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Abstract

The study of the spatial distribution of homicides in historically violent cities is important because it provides new interpretations and potential policies for regions that are characterized by a persistent level of crime. While labor market characteristics have been correlated with its presence, few works have examined spatial patterns with the informal labor market. The empirical strategy begins with the calculation of the Moran index and the LISA test, which confirm a spatial association of homicides in neighborhoods. Subsequently, some linear regression models and a Spatial Durbin Model are estimated to confirm the correlation between homicides and the informal labor market. Finally, the intuition of this spatial correlation is shown in some maps. The main results show that the effect of the labor market on homicides does not come from the characteristics of the formal labor market but from the informal labor market, where working conditions are more precarious (no employment contract, health insurance, unemployment insurance, retirement pension, etc.). Thus, the bulk of this effect occurs in some hillside neighborhoods, areas with characteristics associated with informality, illegality, poverty and the lack of public investment in basic services such as electricity, water supply, sewerage or unpaved streets. These results have practical implications for understanding the correlation between economic incentives and crime in developing countries and in less favored cities in developed regions.

Keywords: homicides, labor informality, hillside, emerging hot spot analysis.
JEL Classification: K14, K42, J46, C31.

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1. Introduction

The spatial analysis of homicides is a topic of great interest to a international academic community (Messner, 1982; Cohen & Tita, 1999; Messner et al., 1999; Baller et al., 2001; Hipp & Williams, 2021; Sadler et al., 2022). This growing literature worldwide has reached consensus on the existence of a spatial relationship between homicides and some socioeconomic variables (Williams, 1984; Bailey, 1984; Loftin & Parker, 1985; Messner & Tardiff, 1986; Tcherni, 2011; Menezes, 2013; Cho et al., 2021). The pioneers in including economic analysis were Beccaria (1764) and Bentham (1789), who explained crime based on the theory of economic rationality, which includes the costs and benefits of committing the crime, which was later formalized by Becker (1968) and Ehrlich (1973). Subsequently, these theories have been related to the labor market in which certain individuals choose between employment and crime in suboptimal conditions (Gould, Weinberg & Mustard, 2002). According to Grogger (1998) and Machin and Meghir (2004), committing a crime is less expensive for people with unfavorable working conditions than for those with favorable working conditions.

Numerous studies analyze the relationship between crime and the formal labor market (Phillips et al., 1972; Gould, Weinberg and Mustard, 2002; Engelhardt, Rocheteau & Rupert, 2008 Ochsen, 2010; Mustard, 2010), particularly understanding the relationship between crime and unemployment rate (Chiricos, 1987; Kapuscinski et al., 1998; Raphael & Winter-Ebmer, 2001; Burdett et al., 2003; Lin, 2008, Nordin & Alén, 2017; Bennett & Ouazad, 2020). For example, Cantor and Land (1985) emphasize that unemployment may affect crime rates in the aggregate through two distinct and potentially counterbalancing mechanisms, namely criminal motivation and criminal opportunity. Especially, some authors relate the labor market with some specific crimes such as homicide (South & Cohen 1985; Krivo & Peterson 2004; Koppensteiner &

Menezes 2021). Likewise, in Latin America, studies on the subject relate the formal labor market using indicators such as employment or unemployment to explain the high crime rates (Dix-Carneiro, Soares & Ulyssea, 2018; Dell, Feigenberg & Teshima 2019; Khanna, Medina, Nyshadham, Posso & Tamayo, 2021).

However, we consider that there is a bias in relation to the studies that analyze the statistical correlations between homicides and the labor market, because in developing regions the labor market presents characteristics that are very different from those of the regions of developed countries. Thus, in developing economies the labor market is dual (Piore, 1980; Kannappan, 1985; Cieślik, 2008; Villamil et al., 2020), which divides the market into two parts, called primary and secondary sectors. The distinction can also be made between formal/informal sectors or sectors with high/low added value. The informal economy consists of labour that is often pay under the table (Yamada, 1996; Günther & Launov, 2012). This market tends to attract the poor and a disproportionate number of minority group members. In this way, our hypothesis is based on the fact that the characteristics of the informal labor market may be more correlated with crime, especially with homicides, than with the characteristics of the formal labor markets typical of developed regions.

In this paper, the analysis is carried out on the city of Cali, Colombia, a developing region with a dual labor market with high rates of labor informality (Nicodemo & García, 2015). Moreover, according to the National Administrative Department of Statistics (DANE in Spanish), the city's rate of labor informality in 2019 was 45.8% (before the Covid-19 pandemic), indicating that approximately half of the city's workers engage in informal activities and have low-quality work. However, only Cali, one of the three main cities of Colombia (in addition to Bogotá and

Medellin), has not converged in the fast homicide rate reduction. Cali's homicide rate in 2019 is 45 per 100,000 residents, one of the highest rates in the world.

Cali is not a small city; it is the third most populous city in Colombia with 2.5 million inhabitants, with an area of 216 square miles and has a Human Development Index (HDI) of 0.791 in the very high category. The city is also divided into neighborhoods with administrative boundaries that could be observed through streets´ location, also these vary from each other significantly. These differences are due to irregular settlements, whereas others are located in the city peripheries, such as hillsides. The majority of the population is also displaced by violence from their cities of origin, which are extremely poor and violent areas. Thus, Cali has spatial differences that are valuable for our analysis, particularly because the hillsides' high homicide and labor informality rates.

Our study contributes to a broader literature that studies the correlation between economic incentives and crime. In particular, our contribution is about understanding the effect that the informal labor market on homicides in a context of spatial analysis. We combine rich data from a unique survey (Encuesta de Empleo y Calidad de Vida de Cali, in Spanish) conducted by the Ministry of Labor (2012), that allows us to obtain information on the characteristics of the population and the labor market in the communes and by neighborhoods in Cali, Colombia, with crime information and administrative data for neighborhood.

Thus, this paper offers a spatial analysis of the relationship between homicides and the labor market and informal labor market in Cali. We first carry out a spatial analysis that motivates the intuition of the potential existence of a spatial correlation that affects the bulk of the correlation between acute labor informality and homicides. Second, we estimate a log-linear model and Spatial Durbin Model (SDM) where three types of interaction effects could be present: endogenous

interaction effects (i), exogenous interaction effects (ii) and correlated effects (iii). Third, we contextualize with maps and characteristics of the hillside neighborhoods the main results on the emerging hot spots.

The main results show that the bulk of the spatial correlation between the labor market and homicides comes from labor informality and not from the indicators traditionally used to measure the formal labor market, such as employment and unemployment. In addition, we present new evidence on the effect of acute labor informality on homicides in the neighborhoods of the city of Cali. Our study also provides the first evidence of emerging hillside hot spots that are related to labor informality in some neighborhood types. These results have policy implications on the provision of public services and promotion of labor formality in hillside areas.

The rest of the paper is organized as follows. Section 2 presents the context Cali City and background. Section 3 describes the data. Section 4 present the empirical strategy. Section 5 reports the main results of the spatial analysis, and section 6 concludes.

2. Context of Cali City and Background

Cali is the shortened form of the official name of the city: Santiago de Cali; the city was founded on 25 July 1536 (485 years) and is located in the Republic of Colombia, a country located in South America. In figure 1, the continental position of the city is observed, which is southwest of the country and 70 miles from the Pacific Ocean, or from the city of Buenaventura, which is the main port of the country. Likewise, the spatial distribution of the city is observed on a map in which it is seen that the city stretches from south to north. The city has this elongated shape because it borders the Cauca River (length 838 miles) to the east and the West Andes (Elevation 13,290 ft) to the west. This causes the city to spread from south to north due to the fact that it has two

geographical limits that are impossible to overcome in the east and in the west. In the east it borders the Cauca River, which has a hydrographic basin of approximately 39,300 mi^2. While in the west it limits with the West Andes range one of the three main branches in which the Andes mountain range in Colombia is divided. It has a height of 13,500 ft. and extends in a south-north direction.

Figure 1. Geographical location of Cali, Colombia

(A) Location of Cali on the American Continent (B) Cali Spatial Imagen

Source: Authors' elaboration with Google Maps.

Cali is Colombia's third most populated city, with approximately two million inhabitants according to the 2018 census conducted by DANE. The inhabitants of the city live in formal and informal neighborhoods. Most of the city's neighborhoods were formally created and are legal, have public services and pay taxes for the homes located in them. However, some of the hillside neighborhoods, far from the downtown of the city, have been created informally by people who have invaded public or private lands to create very precarious housing that over time became

neighborhoods. The majority of these people have been displaced because of violence in their lands of origin. Their regions of origin are extremely poor rural areas without access to public utilities, such as water, sewerage and energy. The economic development in these regions has not advanced, and its socioeconomic structure responds to Spanish colonial times. In majority, these people are indigenous and Afro-Colombian population, who have low education levels and lack access to health services and formal markets.

These neighborhoods in informal settlements invade lands where they build precarious houses, often with only a roof. Also, these houses do not have an electricity, natural gas and water supplies, sewage systems and Internet services. For example, Chong and Yañez-Pagans (2017) study the link between television coverage and homicides in Brazil. They found that people living in areas covered by television signal have significantly lower rates of homicides. This result shows economic development help to reduce criminal problems in society. The houses in informal neighborhoods are temporary shelters that are ultimately slums. The streets are also unpaved; the neighborhoods do not have access to public transportation; and the areas have no commercial and financial establishments.

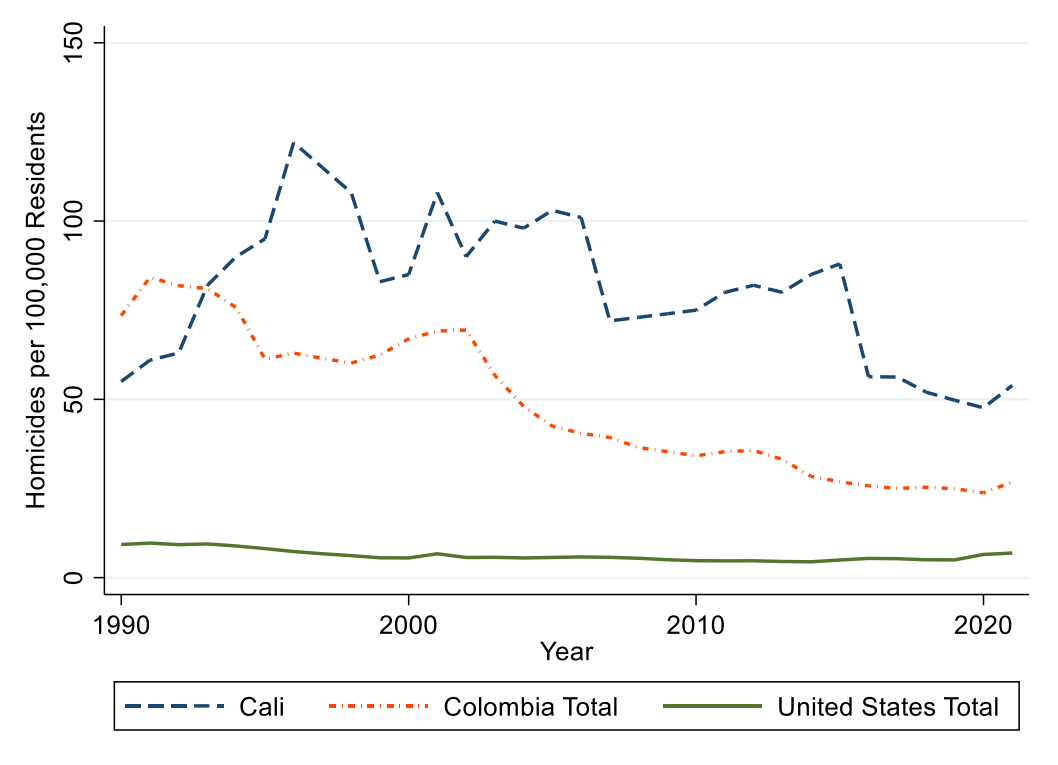
Cali can be considered a violent city because the informal neighborhoods that are located on hillsides have high levels of violence due to the serious problems of poverty and drug trafficking. Cali also had one of the most powerful drug trafficking signs in the world, referred to as the 'Cali Cartel'. The National Government dismantled this cartel with the support of the Drug Enforcement Administration in the mid-1990s after the fall of the Medellin Cartel led by Pablo Escobar. Subsequently, in the first decade of this century, the Cartel del Norte del Valle was dismantled. At that time, these cartels controlled 80% of the cocaine shipment to the United States. This brought about a war between the drug cartels that generated violence without a presence

throughout the country and especially in the cities of Cali and Medellin, where the two most powerful cartels in the world were located.

Homicide rates in Colombia have shown a downward trend after the mid-1990s, which coincides with a worldwide trend towards a reduction in the homicide rate. However, this reduction in homicides has not occurred with the same speed in all the cities of the country. According to the Colombian National Police statistics, the city had 26,687 homicides between 2001 and 2015. The number of homicides in 2019 was 1,114, which is an alarming situation for any city. For these reasons we describe Cali as a violent city. Figure 2 shows Cali's trend homicides rate per 100 thousand inhabitants from 1980 to 2019. An increasing trend is observed trend until 1994 when the rate reached its highest at 122 homicides per 100 thousand inhabitants, which subsequently decreased.

However, the city's number of homicides per 100 thousand inhabitants is historically high, that is 40, 80 and 122 in 1981, 1991 and 1994, respectively. During this century, there were rates per 100,000 inhabitants between 100 and 45 homicides. Rates that currently place the city in the top of cities with the most homicides in absolute and relative measures. The homicide rates in Colombia and the city of Cali are compared with the homicide rate in the United States, where the literature on the subject is abundant and crime is a problem that is taken very seriously by authorities (Sadler, Melde, Zeoli, Wolfe & O'Brien, 2022).

Figure 2. Cali, Colombia and U.S. homicide trends, 1990 to 2021



Source: Authors' elaboration with data from the Colombian National Police.

Cali is a particular case because it is the only city in Colombia that has not converged to the national average of homicide rates, unlike the cities of Bogotá and Medellin. In 2019, Bogotá and Medellin reached rates approximately close to the national average of 24 homicides per 100 thousand inhabitants. However, the gap between Cali and the country's rates has been maintained above the national average. Additionally, Cali has a large homicide business on the city's hillside neighborhoods. Individuals can become a 'Sicario' (hitman or hired killer) and participate in the famous 'Oficinas de Sicariato' (hitmen's offices).

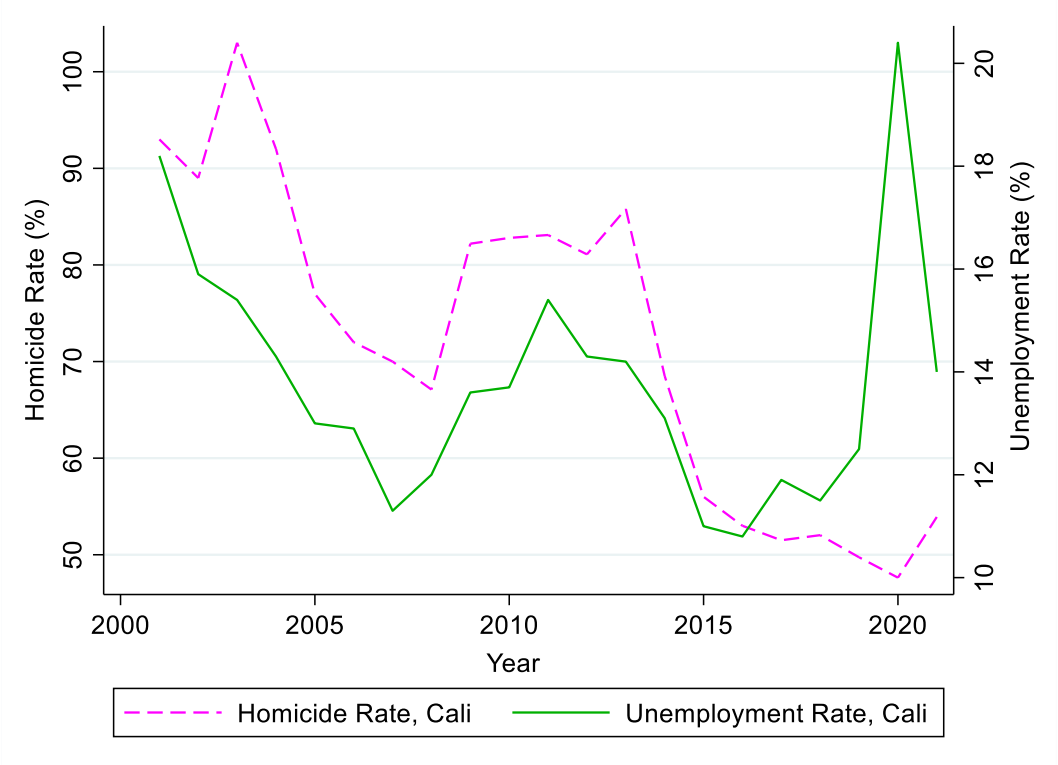
These people are dedicated to kill other individuals for money. Criminal service outsourcing is offered to the highest bidder, whose mission includes collecting debts, kidnapping and murdering. Recently, in some of these hillside neighborhoods, evidence of 'Casas de Pique'

has been found where people are dismembered to make them disappear. The description of the historical and recent violence in the city makes it a violent city.

This problem of high homicide rates occurs in some hillside neighborhoods with precarious socioeconomic conditions, such as high unemployment rates and informal employment. Figure 3 shows the evolution of Cali's homicide rate per 100 thousand inhabitants and unemployment rate. The unemployment rate reflects the behavior of the city's socioeconomic conditions, showing a decreasing trend between 2001 and 2008, reaching 12%. Then, the rate was 15.4% and 13.1% in 2011 and 2013, respectively. The figure shows a simple intuition about the relationship between the labor market and crime in the city.

Additionally, one of the main problems in the labor market is high labor informality rates in developing countries, such as in Cali. According to DANE, the city's labor informality rate in 2019 was 45.8%. Therefore, approximately more than half of the city's workers engage in informal activities. Regions with high labor informality rates have labor markets where the unemployment rate does not measure their workers' real conditions.

Figure 3. Cali's homicide and unemployment rates from 2001–2021



Source: Authors' elaboration using the Colombian National Police and DANE Data.

Thus, analyzing the relationship between homicides and labor informality by neighborhoods in the city of Cali is relevant and stimulating, because labor informality can potentially be related to informal, illegal and criminal activities.

3. Data

This section describes the data used in this study. Labor market data were obtained from the Employment and Quality of Life Survey for Cali conducted by the Ministry of Labor in 2012 (Ministry of Labor, 2012). Only the survey has available information for Cali's data. The data are disaggregated by neighborhood and area in the city called 'Comuna' (commune, a group of

neighborhoods). The survey includes 8,600 households (30,458 people surveyed) in Cali's neighborhoods. This sample size and sampling design guarantee an expected sampling error of not more than 1.2%, and 10% for Cali, the communes and neighborhoods, respectively. This paper uses neighborhoods as units of analysis. The 2012 crime statistics are gathered from the 'Observatorio de Seguridad: Delitos contra la vida' (in Spanish) (Alcaldía de Cali, 2012a). Other socioeconomic variable data for 2012 are collected from the publication 'Cali en cifras' (in Spanish) (Alcaldía de Cali, 2012b). Both data sources are taken from the mayor's office.

Following the Colombian Penal Code, this paper holds that a homicide occurs when '[…] a person kills another person' (Penal Code, law 599 of 2000, Article 103, modified by Article 14 of Law 890 of 2004), in which the perpetrator intends to take the victim's life (Law 890 of 2004). Suicides, homicides in traffic accidents and other homicides in which the victimizer does not intend to take the individual's life are excluded. Homicides resulting from armed conflicts with illegal armed groups, such as guerrillas and illegal paramilitaries, are also excluded. This clarification on the definition of homicide is made because it must be clear that a particular violent crime is being studied, common homicide.

Moreover, we use two labor informality measures, namely relative and acute labor informalities. Relative labor informality is the percentage of people without a labor contract (based on the country's labor laws). In contrast, acute labor informality is the percentage of people who do not have a contract, but are also without health insurance and do not contribute to a pension plan.

Table 1 summarizes all variable statistics, their mean and minimum and maximum standard deviations. The average, minimum and maximum homicide rates by neighborhood are 7, 1 and 42, respectively. The average unemployment rate, relative labor informality and acute labor

informality by neighborhood are 13.84%, 17.52% and 45.99%, respectively. Moreover, the table presents the statistics of other crimes, population, neighborhood characteristics and other relevant variables.

Table 1. Summary of statistics

Variables	Mean	SD	Minimum	Maximum
Dependent variable				
Homicides [a]	7.3632	8.2528	1	42
Independent variables				
Unemployment rate [b]	0.1384	0.1074	0.1000	0.6666
Relative labor informality [c]	0.1752	0.1533	0.1000	0.3343
Acute labor informality [d]	0.4599	0.1959	0.1500	0.7555
Medium stratum [e]	2.8395	1.2042	1	6
Average age [f]	36	6	1	100
Neighborhood area [g]	26.5865	10.1694	5	48
Other crimes [h]				
Cellphone robbery	8.1455	8.1932	1	60
Motorcycle theft	7.9335	8.3600	1	57
Car theft	6.6652	7.6240	1	36
Household theft/burglary	3.9605	3.8995	1	25
Personal injury	17.7152	18.1463	1	111
Sexual offence	3.2238	30627	1	19
Commercial entity theft/burglary	5.5268	8.5483	1	60
Population characteristics				
Population [i]	15435	3874	1800	55000
Neighborhood characteristics [j]				
Family commissary	0.3020	0.1714	0	1

Market places	0.0201	0.1406	0	1
Citizen service centers	0.0704	0.2563	0	1
Police features [k]				
Police stations	0.1342	0.1152	0	1
Police substations	0.0067	0.0817	0	1
Police inspections	0.0604	0.2386	0	1

Source: Authors' elaboration. Note: [a] number of homicides by neighborhood; [b] unemployment rate by neighborhood computed as unemployed population divide by economically active population; [c] labor informality rate by neighborhood calculated as a percentage of people without an employment contract; [d] labor informality rate by neighborhood calculated as a percentage of people without health insurance and pension plan; [e] socioeconomic stratum calculated as its median, with maximum and minimum at 6 and 1, respectively, according to the energy billing service, [f] average age of the inhabitants in a neighborhood calculated as the average age of its inhabitants; [g] neighborhood area calculated by hectares; [h] number of crimes by neighborhood; [i] population calculated as the number of inhabitants in a neighborhood; [j] neighborhood characteristic calculated as a dummy variable, that is 1 = present and 0 = otherwise; [k] police features calculated as a dummy variable, that is 1 = present and 0 = otherwise.

Table 2 contains the statistical correlations of the variables used in the model. Multicollinearity may be a potential problem. Thus, we calculate the correlations of the variables in our model. The correlation between the independent variables suggests that there is no high and statistically significant linear correlation. All values of $r < 0.8$.

Table 2. Correlation of variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Homicides	1																		
2	Unemployment rate	−0.17	1																	
3	Relative labor informality	0.13	−0.28	1																
4	Acute labor informality	0.14	0.05	−0.23	1															
5	Medium stratum	−0.55	−0.13	−0.11	0.02	1														
6	Average age	−0.12	−0.15	−0.11	0.14	−0.05	1													
7	Neighborhood area	0.16	0.12	0.14	0.12	0.11	0.21	1												
8	Cellphone robbery	0.14	−0.06	0.63	0.02	0.25	0.13	0.12	1											
9	Motorcycle theft	0.42	−0.17	0.05	0.08	−0.19	0.08	0.15	0.91	1										
10	Car theft	−0.22	0.11	−0.01	−0.17	0.44	0.07	0.05	0.30	0.11	1									
11	Household theft/burglary	−0.24	0.06	0.04	−0.05	0.58	0.12	0.11	0.36	0.18	0.55	1								
12	Personal injury	0.35	0.11	0.12	0.05	0.08	0.14	0.07	0.21	0.15	0.12	0.05	1							
13	Sexual offence	0.21	−0.07	0.15	0.11	0.09	0.06	0.09	0.10	0.10	0.05	0.04	0.02	1						
14	Burglary	−0.25	−0.21	0.07	−0.05	0.23	0.05	0.15	0.63	−0.12	0.18	0.73	0.04	0.01	1					
15	Population	0.32	0.12	0.05	0.07	0.03	0.25	0.24	0.32	0.14	0.21	0.22	0.08	0.09	0.10	1				
16	Family commissary	0.12	−0.14	0.15	0.20	0.14	0.12	0.03	0.25	0.10	0.02	0.05	0.05	0.05	0.02	0.02	1			
17	Market places	0.18	−0.03	0.03	−0.02	−0.16	0.08	0.08	−0.03	0.17	−0.06	−0.09	0.03	−0.01	0.12	0.15	−0.01	1		
18	Citizen service centers	0.05	0.05	0.02	0.03	0.04	0.07	0.03	0.02	0.08	0.03	0.03	0.05	0.01	0.05	0.1	0.25	−0.05	1	
19	Police stations	0.02	−0.08	0.22	0.07	−0.07	0.10	0.10	0.09	0.12	0.02	−0.05	0.01	0.05	−0.02	0.22	0.05	−0.06	0.01	1
20	Police substations	0.08	−0.13	0.05	0.07	0.05	0.05	0.08	0.06	0.10	0.06	0.04	0.01	0.03	0.04	0.14	−0.02	−0.04	0.02	0.
21	Police inspections	0.05	−0.09	0.16	−0.08	0.04	0.06	0.05	0.04	0.07	0.06	0.05	0.02	0.05	0.01	0.09	0.01	−0.03	0.02	0.

Source: Authors' elaboration

4. Empirical Strategy

We conduct a spatial analysis for the relationship between homicides and labor market variables because the neighborhoods of Cali are highly heterogeneous. Moreover, homicides may not occur randomly but could have spatial interaction factors that would determine their behavior. Therefore, the analysis of homicides and their relationship with labor market variables need to be addressed through a spatial analysis considering different spatial characteristics in which homicides occur. For example, Cohen and Tita (1999) show that homicides can exhibit contagious diffusion patterns, Vélez and Richardson (2012) explain the political economy of neighborhood homicide and examine the role of one elite-driven resource, residential bank loans, in shaping local homicide levels and, Andresen (2006) investigates the spatial aspect of criminal activity.

Then, we examine the existence of spatial relationships between Cali's neighborhoods and how the most violent neighborhoods can infect nearby neighborhoods, expanding in homicides from a point to their surroundings. Furthermore, Cali has been growing disorderly, and some of the neighborhoods have emerged from informal settlements and have attracted numerous informal and illegal activities. According to Anselin (1988) and Anselin, Bera, Florax and Yoon (1996), a spatial analysis must begin with the calculation of a univariate spatial indicator, that is the Moran's I, before performing the local indicators of spatial association (LISA) spatial association tests to identify clusters or contagion effects.

When the existence of a spatial relationship has been verified through the Moran's Index and LISA test, a spatial regression analysis is conducted to validate the existence of a spatial effect in the relationship between homicides and labor market variables. A non-spatial linear econometric model is estimated through ordinary least squares (OLS), where (Y) is vector of the logarithm of homicides for the neighborhoods and (X) is a nxk matrix that includes labor market variables. Then, other control variables and the intercept of the model are estimated as follows:

$$Y = X\beta + \mu \quad (1)$$

The Lagrange multiplier tests are estimated from the OLS model to determine whether the model needs to be extended with spatial interaction effects. According to LeSage & Pace (2009); Elhorst (2014) and LeSage (2014), an econometric approach is available that starts from general to particular or vice versa.

We start with the linear econometric model estimated through OLS and then consider Manski's (1993) model to consider the intermediate spatial econometric models between these two cases. These cases indicate the existence of three types of interaction effects that can explain how neighborhood's behavior in a location can depend on others' behavior in another location: (i) endogenous interaction effects, where the decisions of people in a spatial unit to behave in certain ways depends on the decision of people in another spatial unit; (ii) exogenous interaction effects, where the decision of people in a spatial unit to behave in certain ways depends on the independent explanatory variables of the decision made by people in another spatial units; and (iii) correlated effects, where similar characteristics of the unobserved environment result in a similar behavior.

Accordingly, the general model is presented as follows:

$$Y = \alpha + \rho WY + X\beta + \theta WX + \mu \quad (2)$$

$$\mu = \lambda W\mu + \varepsilon \quad (3)$$

where Y is a matrix 298×1, regarding homicides for 298 neighborhoods. Matrix X has order $298 \times k$, corresponding to k explanatory variables. Where WY denotes endogenous interaction effects between the dependent variables, WX denotes exogenous interaction effects between the independent variables and $W\mu$ denotes interaction effects between the error terms of different spatial units. Otherwise, ρ is the spatial autoregressive coefficient, and λ is the spatial

autocorrelation coefficient. In the eq. (3), the random error, ε, is assumed to be normally distributed with zero mean and finite variance.

However, following Elhorst (2010), a family of models between the general model and non-spatial linear econometric model must be considered to choose the correct model. The intermediate models can be obtained from the general model by imposing restrictions on one or more of its parameters. Thus, spatial econometrics considers two approaches to determining the true data generation process that is from general to specific and from specific to general. Elhorst (2014) presents an approximation method to choose the correct model that describes true data generation. Table 3 shows certain spatial models.

Table 3. Spatial models

General Nesting Spatial Model (GNSM)		
$Y = \rho WY + \alpha + X\beta + WX\theta + \mu$ $\mu = \lambda W\mu + \varepsilon$		
Spatial Durbin error model (SDEM) $\rho = 0$ $Y = \alpha + X\beta + WX\theta + \mu$ $\mu = \lambda W\mu + \varepsilon$	Spatial Durbin model (SDM) $\lambda = 0$ $Y = \rho WY + \alpha + X\beta + WX\theta + \mu$	Spatial autoregressive combination (SAC) $\theta = 0$ $Y = \rho WY + \alpha + X\beta + \mu$ $\mu = \lambda W\mu + \varepsilon$

Source: Adapted from Elhorst (2014)

In order to obtain the appropriate model, we perform specifications tests for hypotheses $H_0: \theta = 0$ and $H_0: \theta + \rho\beta$. We also provide LR and Wald test to compare SDM and SAC models.

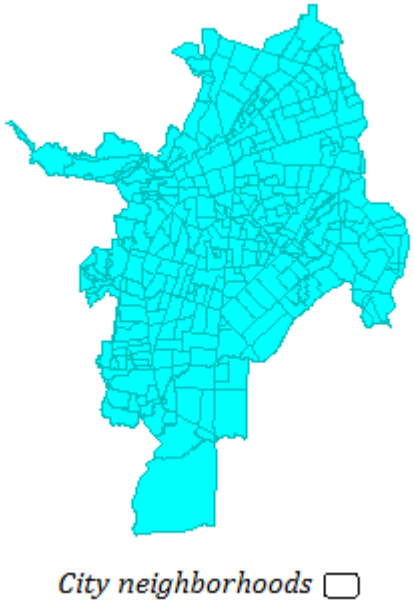
Furthermore, Whitten, Williams and Wimpy (2019) reviewed an approach to interpreting the direct and indirect effects in spatial models and spatial effects.

5. Results

According to the Data and Empirical Strategy section above, we perform an exploratory spatial analysis using the Moran's I and LISA. The Moran's I estimation for the logarithm of Cali's homicides by neighborhood shows a value of 0.4005 that is statistically significant, with a confidence level of 95%. The index was estimated using iterations of 99, 499 and 999 to guarantee the efficiency of the statistical significance test; the result is unchanged. Thus, the existence of positive and global spatial autocorrelation is confirmed, indicating that homicides are not distributed uniformly among neighborhoods because adjacent neighborhoods in a spatial unit show similar homicide rates. This spatial correlation of homicides is contrary to the traditional analysis of routine violence resulting from intolerance, which has uniform distribution.

Figure 4 presents a map with the spatial distribution of the city's neighborhoods with their respective boundaries. Map shows the spatial distribution of all the neighborhoods in the city where it can be seen that the boundaries of the neighborhoods and their average size are relatively similar. In this map you can see again the elongated shape of the city in a direction from south to north.

Figure 4. Cali's neighborhoods



Source: Authors' elaboration.

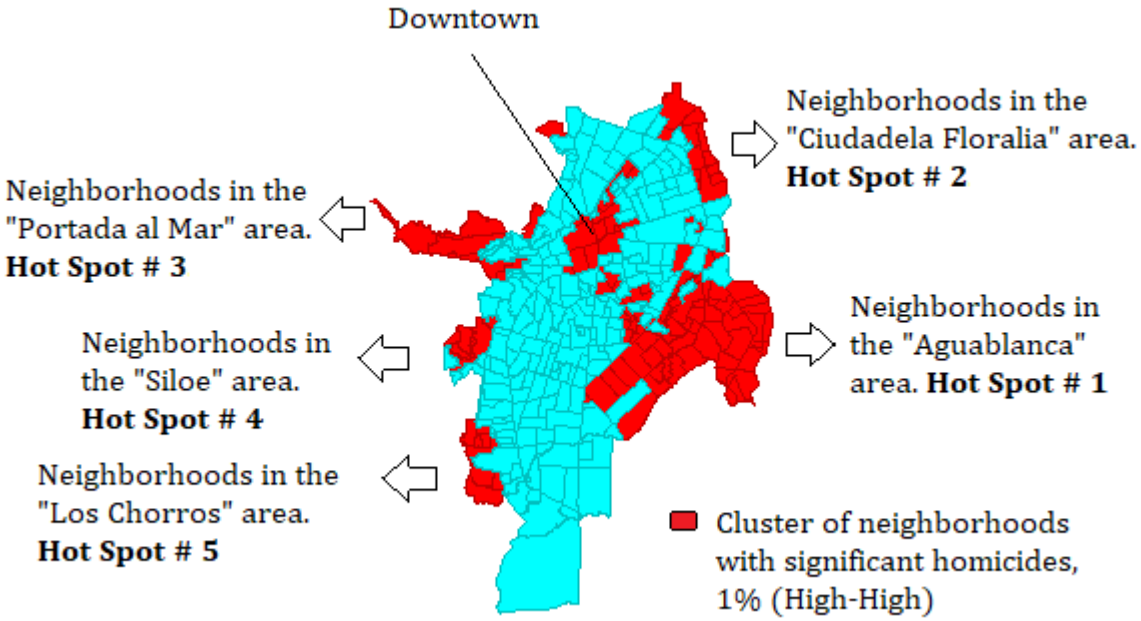
These high homicide rates are scattered throughout the city on a regular basis. In Figure 5, the spatial distribution of homicides in the city is observed, where it can be seen that homicides are not randomly located spatially, but on the contrary, it seems that there is a concentration on the hillsides of the city where neighborhoods that were formed informally are located. The largest informal settlement of neighborhoods in the city is located in an area called Aguablanca, which borders the Cauca River to the east, it is the geographical limit of the city and therefore the city cannot expand beyond that limit. Other hillside areas where some informal neighborhoods are located are the neighborhoods to the west of the city, in the areas known as Siloé, Los Chorros and La Portada al Mar. It is important to highlight that these hillside areas of the city can concentrate more than 1 million inhabitants who live in poor neighborhoods.

Figure 5: Spatial distribution of homicides in Cali, Colombia

Source: Authors' elaboration with data from the National Police of Colombia.

Figure 6 shows a cluster univariate quantile LISA of Cali's homicides that evidence a significant grouping of similar homicide values around certain neighborhoods located in the city limits, predominantly in the eastern and western areas of Cali. Some of these neighborhoods are located on the hillsides of the city and most of them emerged as informal neighborhoods. Another area that is critical is the historical and administrative downtown of the city. Areas in red color in the map show a statistically significant group of neighborhoods with high homicide rates surrounding other neighborhoods with high rates.

Figure 6. Spatial correlation of homicides and labor informality by neighborhood



Source: Authors' elaboration.

The Cali´s hot spots are located on hillsides and downtown areas and they are divided between the eastern and west areas. The eastern areas are the areas called Aguablanca and Ciudadela Floralia, areas with a high number of homicides. On the other hand, the western areas are placed in Los Chorros, Siloé, and La Portada al Mar, areas that border the Andes mountain range. All these neighborhoods are characterized by being areas that were created in an irregular and informal way. Also, it is important to point out a cluster of homicides that is concentrated in the historical and administrative center of the city. This shows that there is a spatial concentration of homicides in neighborhoods located on the city´s hillsides, which were originally informal neighborhoods.

Following our empirical approximation, Table 4 presents two regressions. In the first column, the OLS model is presented, which is rejected in favor of the spatial lag model because

the classical Lagrange multipliers and robust spatial lag were statistically significant. In the case of spatial error, the robust multiplier was not statistically significant as Elhorst (2014) points out that if a spatial phenomenon is found, then the SDM should be estimated.

The spatial lag and spatial error models were estimated using the maximum likelihood method. Thus, the likelihood ratio test can be used as a standard to test the hypotheses $H_0: \theta = 0$ and $H_0: \theta + \rho\beta = 0$. The first and second hypothesis analyze whether the SDM should be simplified into a spatial lag model or spatial error model, respectively. In this case, both hypotheses were rejected, and the best model to perform the spatial analysis is the SDM.

Table 4. Results from OLS and Spatial Durbin Model (SDM)

	OLS	SDM
	(1)	(2)
	Ln (Homicides)	
Labor market variables		
Unemployment rate	-0.001	-0.001
Relative labor informality	-0.001	-0.001
Acute labor informality	0.0080**	0.0061**
Medium stratum	-0.0081***	-0.0258**
Average age	0.0068***	0.0076***
Neighborhood area	0.0001*	0.0001***
Cellphone robbery	0.0199*	0.0163***
Motorcycle theft	0.0199***	0.0148***
Spatial Lag		0.4112***
Lag. unemployment rate		0.0032
Lag. relative labor informality		0.0001
Lag. acute labor informality		0.0029*
Lag. medium stratum		-0.0303
Lag. average age		-0.0051*
Lag. neighborhood area		0.0001
Lag. cellphone robbery		-0.0167
Lag. motorcycle theft		-0.0016
Other crimes	Yes	Yes
Population characteristics	Yes	Yes
Neighborhood characteristics	Yes	Yes

Police features	Yes	Yes
Moran I.	7.02***	
Lagrange multiplier (lag)	66.39***	
Robust LM Lag	21.23***	
Lagrange multiplier (error)	45.34***	
Robust LM (Error)	0.18	
Lagrange multiplier (SARMA)	66.52***	
R-squared	0.4627	
Log likelihood		-64.8121
Breusch-Pagan Test	13.0502	16.3900
Observartions	298	298

Note: All regressions were made with White robust standard error. 'Yes' indicates the incorporation of that variables in the estimation. *** $p < 0.01$; ** $p < 0.05$; and * $p < 0.1$.

Similarly, the additional hypothesis $H_0: \rho = 0$ was examined, which was rejected. Thus, the SDM best describes the spatial relationship between Cali's homicides and labor market variables. Column (2) of Table 4 presents the SDM estimation results, which are a significantly positive effect of acute labor informality on homicides maintained in different econometric specifications. Unemployment rate and relative labor informality are unexpectedly not statistically significant. However, these results cannot be interpreted traditionally as Elhorst (2014) proposes the need to calculate the direct and indirect effects.

Table 5 shows the direct, indirect and total effects of SDM for acute labor informality variable because it presents a positive relationship with homicides. The direct effect is 0.075, and the indirect or spill-over effect is 0.054. Therefore, a neighborhood's homicide rate depends on neighborhood characteristics, such as homicides and acute labor informality. These direct and indirect effects are the endogenous and exogenous interaction effects, respectively.

Table 5. Direct, indirect and total effects from SDM Model

	(1) Direct effect	(2) Indirect effect	(3) Total effect
Dependent variable	Ln (homicides)		
Acute labour informality	0.075***	0.054***	0.129***
All variables	Yes	Yes	Yes

Note: Results obtained with the SDM, column (2) of Table 4. *** $p < 0.01$; ** $p < 0.05$' and * $p < 0.1$. Asymptotic standard errors are obtained from 2500 draws based on Markov Chain Monte Carlo simulation. Simulated z-values are in brackets

Therefore, Cali's homicides and acute labor informality in the neighborhoods have a positive spatial relationship. This finding is our main research contribution given that the crime literature has documented a relationship between unemployment rate and crimes. In this case, for Cali, Colombia, a violent city in a developing country, unemployment rate is not correlated with the behavior of Cali's homicides. This finding is reasonable because people in a labor informality situation face several unsatisfied needs, such as access to health and education systems, and do not consider good socioeconomic conditions as a long-term permanent income.

This spatial relationship is also present particularly in the city's hillsides, where people have several common socioeconomic conditions, such as population living in poverty, lack of access to higher education, informal jobs. The positive relationship between homicides and labor informality is due to the exposure of people in the informal sector to criminal activities in the city. They do not have a labor contract; their incomes are below the minimum legal wage; and they cannot access loans to finance self-employment. These people are in vulnerable conditions, urging them to engage in crimes as a livelihood, also informal workers are also likely to be victims of homicide because they live in the hot spots of the city described above as hillsides. We believe that the neighborhoods that were created informally have had characteristics of informality that enhance aspects related to informality, illegality and criminality.

Figure 7 shows the distances in miles between the city center and these hillside neighborhoods. Our hypothesis suggest that this spatial correlation is presented by the lack of institutionalism that exists in many of these neighborhoods far from where decisions about the city are made. The first map shows that the distance to Aguablanca is 4.89 miles, it is the farthest distance and it has the largest number of neighborhoods in a homicide cluster. The following map shows the distance to the Siloé area, which is 2.78 miles, which is a hot spot but with the shortest distance and the fewest number of neighborhoods in a cluster of homicides. In the maps, the distances with Los Chorros and Ciudadela Floralia are 4.42 and 4.32 miles, respectively. This evidence shows that public policy strategies to reduce these problems of labor informality and homicides must consider a spatial component and the distance from the downtown of the city to the neighborhoods on the hillsides.

Figure 7. Distance from the hillside neighborhoods "emerging hot spot" to the municipal administrative center

(A) Distance to "Aguablanca" area **Hot Spot # 1**[4.89 miles]

(B) Distance to "Siloé" area **Hot Spot # 4** [2.78 miles]

(C) Distance to "Los chorros" area **Hot Spot # 5** [4.42 miles]

(D) Distance to "Ciudadela floralia" area **Hot Spot # 2** [4.32 miles]

Source: Authors' elaboration with Google Maps. Note: The red dot represents the centroid of the hot spot in the hillside neighborhood, the line represents the linear distance in relation to Downtown, and the interval represents the potential paths on Google Maps to cover the distance.

6. Conclusions

We report a spatial econometric analysis in this paper to understand the relationship between homicides and labor market in Cali City, an extremely violent city in a developing country. The relationship between homicides and labor market in places with persistent violence, inefficient labor markets and high rates of labor informality is complex. The mechanism that affects homicides does not emerge from the formal labor market but from the informal labor market. This finding is contrary to previous literature (Cantor & Land, 1985; Chiricos, 1987; South & Cohen, 1985; Raphael & Winter-ebmer, 2001; Burdett, Lagos & Wright, 2003; Krivo & Peterson 2004; Dix-Carneiro, Soares & Ulyssea, 2018; Dell, Feigenberg & Teshima 2019; Khanna, Medina, Nyshadham, Posso & Tamayo, 2021; Koppensteiner & Menezes, 2021), which has focused exclusively on indicators of the formal labor market. Thus, our results show for the

first-time evidence on the positive spatial relationship between labor informality and violent crime, homicides.

The spatial analysis evidences the existence of the city's hot spots given the high homicide rates of adjacent neighborhoods. Similarly, neighborhoods located on hillsides have high acute labor informality rates, people that live in that neighborhoods have less job stability, few work connections or networks and also, they could be victims or perpetrators of homicides in the city. The informal economy is beyond the reach of social protection, labor legislation and protective measures at the workplace. Workplaces may be unsafe and unhealthy with serious and life-threatening hazards. Workers also face long working hours and low productivity and incomes. In addition, this is reflected in the characteristics of the neighborhoods where their homes are located.

This paper contributes to the literature on emerging criminal activity hotspots on hillsides, where there is little control by the city's public administration. Additionally, it shows new evidence from the spatial crime literature that uses neighborhoods (Menezes, Silveira-Neto, Monteiro & Ratton, 2013; Sadler, Melde, Zeoli, Wolfe, & O'Brien, 2022) and from research that analyzes crime with SDM models (Oliveira, Medeiros & Carvalho, 2019). Moreover, the broader implications of these results could be applied to violent cities with informal economy in developing countries and disadvantaged regions within developed countries.

Finally, our findings are also relevant for policy as they suggest that solely forces of policing cannot tackle violent conflict. The great attention to acute labor informality is proposed as a social development programs or policy priority to reduce homicides in specific areas, such as city hot spots that accord with the spatial results. The government should confront labor market and quality education problems in the city and formulate local labor policies. It should also incentive novelty economic policies in the city´s productive activities, particularly on the hillsides.

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