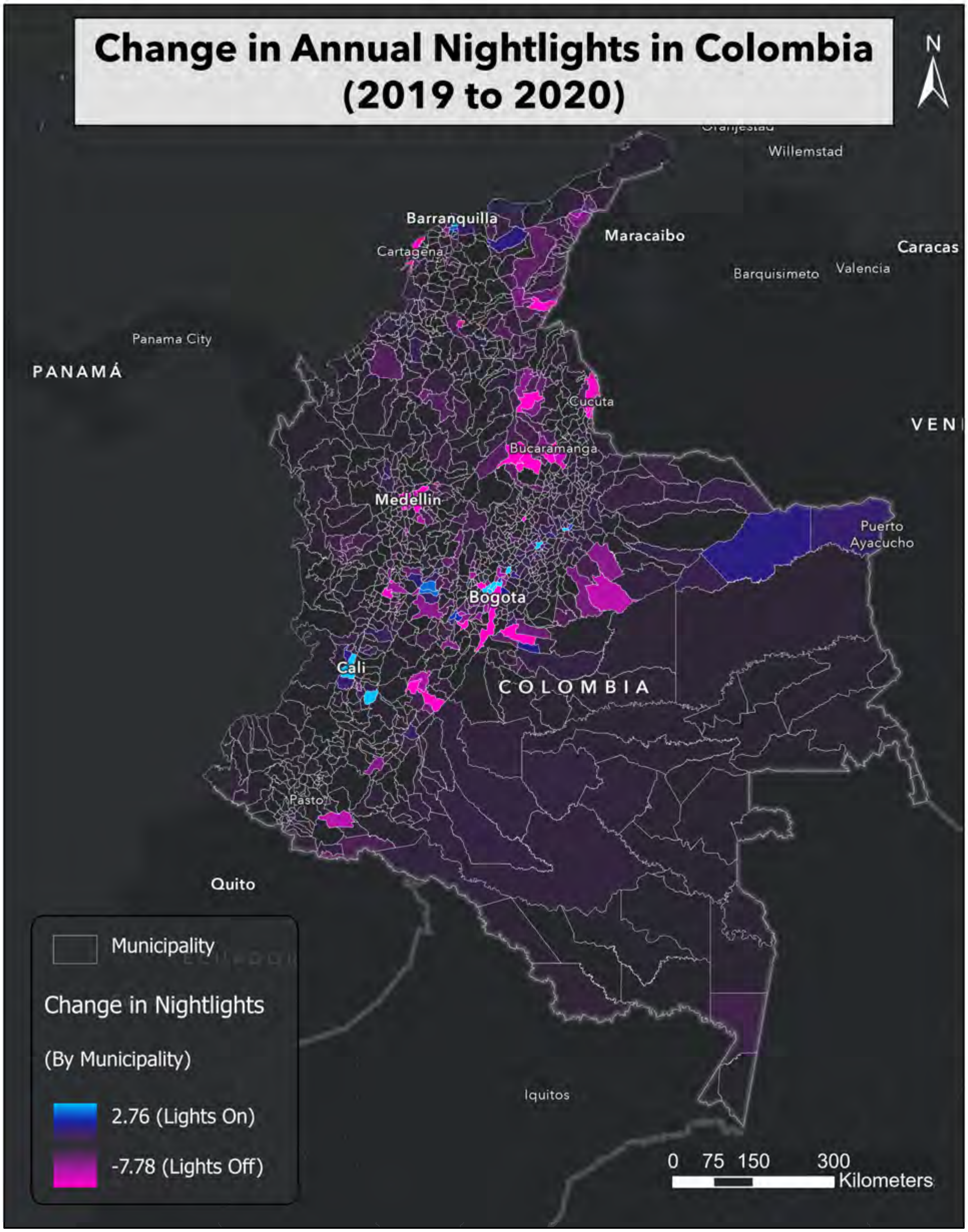

Figure 3: Map of the change in annual nightlights in Colombia by municipality.

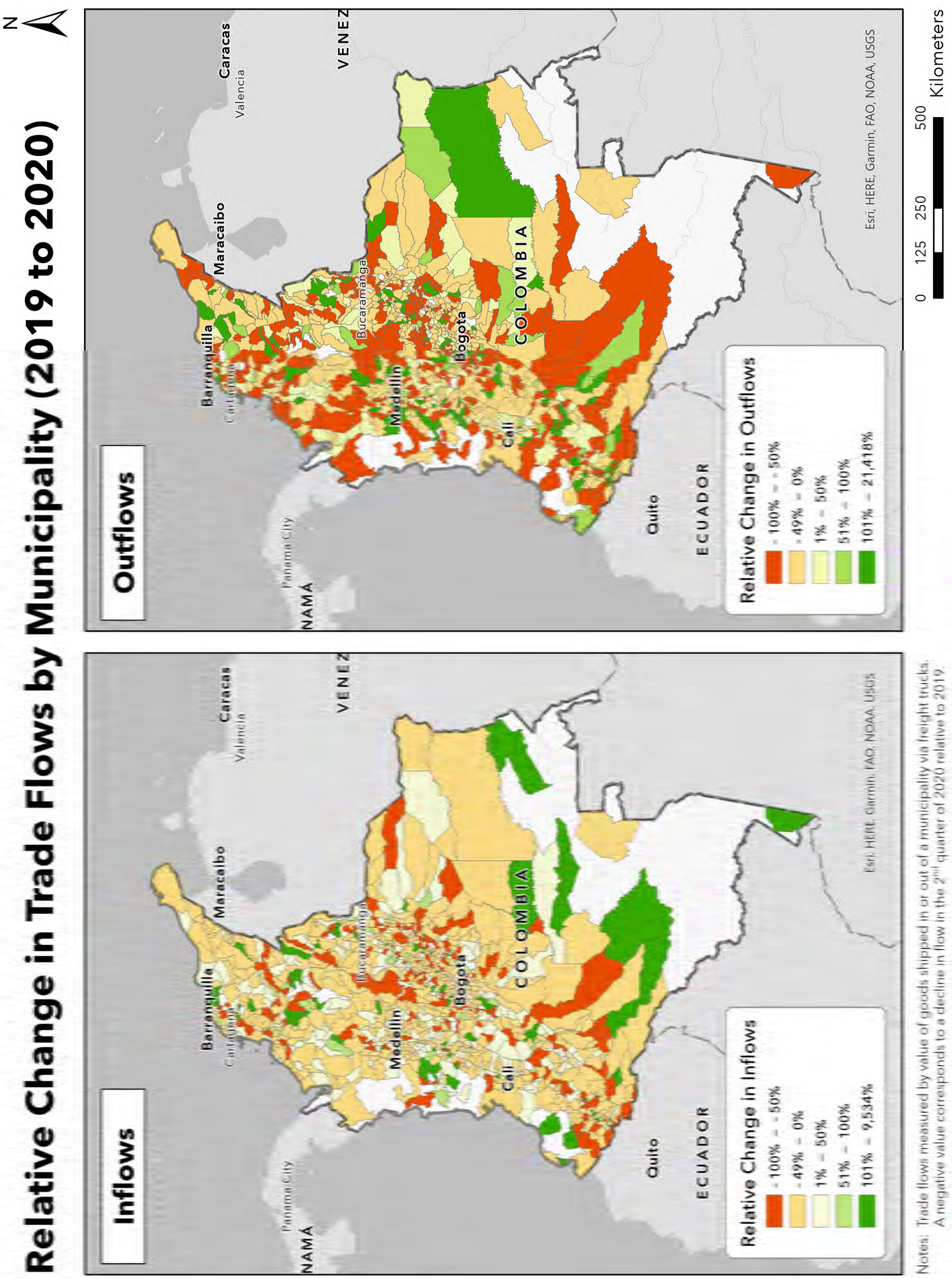

Figure 4: This map highlights which municipalities experienced declines in trade flows and which experienced increases, comparing the 2nd quarter of 2020 to that of 2019.

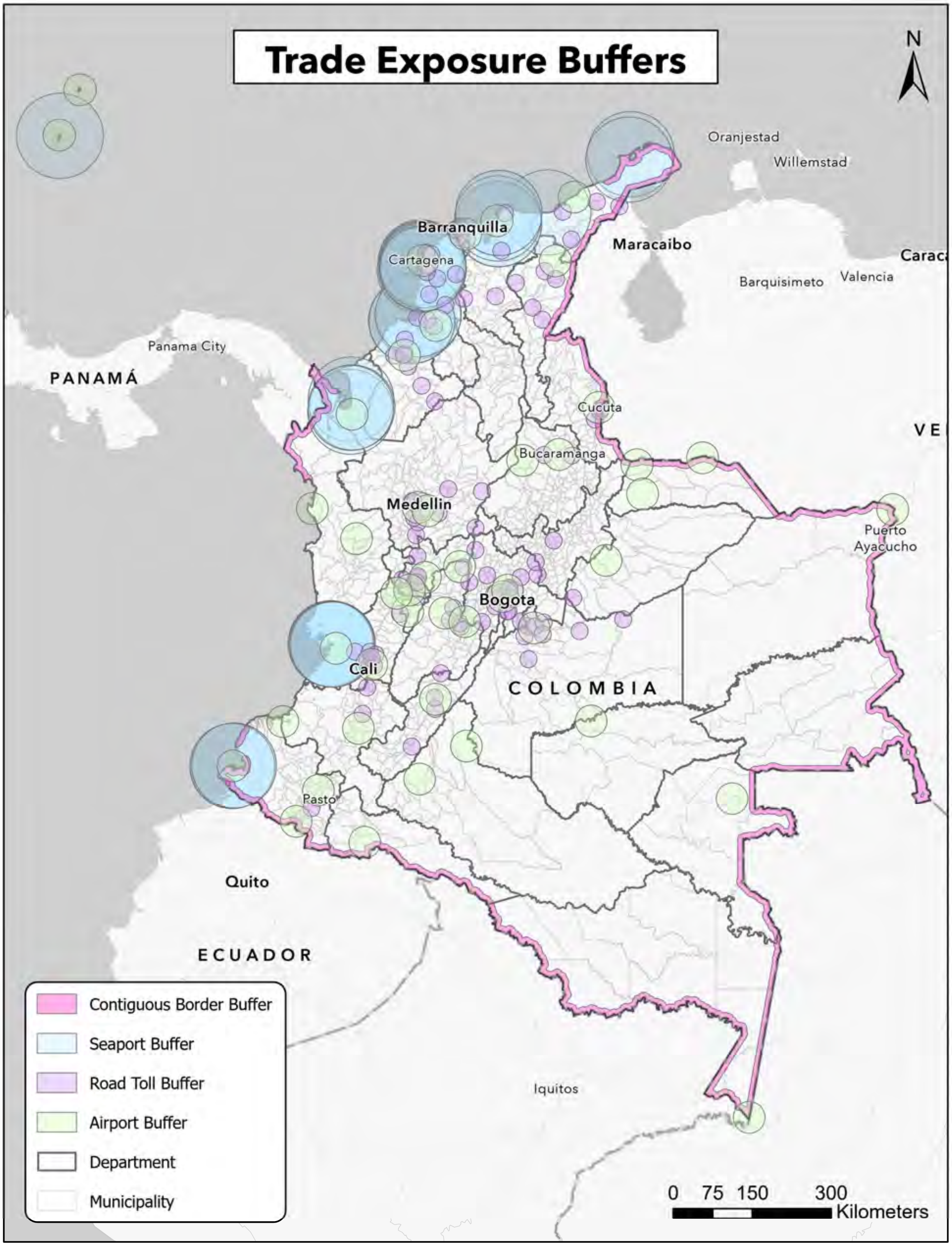

Figure 5: Map of the buffers used in the trade exposure estimation.

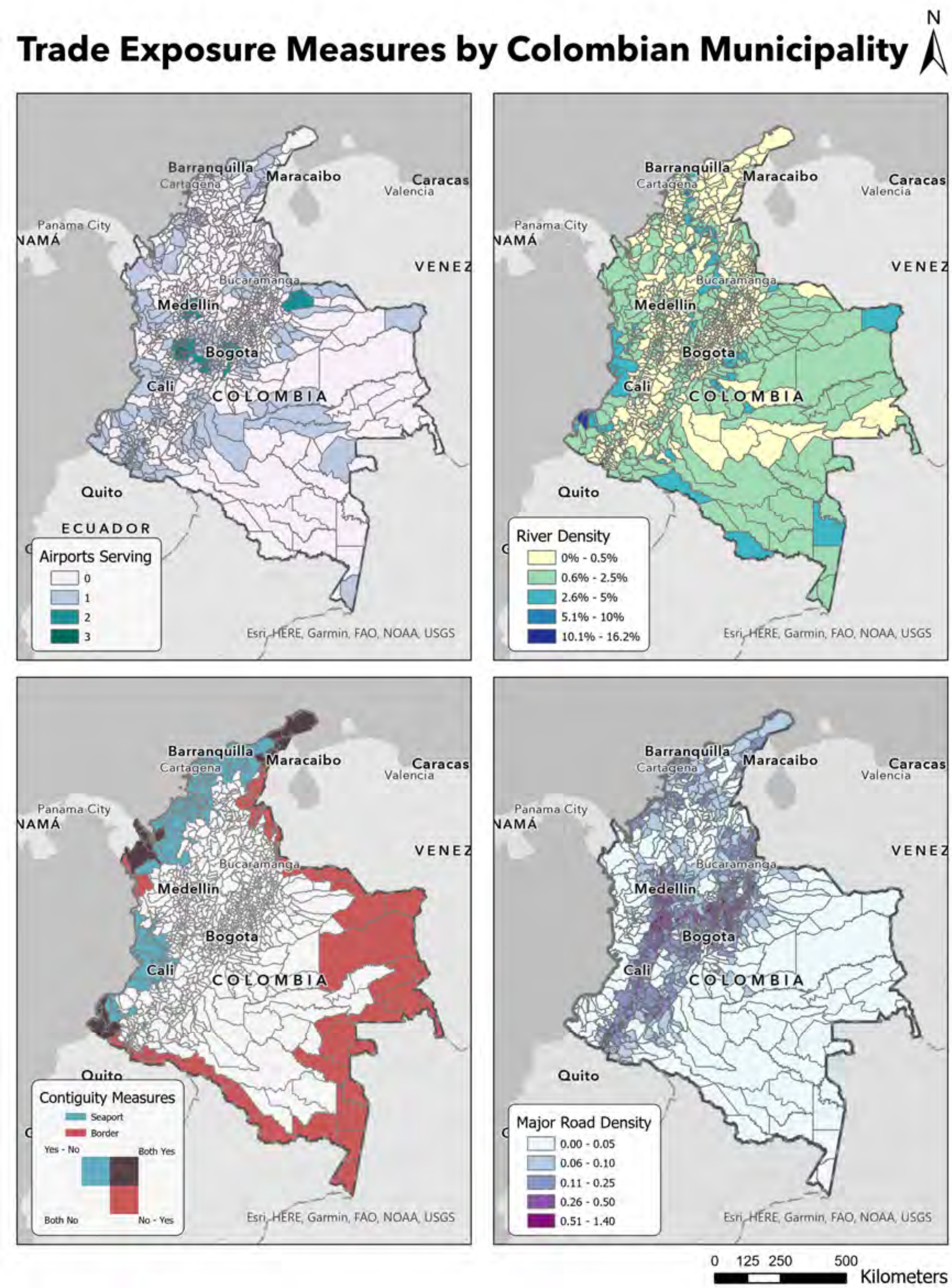

Figure 6: Map summarizing the trade exposure variables by municipality.

Appendices

A Tables

Table A.1: Movement of Domestic Cargo by Mode of Transportation

	Year	Trucking	Rail			River	Air	Maritime	Total
			Non-Coal	Coal	Total				
Millions of tons	2017	233,964	15.9	50,419	50,435	5,200	177	3,563	293,339
	2018	243,171	23.1	47,533	47,556	5,039	176.7	4,352	300,296
	2019	246,990	92.6	50,270	50,363	4,857	167	2,704	305,080
% Share	2017	79.76%	0.01%	17.19%	17.19%	1.77%	0.06%	1.21%	
	2018	80.98%	0.01%	15.83%	15.84%	1.68%	0.06%	1.45%	
	2019	80.96%	0.03%	16.48%	16.51%	1.59%	0.05%	0.89%	

Source: Colombian Ministry of Transport.

Table A.2: Key Dates of COVID-19 Spread Mitigation Policies

Day	Government Responses
03/06/2020	National government confirms first COVID-19 case.
03/12/2020	State of emergency declaration.
03/17/2020	Closure of land, sea, and river borders until May 30.
03/23/2020	Suspension of domestic and international flights.

B Figures

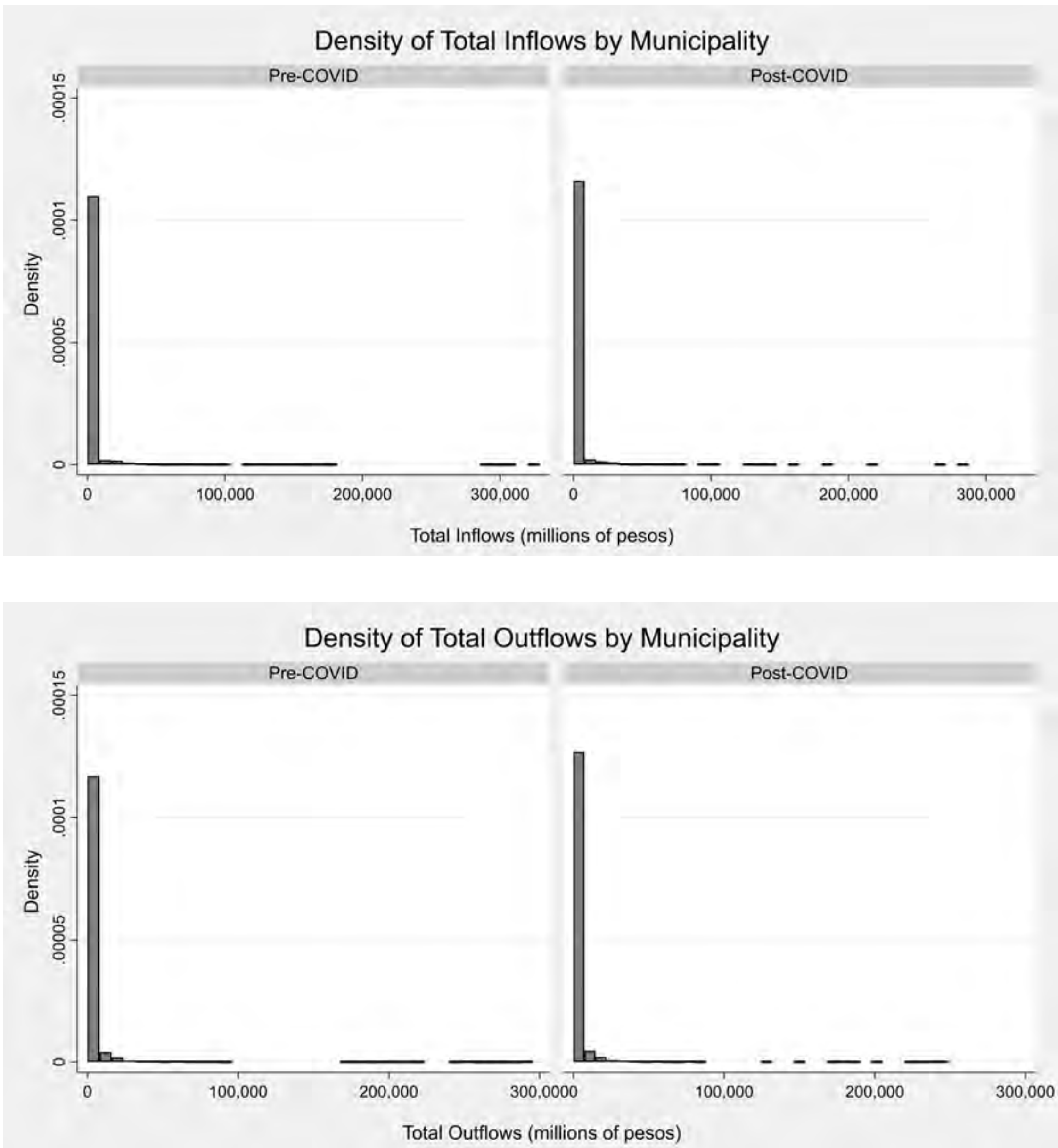

Figure B.1: Distributions of inflow and outflow trade values.

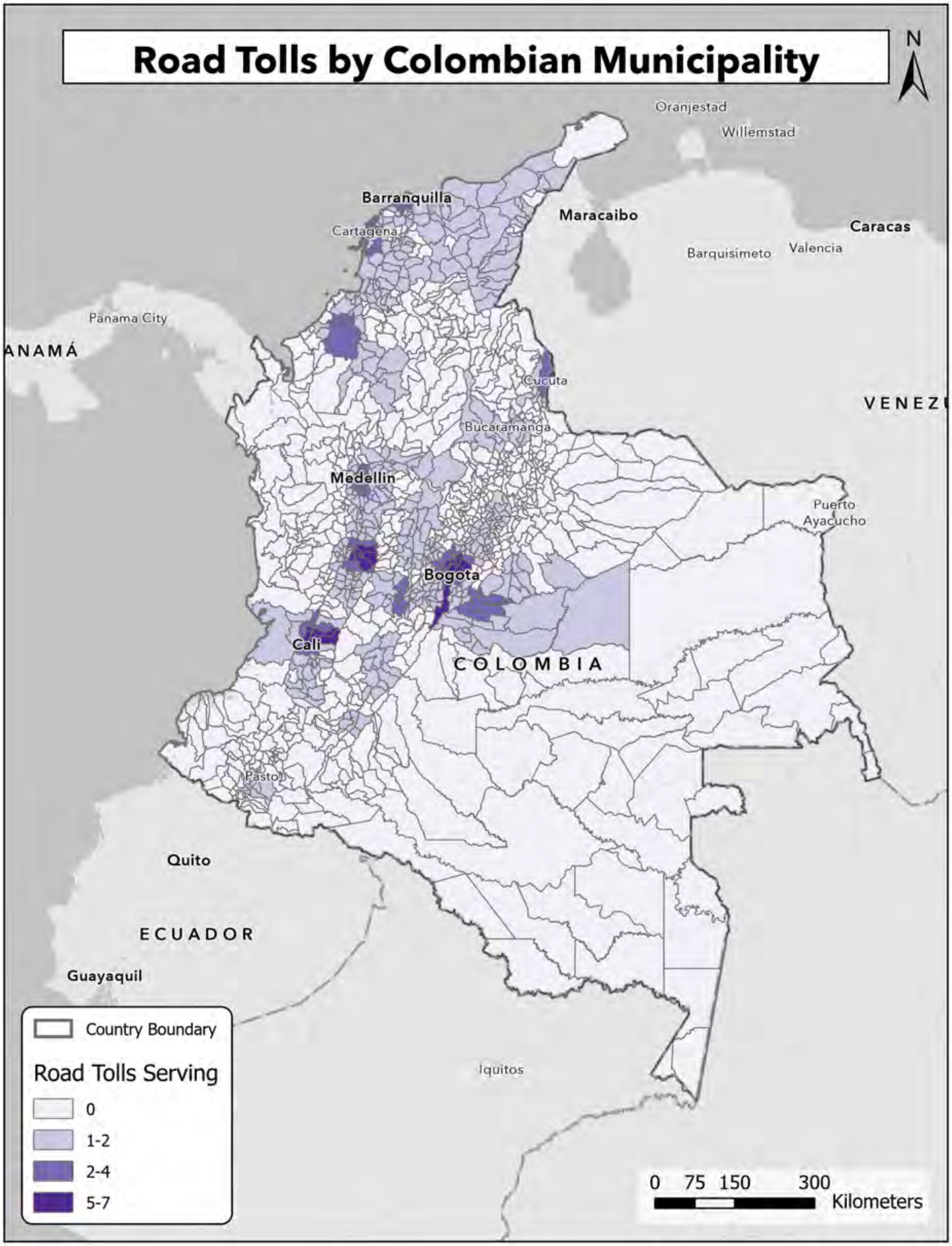

Figure B.2: Map summarizing the number of road tolls by municipality.

Figure B.3: Colombian road network.

Figure B.4: Colombian river network.