Exploring the Spatial Diffusion of Homicides in Mexican Municipalities Through Exploratory Spatial Data Analysis

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Abstract

In this article, we explore the spatial dimension of violence in Mexico by investigating the existence of spatial diffusion patterns associated with the increase in homicides. We specifically use exploratory spatial data analysis, or ESDA, techniques during the 2005-through-2010 period to measure the extent to which Mexican municipalities have experienced an increase in violence levels that have diffused to contiguous municipalities. The findings indicate significant levels of spatial dependency leading to spatial clustering of high-incidence rates of homicides in specific regions of the country, with diffusion patterns of high levels of homicide rates to other nearby municipalities. Furthermore, it has been found that, during the period of analysis, municipalities that acted as contributors to the spread of high-incidence rates have not reduced their levels but are still experiencing high-incidence rates during the period of study.

Introduction

Mexico witnessed a dramatic increase in violence levels during the second half of the 2000s. The most violent scenarios arose in areas with a high level of drug-trafficking activities and a long-standing presence of drug-trafficking organizations (DTOs, or cartels). It has been argued that the dispute among the DTOs concerning taking control of specific territories has been a major contributing factor in terms of the steep increase in violence when compared with previous periods of relatively stable trends in violence.

The role of geography is a crucial aspect when analyzing recent violence levels in the country. This cruciality is because of well-defined patterns across the country of the distribution of past and contemporary violence levels and also the presence of DTOs. On the one hand, drug-trafficking activities routing from Mexico to the United States have very longstanding roots. Such activities date back to at least the mid-1980s, when Colombian cartels extended their influence to the United States via drug-trafficking networks, particularly after the successful enforcement efforts by Colombian authorities against the Colombian Cali and Medellin cartels that eventually gave rise to the emergence of Mexican DTOs. Colombians previously trafficked cocaine through Florida (Payan, 2006). Mexican smugglers made ties with Colombian traffickers and relocated the activity to the northern border.

On the other hand, DTOs have taken advantage of the rugged terrain of the mountains to plant marijuana and opium and, more recently, to produce synthetic drugs. The region referred to as the Golden Triangle, formed by the states of Chihuahua, Durango, and Sinaloa, historically has been a major producer of illicit drugs. Evidence suggests that, in fact, mountainous terrain has a positive relationship with proliferation of armed conflict, which eventually translates to rising homicide rates (Fearon and Laitin, 2003).

Although drug-trafficking and related violence have become serious problems and have hindered the government and national security, the concerns do not apply to the whole territory but only to particular areas. In such areas, the levels of violence, as measured by the number of homicides, have soared dramatically since the end of 2006. The unprecedented increasing levels of violence have been attributed to the confrontation among DTOs, especially after the deployment of federal armed forces to combat these organizations and to eliminate criminal control of public spaces.

These operations were coordinated by military and federal police forces and were backed by state and local security forces. The strategy included the dismantling of criminal organizations, the arrest of the largest possible number of criminals and the confiscation of drug shipments, the deployment of military operations in several regions of the country, and a permanent increase in resources devoted to the military forces. The states exposed to these joint operations were Michoacán (December 2006), Guerrero and Baja California (January 2007), Nuevo León and Tamaulipas (January 2008), Chihuahua (April 2008), and Sinaloa and Durango (May 2008). These states, with the exception of Nuevo León, not coincidentally have a long tradition of being involved in either drug trafficking or the production of illicit drugs. The map in exhibit A1 in the appendix depicts these regions.

These factors may certainly play an important role in explaining the rise in violence and, in particular, the location in which violence became noticeable. The areas with creation and expansion of illegal markets will produce extra murders when contextual factors conducive to lethal violence exist (Zimring and Hawkins, 1997).

In this article, we focus on the spatial dimension of this phenomenon by investigating the existence of spatial diffusion patterns associated with the increase in homicides in Mexican municipalities. We specifically use exploratory spatial data analysis (ESDA) techniques during the 2005-through-2010 period to measure the extent to which Mexican municipalities have experienced an increase in violence levels that have diffused to contiguous municipalities.

Our contribution in this study consists of characterizing the type of spatial diffusion process in municipalities with low or high incidence levels. Using official, publicly available data of homicide records at the municipal level, the analysis employs global and local ESDA techniques to provide a descriptive analysis of the spatial distribution of homicides as well as dynamic changes that enable us to look for patterns across space in spatial dependencies. The analysis aims to answer the following research questions: How does the spatial distribution of homicides depict significant hotspot areas of high violence levels across the country? To what extent is spatial diffusion of high violence focalized within and between those states with longstanding drug-trafficking activities and where the joint operations took place.

Identification of concentrations or clusters of greater criminal activity has appeared as a central mechanism to targeting law enforcement efforts and crime prevention response to crime problems. These clusters of crime are commonly referred to as hotspots—geographic locations "of high crime concentration, relative to the distribution of crime across the whole region of interest" (Chainey and Ratcliffe, 2005: 147). The main interest of the present study is to better understand the existence of hotspots of contemporary violence in the country; nonetheless, the identification of crime hotspots should be considered as the starting point of a more detailed analysis. The conclusion section of this article addresses further research venues on the topic.

The article is structured as follows. The next section, which introduces the methodology based on the ESDA techniques and describes the data used in the analysis, is followed by a section that outlines the results and the final section that draws some conclusions.

Methodology

The methods described in this section are based on the use of ESDA, which helps visualize and describe the spatial distribution of homicides and also helps identify global and local spatial dependencies in the distribution of homicides across municipalities.

When exploring the distribution of homicides through ESDA, a common global indicator of spatial autocorrelation is the Global Moran's I. It indicates the extent to which our variable of interest is clustered, dispersed, or randomly distributed across municipalities by formulating a null hypothesis of randomness in the entire data (Anselin, 1995). The Global Moran's I is denoted in the following equation—

$$I = \frac{N \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}) \sum_{j=1}^{n} (x_i - \bar{x})^2}, \tag{1}$$

where N is the number of cases, x is the mean of the variable, x_i is the variable value at a particular location, x_j is the variable value at another location, and w_{ij} is a weight spatial matrix specifying the spatial interdependency of i relative to j. Positive values of this statistic indicate spatial clustering (for example, high homicide rates are found in close neighbors), while negative values indicate dispersion in the variable of interest.

The significance of this statistic is influenced by the specification of the spatial relationship among the units of analysis or, in other words, by the choice of the spatial weight matrix. In the present analysis, four different standardized weight matrices are considered in the calculation of this indicator: (1) the first order contiguity matrix, (2) the second order contiguity matrix, (3) the k-4 nearest neighbors, and (4) the inverse distance.

Although global spatial measures help to assess the strength of spatial autocorrelation across all spatial units, generating one global statistic, local spatial variations may also exist in the degree of spatial dependency. The latter can be tackled through the computation of local measures of spatial autocorrelation. The use of local statistics can inform us about spatial nonstationarity or spatially varying relationships in our variable of interest, thus identifying statistically significant clusters (Fotheringham, 2009).

To analyze the nature of the local distribution of homicides, a local version of Moran's I or local indicator of spatial autocorrelation (LISA) is employed. This statistic assesses a null hypothesis of spatial randomness by comparing the values of local pairs (that is, the values of each specific location with the values in neighboring locations; Anselin, 1995). It is particularly useful because it allows for the decomposition of spatial association into four categories (HH, LL, HL, and LH): (1) HH, or high-high—when a location with an above-average value is surrounded by neighbors whose values are also above average; (2) LL, or low-low—when a location with a below-average value is surrounded by neighbors whose values are also below average; (3) HL, or high-low—when a location with an above-average value is surrounded by neighbors whose values are below average; and (4) LH, or low-high—when a location with a below-average value is surrounded by neighbors whose values are above average. See Anselin (1993) for a detailed description of the statistical properties of LISA statistics.

Detecting the Spatial Diffusion Process

To explore the possible mechanisms associated with the diffusion process of homicide rates in the municipalities, this section develops an exercise that is useful for studying spatial clusters in a dynamic framework. Cohen and Tita (1999) identified changes in the levels of local-neighbor pairs (LISA clusters), looking at the type of diffusion process of homicide rates within spatial units. Within this framework, it is possible to identify four different mechanisms that may lead to changes from low to high levels (or vice versa) in local spatial units. Expansion and relocation are forms of contagious diffusion in which the status among neighboring spatial units affects the future status of adjoining units, by increasing the level either locally or for the neighbors located in the same local-neighbor pair. A distinction between these two forms is that with relocation the object that is being diffused leaves the point of origin and spreads outward from that point, and with expansion diffusion also spreads from the center but continues to experience high incidence rates of the diffusing phenomenon.

Spatial units can also change from low to high levels through hierarchical diffusion in the forms of isolated or global increases, which reflect increases (or decreases) that do not depend on contact with nearby high-level (or low-level) spatial units. Here the spread does not occur with direct contact but happens more through cultural influences (innovation or imitation) that affect the population or a particular subgroup that may be widely dispersed geographically (Cohen and Tita, 1999).

The idea of this exercise is to compare municipalities with transitions among different significant LISA pairs in successive years. We are especially interested in exploring those yearly transitions (between time *t* and *t*+1) from low to high levels of homicide rates among statistically significant clusters.[1] The case of a transition from an LH at time *t* to an HL or an HH at time *t*+1 indicates a contagious diffusion of high homicide rates, while a transition from an LL to an HL or an LH denotes a hierarchical type of diffusion process. Exhibit 1 shows other possible transition combinations.

Exhibit 1

Dynamics of Change in the Spatial Distribution of Homicide Rates Over Successive Years

Direction of Change	Type of Diffusion	Mechanism of Change	Year-to-Year Change in Local Neighbor Pairs	
			Local Is Diffusion Outcome	Local Is Diffusion Source
From low to high levels	Contagious	Expansion among neighbors	LH to HH	HL to HH
		Relocation among neighbors	LH to HL	HL to LH
	Hierarchichal	Isolated increase	LL to HL	LL to LH
		Global increase	LL to HH	LL to HH
From high to low levels	Contagious	Expansion among neighbors	HL to LL	LH to LL
		Relocation among neighbors	HL to LH	LH to HL
	Hierarchichal	Isolated increase	HH to LH	HH to HL
		Global increase	HH to LL	HH to LL
No change	None	Stationary		

HH = high-high. HL = high-low. LH = low-high. LL = low-low.
Source: Cohen and Tita (1999)

Data Description

The data for homicides come from the vital statistics of the Instituto Nacional de Estadistica y Geografia (INEGI). These data consider all types of homicides (ICD-10: X85-Y09)[2] that occurred in Mexican municipalities from 2005 through 2010. We also explore a database for homicides related to drug rivalry or organized crime released by the Presidencia de la Republica. Starting in 2007, a database on homicides related to organized crime was produced for statistical purposes only; no ministerial or judicial information was included, only the numbers of deaths in municipalities and states. These deaths are classified as homicides related to organized crime if they occur with extreme violence or as an event involving more than two victims and include at least two of the following criteria: the body had an injury that resulted from the use of a firearm; the body had severe injuries and showed signs of torture; the body was found in the interior of a vehicle; the death of the body showed use of materials characteristic of the modus operandi of organized crime; and particular facts related to the death of the body, such as if the event occurred in an ambush, was a persecution, or included the finding of a message linked to organized crime.

[1] In this study, significance levels directly obtained from the LISA calculations differ from those of George and Tita (1990), which consider significant local pairs to be those that involve a change of at least two standard units in the value of LISA local pairs (see the reference for further details).

[2] International Classification of Diseases, World Health Organization.

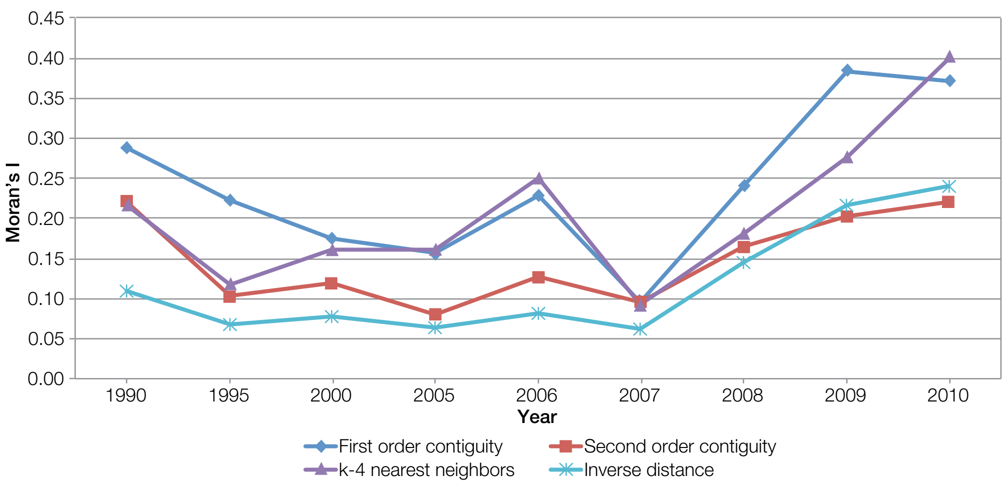
These data exhibit some issues related to data-gathering reliability, however, given that these criteria are used when classifying the homicides and because, for some of the cases, no official death certificate is attached. These factors in turn produce an overestimate of the total counts of homicides related to organized crime or drug rivalry compared with those officially reported by INEGI (Merino and Gomez, 2012). Although we analyze both databases currently available in Mexico, the final set of results is based on mortality data from an official vital statistics report by INEGI; in this sense, the data for narcotics-related homicides are used only for comparison, given the previously mentioned problems related to such a database.[3]

Results

Exhibit 2 shows the Moran's I value of total homicides obtained using different weighting matrices for 5-year intervals from 1990 through 2005 and yearly from 2006 up to 2010.[4] As noted, the spatial dependence of total homicide rates among municipalities does not follow a regular pattern until 2007, when thereafter a constant yearly growth is observed. This pattern indicates that high levels of homicide rates resulted in more clustering across spatial units,[5] and this pattern, obtained

Exhibit 2

Global Moran's I Statistic of Total Homicide Rates in Mexican Municipalities, 1990–2010



[3] Also, Rodriguez-Oreggia and Flores (2012) detected that between 8 and 12 percent of municipalities, at some point in time, have more homicides related to narcotics than the total official account of homicides.

[4] The respective Global Moran's I for narcotics-related homicide rates was also calculated, but the rates are not reported here. Data availability allows for the yearly calculation of homicide rates from 2007 onward, and the results show a higher degree of spatial autocorrelation among observations, confirming the descriptive analysis shown in the previous section. These results are available from the authors upon request.

[5] All values show statistical significance levels of at least $p < 0.05$.

from comparing different weight matrixes, is consistent. The calculations also suggest that the weight matrix assessing the higher degree of spatial dependence occurred with the first order contiguity matrix. The use of this matrix is appropriate for this study because we are interested in the diffusion of homicide rates occurring primarily in contiguous municipalities. Hence, the empirical evidence shown in the subsequent sections rests on this type of weight matrix.

Exhibit 3 reports the prevalence of municipalities within each local cluster type obtained from LISA on a yearly basis during the period of 2005 through 2010 for total homicides (Panel A) and for narcotics-related homicides since 2007 (Panel B). Three main results arise and are described as follows.

First, the number of municipalities exhibiting significance levels for any local-neighbor pairs (cluster type) of total homicide rates rose during the period from 418 to 548. For narcotics-related homicides, the number increased from 191 to 353 municipalities.

Second, at the beginning of the period, approximately 109 municipalities were showing an HH cluster type of total homicides, accounting for 4.4 percent of the municipalities. These municipalities have homicide rate values that are above average and are surrounded by neighbors whose values are also above average. Note that the HH cluster type reached its highest levels in 2008,

Exhibit 3

Percentage of Local-Neighbor Pairs of Homicide Rates in Mexico, 2005–2010

Cluster Type	Year					
	2005	2006	2007	2008	2009	2010
A. Total homicides						
HH (high-high)	4.44	4.97	3.42	7.09	6.32	5.58
	(109)	(122)	(84)	(174)	(155)	(137)
LL (low-low)	8.64	10.47	0.24	10.92	10.47	14.87
	(212)	(257)	(6)	(268)	(257)	(365)
LH (low-high)	2.57	2.04	2.53	2.24	1.96	1.43
	(63)	(50)	(62)	(55)	(48)	(35)
HL (high-low)	1.39	1.18	1.51	1.26	0.86	0.45
	(34)	(29)	(37)	(31)	(21)	(11)
No significant cluster	82.97	81.34	92.3	78.48	80.4	77.67
	(2,036)	(1,996)	(2,265)	(1,926)	(1,973)	(1,906)
B. “Narco” homicides						
HH (high-high)	NA	NA	3.38	4.48	5.54	5.38
			(83)	(110)	(136)	(132)
LL (low-low)	NA	NA	0.20	1.18	2.53	6.68
			(5)	(29)	(62)	(164)
LH (low-high)	NA	NA	2.69	2.36	1.87	1.47
			(66)	(58)	(46)	(36)
HL (high-low)	NA	NA	1.51	1.3	1.02	0.86
			(37)	(32)	(25)	(21)
No significant cluster	NA	NA	92.22	90.67	89.04	85.62
			(2,263)	(2,225)	(2,185)	(2,101)

NA = information not available.

Notes: Pairs of municipalities with significant local clusters (local indicator of spatial autocorrelation, or LISA) of the homicide rate for a respective year. The parentheses denote the total number of municipalities in each local cluster. N = 2,454.

with 7 percent of total municipalities, or approximately 174 municipalities, being included in this type. This HH cluster type shows a consistent decline after reaching its peak in 2009 and 2010, although its values are still higher than the initial values in 2005.

Third, higher levels of narcotics-related homicides surrounded by municipalities with HH levels were concentrated in approximately 83 of the municipalities, or about 3.4 percent of the total, in 2007. During the following 2 years, an upward trend was observed, suggesting an increasing number of municipalities with an HH cluster of narcotics-related homicides. By 2010, HH occurred in approximately 132, or 5.4 percent, of the municipalities.

A useful way to visualize clustering patterns of homicides in Mexico is through mapping. To this end, we combine ArcGIS and GeoDa software capabilities to create a series of maps, which summarizes much of the previous discussion. As discussed previously, we prefer to use total homicides instead of drug rivalry homicides. Consequently, the rest of the analysis relies on total homicide data from INEGI. In exhibit 4, it is possible to distinguish the states with army intervention and also the distribution of only the HH clusters of total homicide rates for each year from 2005 through 2010. The latter are displayed as centroid circles with a graduated color corresponding to each year.

As observed, much of the concentration of high homicide rates at the beginning of the period occurs in the states that will have army intervention later. This concentration in turn supports the argument that the federal government used to deploy armed forces to particular areas within the country that exhibit considerably high levels of violence.

Exhibit 4

Spatial Diffusion of High-High (LISA) Clusters of Total Homicides in Mexico, 2005–2010 (1 of 4)

a. 2005

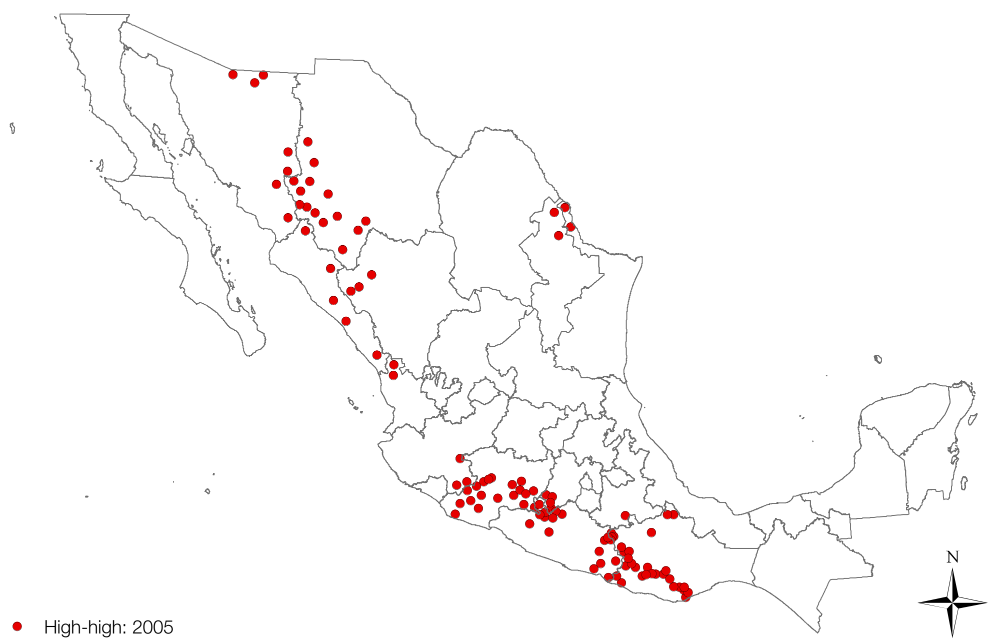
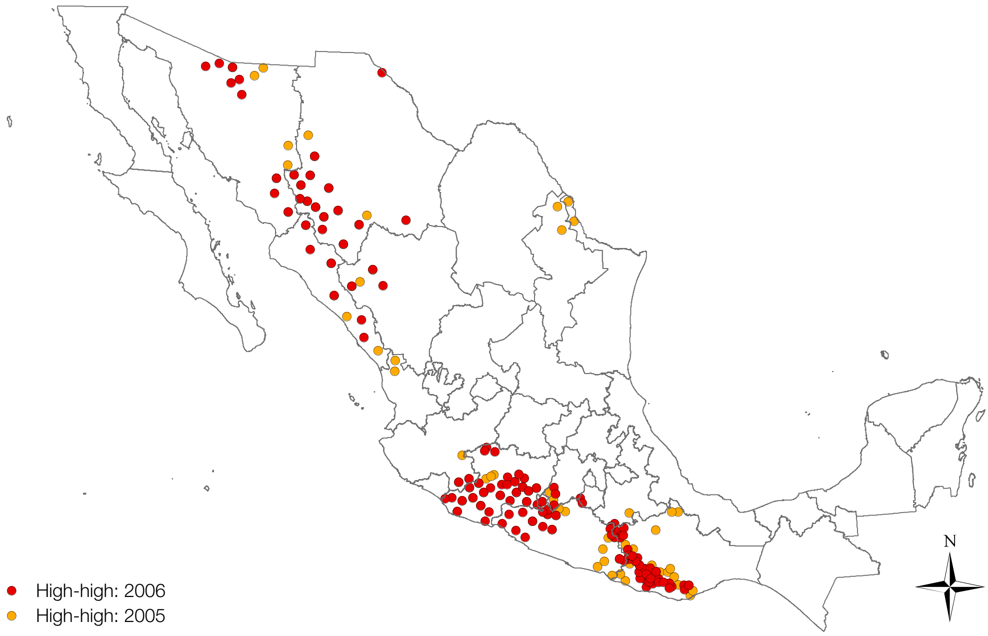


Exhibit 4

Spatial Diffusion of High-High (LISA) Clusters of Total Homicides in Mexico, 2005–2010 (2 of 4)

b. 2005–2006



c. 2005–2007

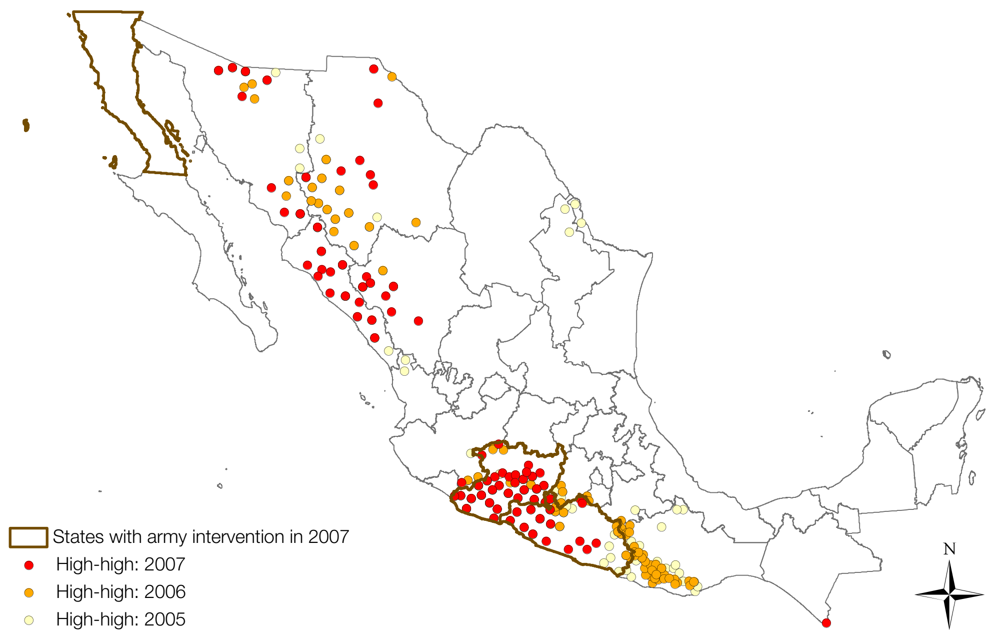
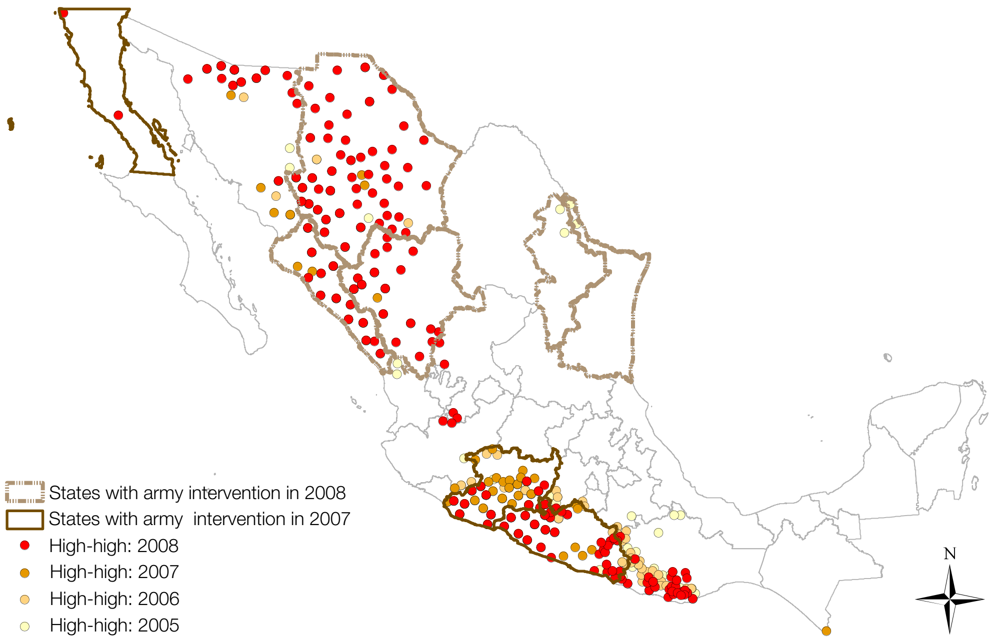


Exhibit 4

Spatial Diffusion of High-High (LISA) Clusters of Total Homicides in Mexico, 2005–2010 (3 of 4)

d. 2005–2008



e. 2005–2009

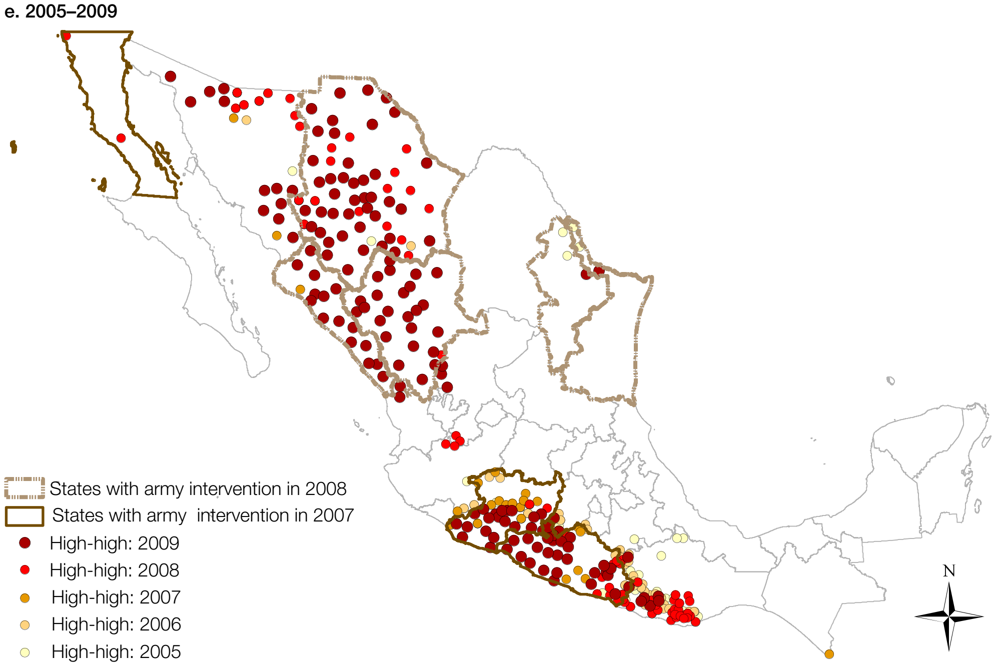
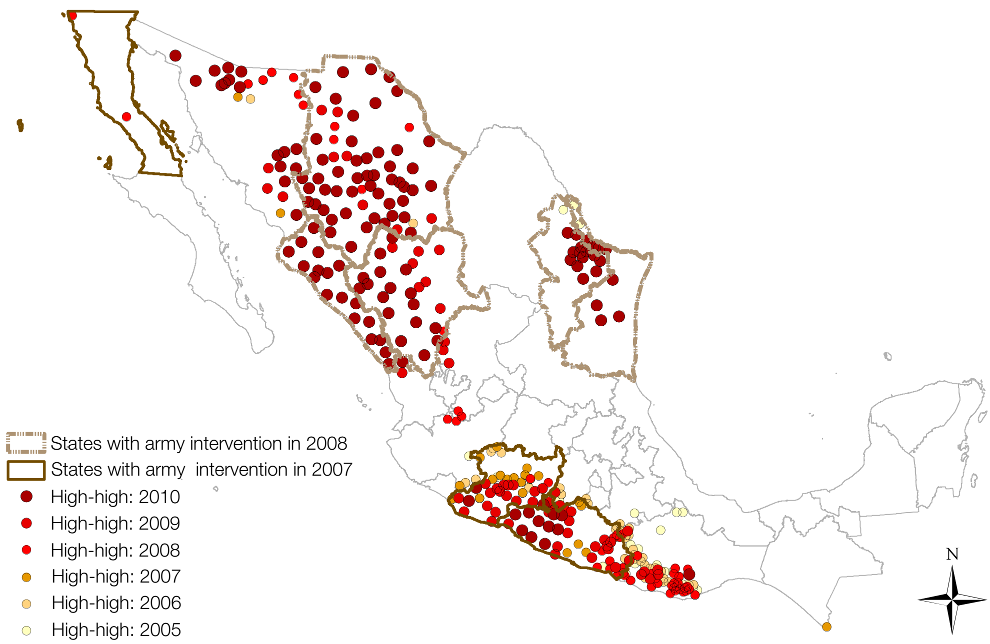


Exhibit 4

Spatial Diffusion of High-High (LISA) Clusters of Total Homicides in Mexico, 2005–2010 (4 of 4)

f. 2005–2010



LISA = local indicator of spatial autocorrelation.

The geographic dispersion patterns followed by these HH clusters are also noteworthy. On the one hand, a greater proportion of municipalities were experiencing clusters of the HH type within the states that, at the beginning of the period, were already experiencing high homicide levels. On the other hand, a considerable proportion of municipalities that experienced transitions from nonsignificant to significant spatial clusters, particularly to HH type, continued to experience high levels of homicide rates despite the deployment of federal forces.

Detecting the Spatial Diffusion Process: Results

The analysis then considers previous results (reported in exhibit 3) to calculate local pair changes. Exhibit 5 reports the results associated with the analysis of total homicide rates. To facilitate the explanation, we first provide the results for the proportion of municipalities that enter into each type of diffusion (contiguous or hierarchical) and have a direction change from low to high levels, and then we determine whether the local pair serves as an outcome or a source of these transitions.[6] As described previously, a high incidence of homicide rates for the period of study tend to be spatially clustered within states in which army interventions actively operate; hence, the analysis also performs a *t*-test for mean differences of each outcome to whether the municipality belongs these states as compared with the rest.

[6] The same analysis was performed for the transition from high to low levels of local significant clusters.

Exhibit 5

Patterns of Yearly Changes in Local-Neighbor Municipalities in Mexico, Homicide Rates, 2005–2010

Municipality As Outcome/Source of Diffusion of Increases in Homicide Rates	Proportion of Municipalities With Change in Homicide Rates in Successive Years
Effect of Neighbor Rate at Time *t* on Local Rate at *t* +1	**Diffusion[a] (all municipalities)**
I. Diffusion outcome	
a. Hierarchichal: isolated or global increases (LL to HL, LL to HH)	0.57
b. Contagious: expansion or relocation increases (LH to HH, LH to HL)	2.32***
II. Diffusion source	
c. Hierarchichal: isolated or global increases (LL to LH, LL to HH)	0.12
d. Contagious: expansion or relocation increases (HL to LH, HL to HH)	0.24
III. No change: stationary	
HH	0.33**
HL	0.00
LH	0.00
LL	0.00
No significant cluster	51.79***

HH = high-high. HL = high-low. LH = low-high. LL = low-low.

[a] Proportion of municipalities with change in homicide rate in succesive years.

*** $p < 0.05$. *** $p < 0.001$.*

Two main findings arise. First, the evidence suggests that transitions from low to high homicide rates follow a contiguous expansion or relocation diffusion type with significantly larger proportions in states with joint army intervention. The diffusion source of high levels of homicide rates is higher among local pairs of municipalities that are contiguous with municipalities that experience high homicide rates at the beginning of each period (year). Second, a significantly larger proportion of municipalities that stayed within the HH cluster type during each successive period occurred in states with army intervention. Approximately one-half of all the municipalities do not show statistically significant levels of any clustering type during successive periods.

As discussed previously, it is possible to identify whether a contiguous source of diffusion outcome has occurred through relocation or if an expansion type of diffusion has taken place. Exhibit 6 separates the proportion of municipalities whose local-pair transitions fit within each of these two types. The results indicate that the spread of homicides resulted from an expansion diffusion. These results provide evidence that the object being diffused (homicide rates) has spread from its original place (municipalities), while the original source of diffusion still has high incidence rates of homicides. Furthermore, a significantly large proportion of the diffusion seems to occur in those municipalities experiencing joint army interventions, as the respective *t*-test shows significant levels.

The findings in this section can be summarized as follows. On the one hand, the analysis reveals that the increase in levels of homicide rates in Mexico has occurred particularly within the states facing joint army interventions. Evidence also indicates significant levels of spatial dependency

Exhibit 6

Mechanism of Change of Homicide Rates in Local Neighbor Municipalities in Mexico, 2005–2010

Municipality As Source of Diffusion of Increases in Homicide Rates	Proportion of Municipalities With Change in Homicide Rates in Successive Years
Effect of Neighbor Rate at Time *t* on Local Rate at *t+1*	**Diffusion[a]**
Contiguous diffusion	
a. Expansion among neighbors (LH to HH)	2.24***
b. Relocation among neighbors (LH to HL)	0.08

HH = high-high. HL = high-low. LH = low-high.

[a] Proportion of municipalities with change in homicide rate in succesive years.

**** $p < 0.001$.*

among municipalities that have high incidence rates of homicides. On the other hand, it appears that high levels of homicide rates are being diffused to other nearby municipalities. The mechanism through which this diffusion takes place suggests that municipalities that act as contributors to the spread of high incidence rates have not reduced their levels, but, on the contrary, continue to experience high incidence rates and that this takes place in greater proportion in municipalities that experience army intervention.

Conclusions

In this article we aim to analyze the extent of the diffusion of violence, measured with the number of homicides, among Mexican municipalities from 2005 to 2010. During this period, Mexico was characterized by a rise in organized crime, and, while some army intervention was executed in some states, violence seems to have displaced to other localities. Here we look at this particular phenomenon using ESDA techniques aimed to examine the dynamics of local spatial clustering, measured by LISA transitions, and thus provide a better description of the extent to which spatial diffusion of violence occurred across the country. For a developing country immersed in an organized crime wave, the analysis and implications are relevant, not only for Mexico, but also for countries in the region facing a similar context.

The findings suggest an increase in significant spatial clusters of homicides for the period of consideration in 2 percentage points of the municipalities. Concentration tends to occur in the first years of analysis in states where army intervention took place later. Even after the army intervention, most of the municipalities in those states remained high-high clusters of violence. The significance test shows a clear contagious effect among neighbors, while HH clusters remain stationary after army interventions.

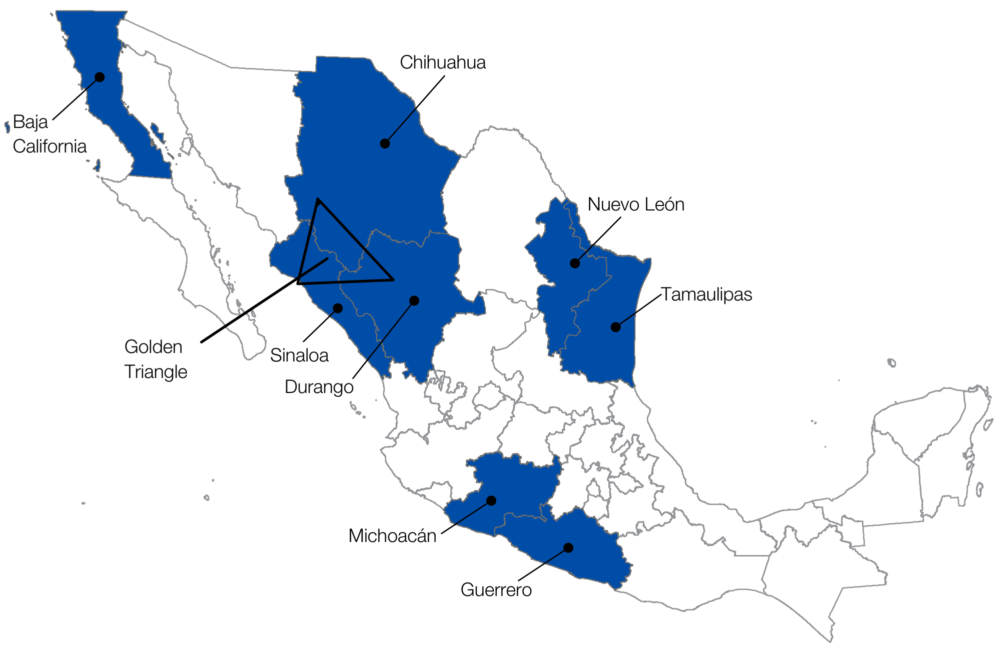
One implication of the analysis suggests that law enforcement policies applied in such hotspot areas were ineffective on spatially restraining levels of violence, at least during the period here considered, leading to the spread of violence levels to neighboring areas. Failure of law enforcement policies calls for the implementation of other actions, either to replace this action or be complementary to it, where homicides have increased and spread among areas.

A final comment addresses the theoretical framework and statistical techniques described here. As explained previously, these techniques explicitly consider the spatial distribution of homicides in which the goal was to show the existence of a geographic diffusion to areas immediately surrounding the direct focus of the policy efforts described. Nonetheless, the inference made from the empirical analysis does not imply a formal causality test between army intervention and rising homicides in absolute terms; other factors, such as clashes among drug cartels or groups within them, could be influential factors.

Appendix

Exhibit A-1

Mexican States Exposed to Army Joint Operations



Note: States with army intervention as part of the "Operativo Conjunto" are in blue.

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