Do local characteristics act in a similar way for the first two waves of COVID-19? Analysis at intraurban level in Barcelona

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ABSTRACT

Background This paper concerns the spatial determinants of the first two waves of COVID-19 at the neighbourhood level.

Methods Using data for the first and second waves of COVID-19 at the neighbourhood level in Barcelona, we analyse whether local characteristics acted in the same way during the two waves and identify typologies of areas depending on such determinants. Univariate and bivariate local Moran's *I* and count data models are used.

Results Some structural effects at the neighbourhood level consistently either boost (e.g. population density) or reduce (e.g. income) COVID-19 cases. Other effects differ between the two waves (i.e. age composition, schools and transport infrastructures).

Conclusions Since certain characteristics influenced the virus diffusion in opposite ways between the two pandemic waves, territorial heterogeneity alone is insufficient to explain COVID-19 outbreaks—individual behaviour also needs to be factored in. Consequently, both econometric and spatial analysis techniques are recommended for tracking the spatiotemporal spread of this disease and for monitoring the effectiveness of policy measures across heterogeneous neighbourhoods.

Keywords geography, public health, socioeconomic factors,

Background

The increasing availability of highly disaggregated spatial data allows researchers and practitioners to analyse the spatial patterns of COVID-19 outbreaks and to identify potentially fine-grained socio-economic determinants. Even though there are outbreaks in rural areas,[1,2] human proximity and interaction are key factors in the spread of the virus,[3] hence the importance of using intra-urban data. Urban living conditions such as population density, agglomeration of people in transport infrastructures and crowding in educational, shopping and healthcare centres facilitate virus transmission. The most densely populated urban areas, especially deprived neighbourhoods, lend themselves to propagation.[3,4] Both biological and social factors are involved,[5] since vulnerability is found to be higher for lower socio-economic groups.[6] As demonstrated by Harlem[1] for New York or Baena-Díez[7] for Barcelona, different neighbourhoods of the same city can have very different contagion rates—this mirrors existing heterogeneities that include income levels, the use of transport infrastructures and per capita available space. Such heterogeneities have also been studied in racial terms,[8] but typically space, rather than biological differences, is key.

Recent research has highlighted the importance of social and mobility prevention measures,[9] but the ability to maintain physical distance and practice hygiene is shaped by socio-economic conditions, and these are easily identified across city neighbourhoods. Although public authorities have implemented strict measures to avoid and control outbreaks in dense urban areas,[10] many factors (for example, public transport systems) are difficult to control.[11] This is further complicated by empirical evidence which suggests changing patterns in the spread of the disease, with different waves affecting different socio-economic profiles.[12]

This paper aims to contribute to empirical literature by analysing the first two waves of the pandemic in Barcelona

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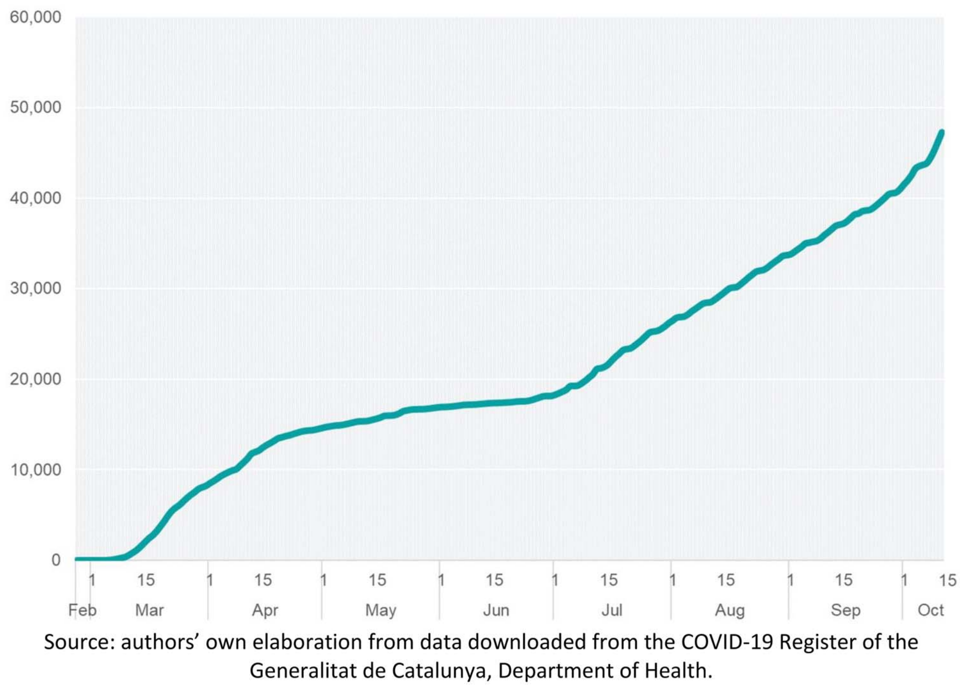


Fig. 1 Cumulative incidence of confirmed COVID-19 cases in the city of Barcelona between 26th February and 16th October 2020. Source: authors' own elaboration from data downloaded from the COVID-19 Register of the Generalitat de Catalunya, Department of Health.

(Spain) and the way in which public and private measures helped to prevent the spread of COVID-19. Mortality levels were significantly reduced in the second wave and the profile of the people infected changed. In the first wave, most of the positive cases were reported in retirement homes but improved public health measures changed this in the second wave. The physical distancing and prevention measures that had been followed during the first wave were considerably relaxed during the second one with a reopening of shops and social and economic activities. These changes, however, led to a considerable increase in infection rates among the younger population. There is a clear need to monitor the evolution of pandemics and to test the adequacy of the public health measures and policies implemented. Here, spatial analysis techniques present undeniable opportunities for adapting these measures to heterogeneous neighbourhoods.

Methods

We use descriptive cartography, including choropleth maps, and a local Moran's indicator to test whether the two waves of the pandemic had different spatial patterns. We then use econometric count data models to identify potentially important neighbourhood characteristics—these include population density, income levels, proximity to neuralgic transport stations, demographic structure and land use. To detect different impacts the two waves have on individual neighbourhoods, we implement bivariate local Moran's indicators, crossing the number of positive cases per 100 000 inhabitants and the independent variables. Additional details on this are available in the Appendices.

Data

Data on COVID-19-positive cases at the neighbourhood level (73 units) of Barcelona was provided by the Local Public Health Office of Barcelona (*Agència de Salut Pública de Barcelona*). To simplify the analysis, to avoid bias due to lack of daily updating and to avoid unnecessary heterogeneity in the data, we grouped the data into two waves. The first is the period from February 26th to July 15th, and the second runs from July 16th to October 16th. The transition point between the two waves is identified as being about 3 weeks after the state of alarm ended in Catalonia (i.e. June 20th). Physical distancing and everyday preventive actions were considerably relaxed by a significant part of the population (see Fig. 1 for cumulative data on COVID-19 cases in Barcelona), and the second wave started from then. In response to this new growth in cases, at the end of October the public authorities had to re-implement new measures and restrictions on mobility and social and economic activities.

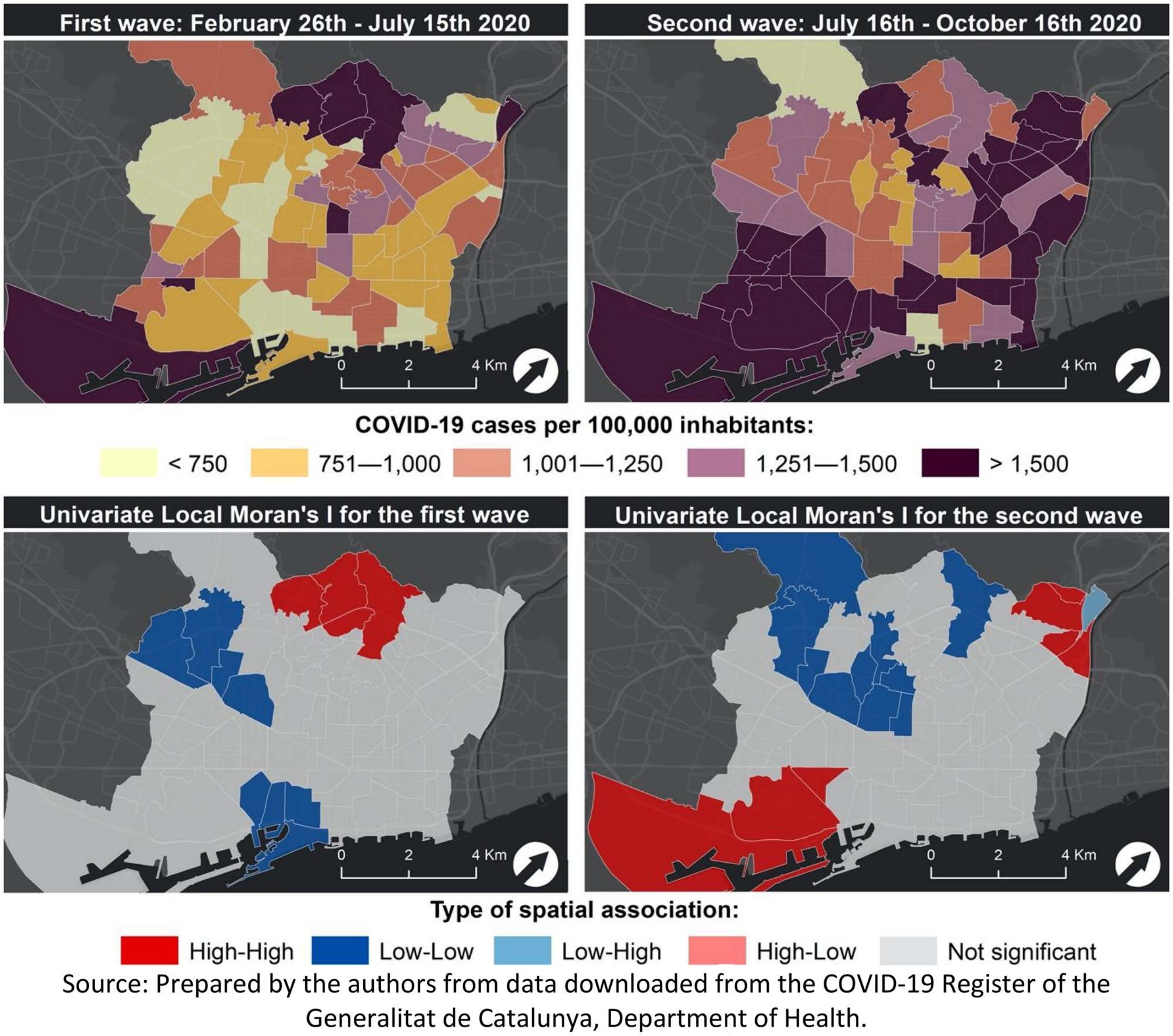


Fig. 2 Choropleth maps and univariate local Moran's *I* of confirmed COVID-19 cases per 100 000 inhabitants during the first wave (26th February—15th July) and the second wave (16th July—16th October 2020).

Results

Our dataset comprises 41 606 Covid-positive cases reported in Barcelona between February 26th and October 16th. Figure 2 shows the COVID-19 cases relative to the total population together with a local Moran's I, which allows us to identify some significant positive clusters (red areas), as well as significant clusters of less affected neighbourhoods (dark blue areas).

In addition to these descriptive approaches, we aim to identify the important characteristics, such as residential density, age structure of the population and income levels, of each neighbourhood. This is especially relevant in a city such as Barcelona, where neighbourhoods greatly differ in terms of their socioeconomic status and built environment characteristics. To identify which socioeconomic characteristics best explain positive COVID-19 cases, we hypothesized five sets of variables. These were related to (i) population (total population—POP—and population density by residential area—DENSITY), (ii) age structure (percentage of young residents—YOUNG, those aged between 15 and 34—and elder residents—ELDER, those aged over 65), (iii) income levels (INCOME, mean income), (iv) land use patterns (SCHOOLS, surface used for educational facilities) and (v) transport infras-

Table 1 Determinants of confirmed COVID-19 cases

	February–July	*July–October*
POP	0.00003***	0.00003***
	(6.96e−07)	(5.54e−07)
DENSITY	0.00035***	0.00080***
	(0.00004)	(0.00003)
YOUNG	−0.02560**	0.13218***
	(0.00986)	(0.00811)
ELDER	0.03553***	−0.01022***
	(0.00249)	(0.00194)
INCOME	−0.00074**	−0.00327***
	(0.00028)	(0.00023)
SCHOOLS	−6.13e−07***	1.59e−06***
	(1.67e−07)	(1.23e−07)
TRANSPORT	0.00003	−0.00013***
	(0.00001)	(0.00001)
Cons.	3.78116***	3.60391***
	(0.13322)	(0.11158)
Observations	73	73
Log Link	−1029.0398	−1252.6305

***$P < 0.01$; **$P < 0.05$; *$P < 0.1$.

Source: Authors' calculations. Standard errors in brackets.

tructures (TRANSPORT, distance to the nearest intermodal station).

The dependent variable is the number of Covid-positive cases, so the most appropriate estimation procedure is that of count data models, specifically a Poisson model. Table 1 shows the results of the estimation for the two COVID-19 waves considered.

As has already been demonstrated for several cities, characteristics such as DENSITY and INCOME have a clear and significant effect on positive cases of COVID-19.[6,13] This is as expected, since there is empirical evidence that (i) potential social interactions increase with population density triggering disease transmission and (ii) higher-income populations have additional resources to protect themselves against potential contagion—there is, for example, a clear link between income and the possibility of switching to remote working.

In addition to exploring these variables, we focus on the determinants, namely age composition, land use and transport infrastructures, which differ between the two waves. It is first important to explain *why* the waves are different. During first wave, there was a total lockdown for education institutions and most shopping activities between March 13th and June 18th, interactions among teenagers were reduced to a minimum and most Covid-positive cases occurred in senior residential care centres. During the second wave, this reversed, with most economic activities and schools resuming and protective measures being taken in residential care centres. Social interactions, especially among young people, increased and self-protective measures relaxed. As shown in Table 1, this had a clear effect on transmission.

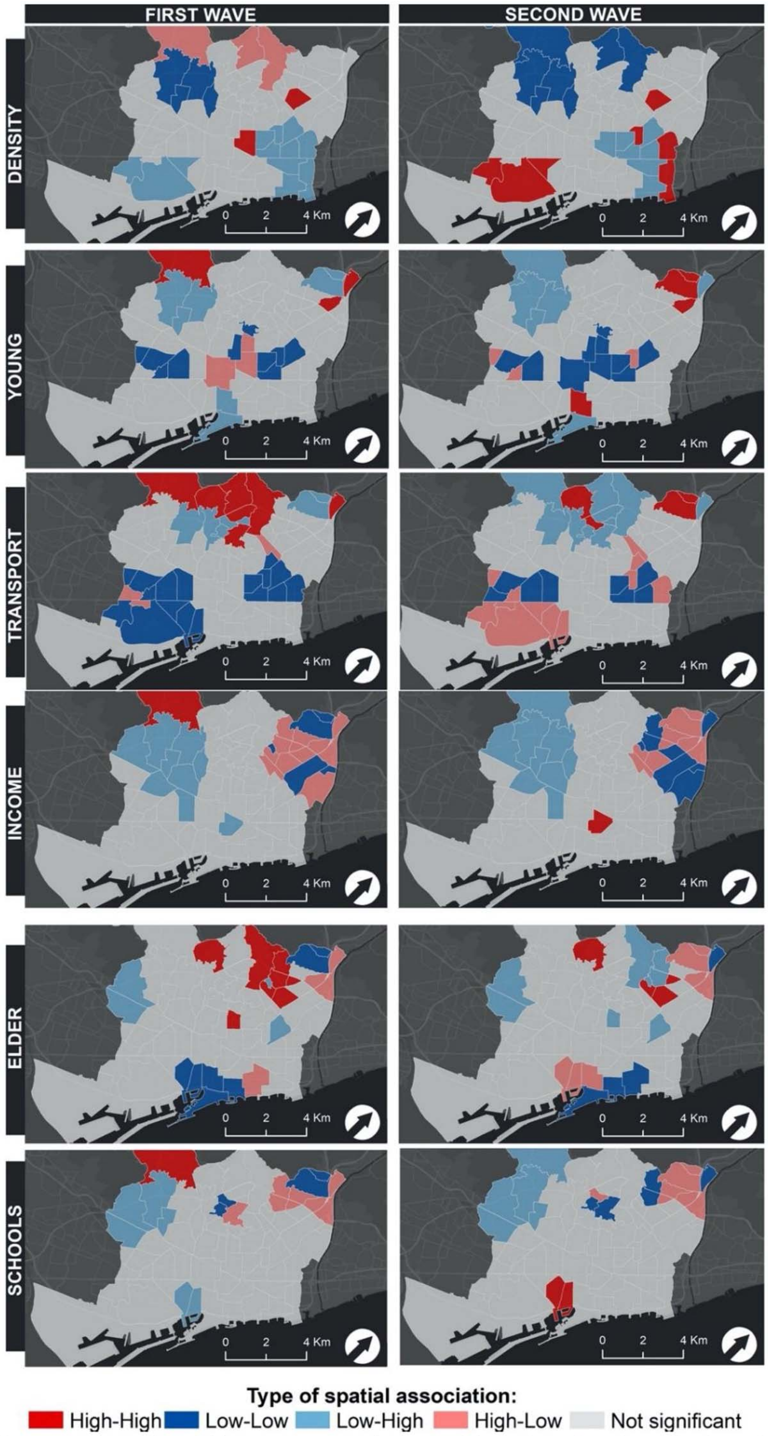
The results show that the roles of the young and aged population reverse. The percentage of young population (YOUNG) has a negative effect in the first wave but a positive one in the second wave, and vice versa for the elder population. Secondly, since schools, high schools and universities reopened, the surface used for educational centres (SCHOOLS) switched from a negative to a positive effect, as young people interacted again. This is an important finding, opening educational facilities boosts pandemic growth, even if these institutions implement all required hygiene measures. Thirdly, proximity to transport infrastructure (TRANSPORT) did not have a significant effect during the first wave (because most people were in confinement and not using them). However, this changed when economic activity restarted,[14,15] and, the greater the distance to these infrastructures, the lower the number of reported cases.

Figure 3 presents the results of the bivariate local Moran's I and shows the spatiotemporal shifts between neighbourhoods and pandemic waves. It is important to emphasize that no single variable is sufficient to explain the evolution of the pandemic. There are multiple vulnerabilities that, combined over space and time, lead to a greater or lesser incidence of the virus. The variable related to INCOME is stable across the two waves and highlights the vulnerability of the less prosperous north-eastern neighbourhoods of Nou Barris and Sant Andreu, than that of the more affluent north-western Sarrià-Sant Gervasi and les Corts. The DENSITY emerges as a key variable in the second wave, when greater mobility was allowed, especially in the eastern areas adjacent to neighbouring cities, such as Besòs, el Maresme, la Verneda and la Pau, and in central neighbourhoods such as Sant Antoni and el Poble Sec. Similarly, in the second wave, the variable SCHOOLS plays a significant role, especially in Ciutat Vella (el Raval and Barri Gòtic).

Discussion

Main findings of this study

This paper has analysed the determinants of COVID-19-positive cases during the first two waves of the disease in Barcelona (Spain). We have shown that some determinants, such as income and population density, differ little between the two waves. Others, however, differ distinctly based on socioeconomic, population and built environment neighbourhood heterogeneities. The explanatory variables' roles vary



Note: spatial association should be interpreted as neighbourhoods where high or low values of COVID-19 cases per 100,000 inhabitants in the first or second waves were surrounded by high or low values of each explanatory variable.

Source: Prepared by the authors from data provided by the Local Public Health Office of Barcelona and the Department of Statistics of Barcelona

Fig. 3 Bivariate local Moran's *I* of confirmed COVID-19 cases per 100 000 inhabitants in the two COVID-19 waves and the explanatory variables.

over both time and space, pointing to the multicausality of neighbourhood vulnerabilities.

What is already known on this topic

Studies of several urban areas provide empirical evidence that population density, and socioeconomic inequalities between neighbourhoods, impacts on COVID-19 transmission.

What this study adds

In addition to the results in the existing literature, we (i) identify the different determinants of the COVID-19 incidence at the neighbourhood level for the first and second waves of the pandemic and (ii) unravel the differing impact of the explanatory variables for neighbourhoods in Barcelona. We highlight the fact that multiple variables influence virus propagation, most affecting the most vulnerable people and neighbourhoods, and that this differs between the two waves. Public health measures may successfully reduce the vulnerability of some groups in the second wave, especially in the case of elder people. Nevertheless, the way back to normal activities since July has conducted to a growing Covid-positive incidence of younger people. Moreover, our results show that reopening of schools during the second wave increased virus transmission. Because of neighbourhood heterogeneity, a combination of individual responsibility and territory-specific public measures should be implemented in order to reduce COVID-19 transmission.

Limitations of this study

This study uses official data for positive COVID-19 cases reported from PCR's tests. Testing and contact tracing was considerably lower in the first wave, with potential consequences for underreporting.[16]

Conclusion

This paper has shown that urban heterogeneities matter when explaining COVID-19 outbreaks, some areas are more exposed than others. Exposure is shaped by individual behaviour, and individual and social attitudes towards social interaction and physical distancing change over time. Our study shows the effects of the public health measures taken by public authorities after the first wave and of the relaxing of social preventive measures during the second wave. It thus highlights the importance of both public and private measures in fighting the pandemic, and the need to tailor these to the structural characteristics of each area. Econometric and spatial analysis techniques are recommended for spatiotemporal disease tracking and monitoring the effectiveness of policy measures in heterogeneous neighbourhoods.

Supplementary data

Supplementary data are available at the *Journal of Public Health* online.

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Author's contributions

AD collected the data; AD, AG and JMAC analysed and interpreted the data; AD designed the cartography and AD, AG and JMAC wrote, revised and submitted the manuscript.

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