

Epidemics of drug gang murders? Spatial and spatial-temporal patterning of homicide in a Latin American city (Montevideo)

Abstract

Despite economic, political and social gains after the years of dictatorial regimes and civil wars in the 1980s, the Latin American region has experienced increasing levels of violence and criminality that place it among the most violent in the world. However, despite this obvious importance and scientific relevance, it remains an understudied setting. The present study addresses the rise in homicide levels in one Latin American city (Montevideo), seeking to understand the nature of trends of increasing violence. To this aim, it uses Spatial Data Analysis and epidemiological techniques to explore in detail patterns of homicide location clustering and space-time association of homicide events. The findings show increasing levels of spatial autocorrelation and space-time association of homicides, suggesting that the spatial process at work behind the increase in violence might be one of Diffusion or contagion. This, in turn, would seem to lend some support to widespread views and scattered evidence that the rise in lethal violence could reflect an emerging gang problem centered around the retail distribution of drugs, particularly a local form of crack cocaine.

Keywords: drugs, gangs, homicide, Latin America, epidemic

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Javier Donnangelo

Department of Sociology, Universidad de la República, Uruguay

Correspondence: Javier Donnangelo, Department of Sociology, Universidad de la República, Uruguay

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Introduction

Despite economic, political and social gains after the era of dictatorial regimes and civil wars in the 1980s, the Latin American region has experienced increasing levels of violence and criminality that sharply diverge from trends in other continents.¹ Studying this is an important research endeavour for at least two reasons: despite being among the most violent in the world,² the Latin American region remains an understudied context, with most articles on criminological journals focusing on the USA or, at most, Europe and Australia; second, the trend followed by Latin American countries runs contrary to much criminological theorizing and comes, therefore, as a puzzling and unexpected phenomenon. Needless to say, this gives the subject much theoretical relevance as well as a fascinating and intriguing character.

The city of Montevideo (capital of Uruguay) has not been an exception to these wider regional trends and patterns. After several years of great stability at around 100 cases per year, in 2012 the number of homicides in the city reached 148 and, since then, it has not fallen below this last figure again. Relative to population size, the number of homicides in 2012 represented a rate of 11 per 100,000 inhabitants. During more recent years, the city's homicide rate continued to rise, reaching values of around 14 per 100,000 inhabitants between 2022-2024.³

Though there is a great deal of anecdotal evidence in the form of field experiences of police officers and news stories that suggests these developments might well be linked to the booming of illegal markets (particularly those centered around the drug trade) and an emerging gang problem, there has been little systematic effort to address the nature of the rise in homicide through data and rigorous scientific analysis. Besides, the few studies that have attempted to do so have encountered difficulties in arriving at a definitive diagnosis of the causes of the increase in violence, stemming from problems of traditional data sources for studying homicide circumstances widely acknowledged in the literature.^{4,5} In particular, the lack of clearly stated

motives for homicides in Police case files and the fact that the structure of these reports is largely unstandardized across police Departments and even stations, have impaired progress in understanding what the nature and driving forces of the rising trend are.¹ This has only been compounded by decreasing clearance levels, which means that for a substantial proportion of homicides there are no case files at all or only very short ones, with almost no useful information for research purposes.

Since the literature on Diffusion of social phenomena and, more generally, epidemics of any kind provides a set of useful concepts and methods to understand the multiplication of events, this article applies an epidemiological and spatial data analysis approach to the study of the increase in homicides in the city of Montevideo. In this way, it seeks to provide a supplementary approach to prior studies based on the analysis of the narratives in police case files, thus allowing further insight into the causes of the rising trend in violence. More specifically, very likely for the first time for a Latin American country, this study reports the results of a spatial data analysis of homicide clustering using the join counts method for studying spatial autocorrelation, and a spatial-temporal analysis of homicide events using the Knox coefficient. In sum, therefore, the article explores whether the rise in homicide in Montevideo can be explained as a Diffusion process.

Background

Contagion and diffusion of violence

The literature on Diffusion of social phenomena has frequently resorted expressly or tacitly, to epidemic analogies and, particularly, ¹The narrative about the unfolding of events leading to a homicide contained in police reports is often quite brief and sketchy. The main reason for this is that it aims at providing information that is important from an administrative and forensic standpoint, rather than conveying a deep description of the context and motivations surrounding a homicide. It is not always easy, then, to classify the precipitating circumstances of a homicide (for example, to determine if it was the result of a drug-related conflict) on the basis of these reports. A more detailed discussion of the limitations of this type of data source can be found in Donnangelo (2024).³²

to the idea of the “contagion” of social conditions between groups and/or societies (Hagerstrand, 1953).^{6,7} Citing Hagerstrand’s classic work on the diffusion of technological innovations, Odland⁷ argues that the adoption of an innovation depends on *previous adoptions*. This is so because the process of expansion depends on the circulation of information about the new technology and the results of adopting it coming into the possession of the early adopters. In turn, these innovators pass on the new technology to new people through personal interactions between innovators and those who have not yet adopted a change but may soon. Obviously, this interaction is greatly facilitated by physical proximity between innovators and people who have not yet adopted the new technology. This process plays a major role in facilitating dissemination of any kind (see also Gladwell).⁸ Statistically, Odland argues that such a process determines that *the geographical distribution of the adoption of an innovation at any given time is associated with the distribution corresponding to earlier moments*. In other words, new adoptions tend to occur in the vicinity of the first adoptions, thus generating a conditioning of the location of new cases whereby these will appear nearby the places corresponding to the earlier cases.

For Odland, moreover, the space-time process of diffusion of an innovation is but a particular case of a more general class of epidemic phenomena, which include the spread of diseases. The analogies of contagion and diffusion have been used with some frequency in criminological studies dealing with the analysis of the expansion of violence and, particularly, gangs, drugs and, in general, organized crime^{9–19} One reason for this is that they are potentially useful to account for the dynamics followed by certain varieties of homicide (such as those derived from gang wars for control of drug trafficking), characterized by the interconnection and concatenation between events through processes of revenge and retaliation, a feature that resembles the lack of independence between epidemiological (contagious) events. Indeed, as established by a wide variety of studies on the phenomenon of gangs, the patterns of revenge killings and retaliation in which gangs are usually involved tend to produce escalation of violence.^{20–30}

More recent theoretical developments have focused on the related notion of crime cascades.³¹ This concept refers to processes by which phenomena of a certain kind give rise to new identical or related phenomena, sending shock waves through time and space that multiply crime events and other undesirable social outcomes. According to Braithwaite, in fact, contagion in biology and cascade phenomena in the social sciences share a core of meaning: they constitute processes by which the existence of one phenomenon induces the appearance of other phenomena of the same type (or mutations), thus configuring a scenario that demands an approach that focuses on *endogenous* mechanisms of expansion rather than the classical *exogenous* factors that dominate criminological thinking.

Empirically, the shift in focus from exogenous explanatory factors to endogenous processes also seems to be justified by the disproportion between the variability of criminal phenomena and that of the factors classically proposed as their causes. Thus, Braithwaite points out that the magnitude of criminal phenomena exhibits brutal disparities across space and time, which are usually accompanied by much more modest differences in their exogenous correlates.

Gangs and drugs as conduits for the contagion and diffusion of violence

The possible mechanisms for the “contagion” of violence have often been conceptualized in terms of the intersection of group

processes and certain kinds of economic activity. Thus, youth gangs dedicated to the distribution of goods in markets not regulated by legal mechanisms for resolving disputes and conflicts (such as those of drugs), have been repeatedly pointed out in the literature as a factor that can produce the diffusion of violence. Cohen and Tita,¹² for example, analyzing the growth of homicides during the second half of the 1980s in the United States, explained the concentration of this growth in young Afro-American victims and offenders and in incidents perpetrated with firearms, in terms of the growing participation of this segment of the population in urban gangs and crack markets.^{33,34}

Gang violence has also been shown to display several important spatial characteristics. First, it is strongly related to the spatial or geographic adjacency of gang territory.²⁹ Secondly, gang homicides display a higher degree of spatial autocorrelation than other varieties of lethal violence.¹⁸ Finally, a spatial association between drug distribution areas and gang areas has been documented in rigorous empirical studies using spatial scanning techniques.³⁵

Research has also shown that group processes such as reciprocity are paramount to understanding patterns of violence between gangs.²⁹ The latter pattern is consistent with the findings of Klein and Maxson,³⁶ who established, in comparing gang homicides with other types of lethal violence, that the former were much more often based on fear of retaliation.²¹

As for the nexus between drugs and violence, it has been long theoretically acknowledged and empirically documented.^{4,37–41} In particular, “systemic” violence has been pointed out as an inevitable and frequent consequence of illegal markets, which by definition operate outside the legal mechanisms for regulating transactions (and the conflicts associated with them). In this type of market, therefore, violence appears as the only means available for the resolution of conflicts stemming from competition among dealers and the enforcement of codes of conduct and work discipline among the members of illegal economic groups.

Crack markets, specifically, have been considered to have high potential for violence, due to peculiarities of their organization and the psychopharmacological properties of this drug.^{12,42,43} Thus, because it is a relatively low-cost substance, a small initial capital is required to start the distribution of this drug. Because it is much cheaper than cocaine, acquiring a large enough batch to enter the market as a retail distributor requires an investment within the reach of many more people than in the case of more expensive drugs. This, in turn, leads to a rapid saturation of retail distribution, with the consequent increase in competition and the consequent territorial conflicts. Therefore, the distribution of crack is a feasible activity for many individuals who see in it a means of quickly obtaining a level of income well above that which is accessible to them through more conventional activities.

From a psychopharmacological point of view, crack also has peculiarities that could enhance the probability of violent outbursts around its marketing and consumption. Thus, it seems characteristic of this drug to produce a rapid and intense (but brief) climax, followed by states of depression and distorted forms of thinking (particularly paranoid thoughts).³⁹ Obviously, this can only create a mood prone to the acquisition of weapons for defensive purposes, as well as to the carrying out of preemptive strikes in order to neutralize expected future aggression.

Recent trends in violence in Latin America

Bergman¹ has shown that Homicide rates in countries such as Brazil, Mexico and Venezuela (as well as most of those in Central

America) have reached unprecedented levels over the last couple of decades, and even traditionally safe countries such as Argentina, Chile and Uruguay have experienced notable increases in their crime rates. To explain this, Bergman highlights the importance of illegal markets associated with drug trafficking, which are the most lucrative of all illicit transactions. He underscores, in this sense, that the immense profitability of these goods created by the existence of a very large consumer base associated with a supply limited by prohibitionist policies creates unmatched profit opportunities for hundreds of thousands of individuals from poor backgrounds.

But Bergman also highlights a new aspect of drug trafficking in Latin America. He points out that, although Latin American countries have traditionally been exporters of drugs to centres of consumption in Europe and North America, since the end of the 1980s local consumption has been increasing as well (not only in producing countries such as Colombia, Peru and Bolivia), but in the region as a whole. In particular, various forms of smokable coca paste obtained from the first phases of the processing of coca leaves (i.e. a local form of “crack”) have burst onto the scene in major cities across the continent, becoming extremely popular, due to their low cost, among cohorts of young users in economically deprived areas.

Thus, in addition to conflicts between large exporter organisations (the so-called cartels), many cities are experiencing outbreaks of violence originating in conflicts between small distributors who dispute territory and the right to produce and sell. Examples of the latter provided by Bergman (2018) include the three medium-sized cities of Fortaleza (Brazil), Acapulco (Mexico) and Rosario (Argentina, province of Santa Fe).ⁱⁱ

Homicide in the city of Montevideo

Though there has not been much systematic research aimed at explaining the causes of the increase in violence in Montevideo, Donnangelo³² has uncovered several important patterns. Thus, the increase in homicides in 2012 did not encompass all varieties of this type of events. Neither homicides resulting from property offences (robbery and burglary), nor those arising from domestic or intrafamilial conflicts, recorded significant increases during 2012. Likewise, there was not a noticeable increase in what is often termed “character contests”: somewhat spontaneous altercations between acquaintances about saving face.^{44–47} On the other hand, homicides involving firearms, those occurring in public places and those involving victims with criminal backgrounds, all recorded increases over the previous years. Drive-by shootings with fatal outcomes were, too, among the types that increased. Also, in parallel to the rise in homicides, during 2012 there was a decrease in the clearance rate of this crime (or, in other words, unsolved homicides were another of the categories that clearly rose). Taken together, the latter patterns are quite consistent with the features posited in the literature as characteristic of homicides linked to the activity of more or less organized criminal groups.^{22,23,25,48–50} Though informative, due to the high share of unsolved cases, the aforementioned patterns do not provide a complete picture regarding the circumstances surrounding many homicides.

ⁱⁱThe case of Rosario is particularly important in the context of the present study, because of the geographical proximity between this city and Montevideo, as well as the striking similarity between the two places. Thus, both cities have very similar population sizes and are ports of main importance in the region. *In addition, trends in homicide in Rosario are remarkably like that for Montevideo, with upward turns (“peaks”) during the same years.* Indeed, *in both cities homicides rose very clearly from 2012 onwards* (Ministerio de Seguridad y Fiscalía General de la Provincia de Santa Fe, no date).

The current study

This study seeks to contribute to the understanding of recent rises in homicide levels in the city of Montevideo. With about 1.4 million inhabitants, Montevideo is the capital of Uruguay (a country with a total population of about 3.5 million). It is the largest city in the country and a rather dense one, with its population representing some 40% of the total population of Uruguay spread over just 0.3% of the national territory.

As regards social conditions, Montevideo has welfare levels well below those of, say, most Western European cities, although it has traditionally been above most large Latin American cities. By way of example, around 2016, the population below the poverty line represented 13% of the total population of the city.⁵¹ As for unemployment, in July 2016 it stood at around 9%.⁵² According to census data, as of 2011 about a quarter of the people were living in rented housing.⁵³ Regarding schooling, about a quarter of the population older than 25 has not reached high school, 42% have some high school education and, finally, about a fifth have at least 4 years of college education.⁵⁴

Though traditionally among the most developed countries in Latin America and despite having experienced recently a period of economic recovery, Uruguay is unexpectedly seeing levels of lethal violence unprecedented in its history (though still somewhat low by Latin American standards).^{55,56} Thus, after many years of being remarkably flat, in 2012 the homicide rate in Montevideo started rising. By 2018 it had almost doubled and there is nothing yet to suggest that homicides might start to reverse to their pre 2012 numbers any time soon.

This troublesome trend, which elicits much concern locally, is shown in Table 1: On the basis of largely anecdotal evidence, the rise in homicide levels has come to be seen by many as the result of wars between criminal groups over the distribution of a form of smokable cocaine (a local form of crack known as “Pasta Base”) introduced around 2004. There are also some more objective indicators that this might be so, in the form of statistical data showing sharp increases in the number of people convicted of drug crimes over the last decade.ⁱⁱⁱ

Table 1 Homicide counts, Population and Homicide Rate, by Year – Montevideo

Year	Homicides (victims)	Population	Rate (per 100,000)
1998	110	1,393,802	7.9
1999	106	1,397,549	7.6
2000	104	1,396,390	7.4
2001	109	1,390,052	7.8
2002	128	1,380,535	9.3
2003	80	1,369,544	5.8
2004	92	1,365,373	6.7
2005	86	1,366,427	6.3
2006	81	1,365,327	5.9
2007	82	1,362,150	6.0
2008	108	1,360,718	7.9
2009	114	1,364,782	8.4
2010	113	1,370,942	8.2
2011	110	1,375,540	8.0
2012	148	1,376,602	10.8
2013	163	1,377,617	11.8
2014	153	1,378,611	11.1

ⁱⁱⁱThe rate per 100,000 inhabitants of people convicted on these charges went from about 8 to 60 between 2000 and 2021 (Donnangelo, 2024).³²

Table 1 Continued..

2015	169	1,379,560	12.3
2016	147	1,380,432	10.6
2017	161	1,381,228	11.7
2018	223	1,381,946	16.1
2019	217	1,382,579	15.7
2020	170	1,383,135	12.3
2021	171	1,383,601	12.4
2022	216	1,383,965	15.6
2023	208	1,384,210	15
2024	231	1,384,324	16.7

Source: Uruguay's National Bureau of Statistics and Ministry of Interior

However, systematic research on the causes of recent increases in homicide rates in the city is scarce, and the little evidence available is limited by issues with the data sources that prior research has relied upon. To more thoroughly assess widespread views among practitioners and the public at large, therefore, the present study seeks to evaluate the extent to which the rise in violence in the city might be regarded as a process of Diffusion (as would be implied by any hypothesis positing endogenous forces such as gang wars as the conduit for the multiplication of homicides). In this regard, the study pursues two main objectives, namely:

On the one hand, it seeks to determine whether, as would be expected under a process of diffusion or contagion of violence, the level of clustering and autocorrelation of the spatial distribution of homicides in the city of Montevideo increased concomitantly with the increase in the homicide rate.

On the other hand, the study analyzes the degree to which homicides in recent years follow a spatial distribution associated with their temporal distribution, another characteristic of contagion or epidemic phenomena. More specifically, the article seeks to assess whether the geographically closest events are also close in time beyond what could be expected by chance.

The study compares the territorial concentration and space-time characteristics of the homicide distributions corresponding to two periods of time characterized by very different levels of violence: one prior to the increase in the homicide rate in the city of Montevideo (years 2005-2007), and another comprising the years of the onset phase in the surge of homicides (2012-2014). It is hoped that this will aid the identification of factors driving the recent upward trend in the rate of violent deaths in the city will be elucidated.

In sum, then, this article seeks to answer the following research question: can the increase in the homicide rate in the city of Montevideo in recent years be explained as a phenomenon of diffusion and contagion of violence?

Data and methods

All the information about homicide on which the analyses in this study are based comes from crimes recorded by the police.^{iv} In the city

^{iv}The definition of homicide used in this study is the same as that given in the Uruguayan Penal Code. It also coincides with the one used by UNODC (2019) in its global study on violence. Consequently, homicide is defined as deaths resulting from an intentional and unlawful assault inflicted on one person by another or others. This definition has a number of advantages or strengths. First of all, it's simple and clear, and it makes intuitive sense. Second, it accurately delineates a set of observable facts, all of which have in common a number of important attributes (which differentiate them, at the same time, from other types of deaths from external causes). Finally, because of these strengths, it is widely used internationally, which makes it easier to make comparisons across nations. Finally, it must be added that the counting unit used in this study is the victim (not offenders or events).

of Montevideo, since 2002 the police records crimes that come to their knowledge in a single information system. This information system has recently been reviewed and awarded a level A (highest) grade by a UN's sponsored review.⁵⁶

For the period prior to the increase in the city's homicide rate (years 2005-2007), 408 murders (both completed and attempted) were considered⁵⁷. This amounts to all events of these kinds recorded by the police during that three-year period. As for the period after the increase in the levels of violence in Montevideo (years 2012-2014), 633 homicides (also including attempts) were recorded in the city, all of which were, again, used for this study.

Though statistics based on reported crimes present widely acknowledged limitations stemming from issues of dark figures and potential unreliability of police recording practices^{57,58} these are of less concern in the case of homicide, which is regarded as the most reliably reported type of crime due to its seriousness and the notorious difficulties involved in disposing of dead bodies (Wikstrom, 1985). Homicide is also a reasonably well-defined crime and one whose definition is fairly stable, which allows for very consistent recording both within and across jurisdictions.⁵⁹

Clustering of homicide events (Spatial autocorrelation)

To analyze the degree of spatial clustering of homicides in each of the two periods considered in this study, autocorrelation measures were calculated for each of them. For each period, "join-counts" coefficients were calculated from a grid of 500 square meters overlayed on the map of the city.^{60,61} Each square cell ("quadrats") within this grid was classified according to whether or not there had been a homicide event during each of the periods considered. Then, the prevalence of cells with homicides that were adjacent within this grid was quantified for each period.^{vi}

The size of the cells that make up the grid (500 square meters) was chosen because it likely represents a spatial scale capable of reflecting and capturing processes at the neighborhood level. Input from people with field experience (interviewed police officers) about the territorial scope of the alleged gang wars over drug sales areas also influenced this choice.

The so-called join-counts coefficient provides a measure of the degree to which a binary attribute is present in areas that are adjacent or contiguous to one another.^{62,7} In other words, it measures the concordance in the values that a binary classification takes across areas with a common boundary. More specifically, the coefficient counts the number of coincidences in the values of a variable between contiguous observations in space. The two categories of the binary attribute (present or absent) are generally denoted as "black" (present) and "white" (absent). If the subareas that make up a region are classified in terms of a binary variable X that takes the value 1 if a binary attribute is present and 0 when it is not, and polygons with homicides (x=1) are denoted by B (black) while those that do not have homicides (x=0) are denoted by W (white), it is possible to calculate the following statistic (Odland, 1988):

^vThe inclusion of attempted homicides may seem like a somewhat unusual decision. A detailed justification for this is therefore included as an [Appendix](#).

^{vi}The prevalence of homicides in each of the "areas" (quadrats of 500 meters on each side) that form the grid was measured as a dichotomous classification: that is, the homicide scale used takes two values (square polygons with at least one murder and grid cells without murders during each period). This homicide scale was adopted to minimize potential problems associated with the use of an asymmetric variable for the calculation of parametric correlation measures based on more restrictive assumptions regarding the normality of the underlying distribution, the linear nature of the cross-products, etc.

$$BB = 1 / 2 \sum \sum w_{ij} x_i x_j \quad (1)$$

where $w_{ij}=1$ if the observations (polygons) i and j are adjacent or $w_{ij}=0$ if they are not.

Formula (1) simply expresses the number of coincidences between adjacent regions (meaning by coincidence the case where the two members of a contiguous pair present the attribute in question).

Association between the spatial and temporal distribution of homicides

As said above, it seems likely that a process based on the violent control of markets (with its corollary of spiralling mutual aggression) will produce statistical patterns characterized by a degree of association between the temporal distance separating events and their geographical separation. More specifically, given that the territorial scale of the alleged process of violent competition is likely local, it is to be expected that geographically close homicides will also be close in time.

To explore the extent to which the rise in homicides in Montevideo presents the above characteristic, the Knox coefficient was used.^{63–65} The latter is a measure developed in the context of epidemiological studies, as a means of studying the possible contagious nature of childhood leukaemia. Its computation requires data on the location and timing (date) of the events of interest and is based on the consideration of $n(n-1)$ pairs of cases formed from the observation of n cases (i.e., a square matrix without the diagonal). For each of these pairs, the temporal and spatial separation between the two members is determined. Once this is done, the pairs are dichotomously classified in two dimensions as close in time/distant and close in space/distant. Finally, the pairs of cases (events) are assigned to a 2×2 matrix whose cells result from the cross-classification of the (dichotomized) dimensions time and space, as shown in Table 2:

Table 2 Schematic of Knox Analysis

		separation in time	
		close	distant
separation in space	close	(cases close in time and space)	Cases close in space; distant in time
	distant	Cases close in time; distant in space	Cases distant both in time and space

What constitutes the near or distant categories in both variables is decided in the specific case by the analyst. The degree of association between the spatial and temporal proximity of the cases is determined by evaluating the frequencies of the table against the chi-square distribution of events categorized by a chance pattern.^{vii}

Results

The maps in Figure 1 and 2 below show the local join counts cores for each of the periods studied in this article, using a Queen contiguity criterion.^{viii} The cores represent square areas around which there are

^{vii}Actually, the observed frequencies are compared with a series of simulations obtained by keeping the locations of the events fixed and randomly distributing the dates on which they occurred among them. In this way, possible problems of lack of mutual independence between the $n(n-1)$ pairs of events (which obviously contain common cases or cases that appear in multiple pairs) are corrected. The resulting distribution of simulations thus represents a pseudo-significance or probability value.

^{viii}Autocorrelation measures describe the degree of similarity in a given

coincidences with the adjacent polygons. In other words, cores are the centers of blocks or clusters of joins:

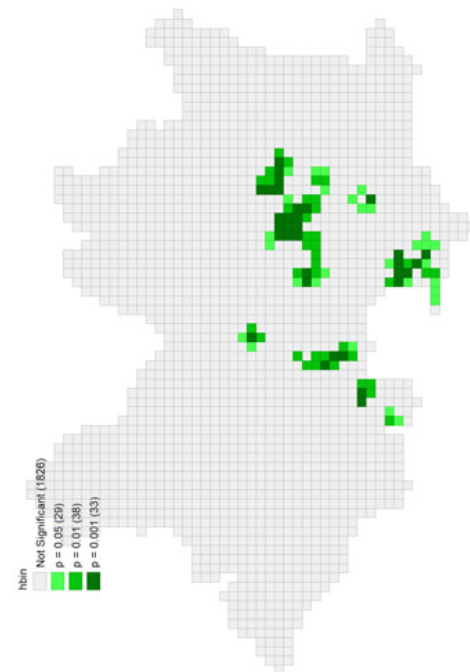


Figure 1 Homicide location Local Join-Counts coefficients (Cores) – Montevideo, 2005-2007 (500m²quadrats) (Attempted Homicide included).

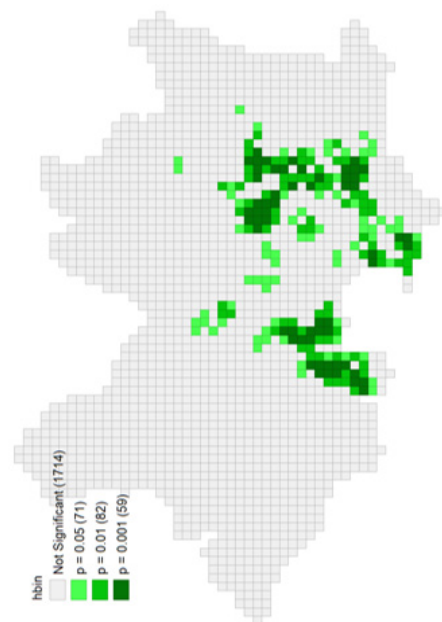


Figure 2 Homicide location Local Join-Counts coefficients (Cores) – Montevideo, 2012-2014 (500 m² quadrats) (Attempted Homicide included).

variable between observations that are considered to be neighbors. Therefore, its calculation requires specifying the structure of the neighborhood relationships between the units of analysis (i.e., determining or defining which observations are neighbors). Normally, this is done on the basis of spatial adjacency (existence of a shared edge of length greater than zero). By analogy, the various types of adjacency or spatial contiguity are designated by terms corresponding to the names of the pieces that execute certain moves in the game of chess. The "Queen" criterion, therefore, defines neighbors as polygons that share an edge or vertex within a map.^{68–71}

The preceding maps were generated with Geoda⁶⁶ Generally speaking, the second map looks more compact, particularly in areas of the southwest and southeast of the city. This suggests that the trend towards the formation of blocks of *adjacent* polygons containing homicides may have been accentuated in recent years. Such a configuration, in which polygons containing homicides are arranged side by side, is probably consistent with neighborhood-scale processes, particularly if the size of the polygons considered is not too large. Table 3 reports the numbers of square areas with significant join-count coefficients that are the “cores” of clusters of polygons with homicides, for the two periods compared in this study:

Table 3 Join-counts cores for two time periods (City of Montevideo)

Period	join counts cores (BB)
Years 2005-2007	100
Years 2012-2014	212

As can be seen from table 3 above, the number of statistically significant cores more than doubled between the two periods analyzed. This means that the number of adjacent polygons with similar values of the attribute of interest (that is, that exhibit homicides), grew considerably during the years that mark the rise in the city’s homicide rate.

Knox coefficients

The Knox index for the two periods analysed in this study (the one prior to the increase in homicides in Montevideo and the first three years of the rising phase) is presented below (Table 4–7). In order to consider different scenarios, for each of the periods, the distance between the cases is conceptualized in two different ways: in relation to the median separations in time and space between all the cases (in such a way that two cases are considered close to each other with respect to time or space if they are both below the respective median separation); in relation to limits of 90 days and 1,750 meters, in such a way that two cases are considered close in time and space if the distance between them is below both limits.^{ix}

Table 4 Knox Index: Period of Homicide Increase in Montevideo (2012-14) - Observed Frequencies (Spatial proximity criterion: ≤1,750 m.; Temporal proximity criterion ≤90 days)

Time separation	Space separation			
		close	distant	TOTAL
	close	1,864	30,133	31,997
	distant	8,947	159,084	168,031
	TOTAL	10,811	189,217	200,028

Table 5 Knox Index (2012-14) - Expected Frequencies

Time separation	Space separation			
		close	distant	TOTAL
	close	1,729	30,267	31,996
	distant	9,081	158,949	168,030
	TOTAL	10,810	189,216	200,026

Chi-square.....: 13.19239

Probability of the Chi-square value (under the null hypothesis of independence between space and time): 0.00010

^{ix}The limit of 1,750 meters was set according to the typical distance between areas that, in the opinion of experienced police investigators interviewed for this work, house rival gangs. Officers interviewed also believed that 90 days was a reasonable time interval within which retaliations for a homicide or attempted homicide could be expected.

Sample size: 633 (homicides)

Simulation runs: 999

Table 6 Knox Index: Period Prior to Montevideo’s Homicide Surge (2005-07) - Observed Frequencies (Spatial proximity criterion: ≤1,750 m.; Temporal proximity criterion ≤90 days)

Time separation	Space separation			
		close	distant	TOTAL
	close	721	12,286	13,007
	distant	4,032	65,989	70,021
	TOTAL	4,753	78,275	83,028

Table 7 Knox Index (2005-07) - Expected Frequencies

Time separation	Space separation			
		close	distant	TOTAL
	close	745	12,262	13,007
	distant	4,008	66,013	70,021
	TOTAL	4,753	78,275	83,028

Chi-square.: 0.94045

Probability of the Chi-square value (under the null hypothesis of independence between space and time): 1.00000

Number of cases (homicides): 408

Simulation runs: 999

(Data for the two time periods based on the median separations is available from the author on request.)

The above results were generated with CrimeStat®.⁶⁷ From the comparison of the results between both periods it is clear that, regardless of the criterion of proximity used, the homicides of the first period do not seem to exhibit an association between time and space, while a highly significant time-space interaction (chi-square probability below 3%) is appreciated, also independent of the criterion of proximity, in the case of the phase of increase in the number of homicides.

Discussion

The spatial pattern identified in this article departs markedly from the parameters that define a model of randomness in the spatial distribution of events. More specifically, the two defining features of a Poisson-like distribution of events over space (equal probability of all subareas of “receiving” an event and mutual independence of the events in question) seem clearly absent from the empirical patterns observed throughout the preceding pages.

Indeed, the spatial autocorrelation of homicides in Montevideo in recent years (a feature that suggests the lack of mutual independence of many of these events) is higher than that of homicides corresponding to the period in which the rate of this type of event remained stable. Indeed, during the most recent period of the two compared, there would seem to be a tendency for “hot” quadrats to be arranged side by side with one another, thus forming more compact blocks of violent areas. Moreover, this trend seems to have developed taking as a starting point the square areas that had homicides during the first of the periods considered. That is, new polygons with homicides seem to have appeared around traditionally violent ones.

Likewise, during the period of rise in the homicide rate in the city (but not during the years prior to it), a statistically significant association was found between the temporal distribution and the spatial distribution of the pairs formed by this type of violent events.

This association is such that events that are closer in space tend also to be closer in time, beyond what could be expected by chance alone.

All the above seems roughly consistent with a Diffusion or, more generally, contagion-like process. Obviously, contagious events follow defined patterns of territorial and temporal distribution, characterized by the fact that new or more recent events tend to show up in areas and times close to the first cases to appear. This is evidently due to their contagious nature. Since the probability of contact between sick and healthy agents (required for contagion to occur) is higher between individuals close to one another, this means that new cases appear close to previous cases and not long after them (contagion does not usually occur much later because the carriers of the infection cease to be carriers after a while, either by recovery or death). This means that the probability of observing a case in a given area and period is not independent of the probability of other areas and periods (given a case, the probability of a nearby area recording another case in a nearby period is increased). All this determines that the cases of an epidemic tend to be neighbors in space and time and gives rise to a pattern characterized by the formation of clusters of events around the first cases that appeared and within which the temporal separations between cases are short. From a spatial standpoint, therefore, such events differ considerably from a random distribution over the territory (i.e. a Poisson distribution), presenting a significant level of autocorrelation and, therefore, of spatial clustering. Likewise, the geographical proximity within pairs of these elements is not statistically independent of their temporal proximity, but rather the members of a pair of events that constitute close neighbors in the territory also tend to be close neighbors in time.

Broadly speaking, then, the spatial and space-time patterning followed by homicides in Montevideo seems consistent with the statistical features of processes of Diffusion and Contagion. Though increasing autocorrelation and space-time association are not necessarily unique to such processes, there are many reasons that suggest that an interpretation cast in terms of mechanisms of Diffusion and Contagion of violence might explain the rise of homicides in the city. Thus, besides regional trends uncovered by competent research (Bergman, 2018), as hinted at on the preceding pages there is also much anecdotal evidence of an emerging gang problem within the city. In fact, it can safely be said that the view that increasing violence stems from territorial competition over control of sales areas for drugs, has become the dominant explanation of the problem, both among practitioners (such as Police and other criminal justice operators) and society at large (including the media).

In light of the evidence produced by this study, the above view cannot be ruled out or easily dismissed. Though the evidence cannot be regarded as conclusive, it does seem compatible with some important features posited in the literature as characteristic of gang violence. Thus, gang violence is often assumed to be largely retaliatory in nature. It might be thought therefore, that gang homicides have in common with epidemiological events the fact that the "cases" are not independent of each other. Indeed, the lack of mutual independence between homicide events stemming from a dynamic based on the mechanism of revenge and retaliation in which one homicide leads to another that is a response to the first and so on, creates favorable conditions so that, after the occurrence of a homicide in a certain area, the probability of receiving a new event of this type is increased (compared to other areas). Therefore, just as cases of a contagious disease derive from others (through contact between infected people and healthy people), homicides inscribed in dynamics of settling scores and retaliation between gangs also originate from other murders, since they essentially represent a reaction or response to a

previous aggression. In this sense the kind of dynamic underlying homicides originating in clashes between more or less organized criminal groups is similar to the process of expansion of an epidemic and, like it, probably produces spatial statistical patterns that are not well described by the classical (Poisson) model of spatial randomness. Although the mechanism of concatenation between acts of lethal violence is obviously different from that of the transmission of a pathogen, the epidemic analogy nevertheless makes intuitive sense.

Additionally, the gang-drugs epidemic scenario is likely to foster spatial processes as the observed in Montevideo through several other mechanisms. Thus, drug-gangs occupying adjacent areas seem highly likely to engage in competition and conflict, and therefore to produce, almost by definition, growing levels of autocorrelation in the location of homicide events. Likewise, increasing spatial autocorrelation could also be brought about by the fact that members of the same gang are likely to live close to one another. It would therefore seem logical that homicides having the members of a given gang as victims would show up at relatively *short distances from each other*.

Though an interpretation of the rise in violence in Montevideo cast in terms of gang conflict would seem a plausible one, some caveats and limitations of the present study should be kept in mind.

First, it should be noted that the literature on the Diffusion of violence has posited other mechanisms as driving forces besides endogenous processes such as the mutual dependence of events stemming from retaliation. In particular, spread of violence has been linked to growing levels of fear which, in turn, result in more gun-carrying and ownership. Thus, in this view, violence spreads through the proliferation of guns and the resulting increase in the lethality of conflicts.^{13,33} Though not necessarily an incompatible view with the gang violence explanation (people might arm themselves out of fear of the presence of gangs in their milieu), this does posit a Diffusion cause that might stand alone. Findings in Donnangelo³² however, show that the share of gun suicides did not increase in Montevideo between 2006 and 2012, which would seem to cast doubt on gun availability as an alternative mechanism for explaining the spread of violence.

Second, it has been shown that Knox coefficients might yield significant values even in the absence of truly contagious processes.⁷² That is, events that are clustered in time and space (but that are unrelated), might give rise to space-time associations as measured by the Knox index. Though this shortcoming should not be overlooked, it is probably of less concern when the results of using the Knox coefficient are coupled with other pieces of evidence and placed within a sound theoretical argument for a case of contagious spread of some condition. Moreover, from a policy standpoint, due to its simplicity and intuitive meaning, the Knox coefficient would seem to have definite advantages over more complex alternatives such as self-exciting point processes, which demand a fairly sophisticated mathematical background to be interpreted and whose results are, therefore, extremely difficult to convey to decision-makers.

Also related to the Knox method, it must be pointed out that it requires a certain degree of subjectivity, which is evident in the absence of univocal criteria for defining the intervals of distance and time that constitute close cases. In this sense, the conclusions of the present analysis would be strengthened if it is replicated using intervals of different amplitude or, more radically, similar methods that do not leave the analyst to decide which stretches of temporal and spatial distance to use.^x This being said, it must also be noted that

^xAn interesting possibility in this sense is the use of the method proposed by Jacquez (1996) based on the consideration of "nearest neighbors" (see also Mantel, 1967 for an alternative to Knox's method that solves some of its problems but

the consistency of the results reported in this article across a variety of proximity criteria looks quite remarkable. It should be noted, in this regard, the easiness with which the association between spatial and temporal distances can be obscured by multiple factors. If the mechanism underlying this association is, as hypothesized in this study, that homicides (or a good part of them) are rooted in reciprocal aggressions between criminal gangs, the continuity and fluidity of this process can indeed be disturbed in many ways. It is evident, for example, that factors such as the precautions of those involved, their eventual removal from the reach of their enemies due to imprisonment, and interference of police presence in the plans and preparations for revenge, constitute just some of the processes that can conspire against an immediate retaliation to a previous aggression.73–88

Conclusion

In all likelihood, this study provides the first analysis of violence in Latin America as a diffusion or contagion phenomenon, and the first application of epidemiological and spatial analysis techniques such as Knox coefficients and Join Counts autocorrelation coefficients to the study of homicides in the region. The use of these methods yields results consistent with those expected if the increase in violence in Montevideo were due to endogenous mechanisms and diffusion and contagion processes. Although such processes are, in principle, compatible with various causal factors, the regional trends documented by competent studies, the evolution of the number of people convicted for drug-related offenses and the existence of abundant anecdotal evidence from both police field experiences and accounts from residents of poor areas on the outskirts of Montevideo, all suggest that the widespread popular perception that the problem is related to an emerging drug-gang problem is by no means implausible. Although the data presented in this article do not allow us to conclusively affirm that the above is the primary mechanism behind the increase in violence levels in the city, they are sufficient to establish this explanation as a viable scientific hypothesis worthy of further exploration in future research. Though discussion of very broad issues of social policy is clearly beyond the scope of the data analyzed in this study (mainly concerned with patterns of the location of homicides), it is the personal view of the author that the possibility of an emerging problem of gangs focused on drug distribution also poses issues related to inequality. Indeed, it would seem reasonable to expect that, in low- and middle-income countries (such as Uruguay) where, despite recent improvements, strong socioeconomic inequalities persist, certain illegal markets still represent a profitable alternative to legal occupations available to broad social groups, such as young people from poor backgrounds with low levels of education. In the view of the author, this suggests that any substantial and lasting change in the current levels of violence in cities like Montevideo may require structural reforms to move large numbers of people out of the impoverishment in which they currently find themselves and to reduce the still significant levels of social inequality that exist. As a more immediate (though perhaps with more side effects) solution or palliative, the problem could also be targeted through public health policies focused on harm reduction rather than on the prohibition of substances (which, as is becoming increasingly clear in light of international experience, has no other effect than to raise market prices and thus dramatically increase the economic profitability of drug trafficking).

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None.

does not completely eliminate the need for subjective judgments on the part of the researcher or analyst).

Conflicts of interest

The author declares there is no conflict of interest.

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