

Reduced mobility? Urban exodus? Internal population movements during the COVID-19 pandemic in Latin American countries

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Abstract. The COVID-19 pandemic has impacted the national systems of population movement around the world. Existing work has focused on countries of the Global North and restricted to the immediate effects of COVID-19 data during 2020. Data have represented a major limitation to monitor change in mobility patterns in countries in the Global South. Drawing on aggregate anonymised mobile phone location data from Meta-Facebook users, we aim to analyse the extent and persistence of changes in the levels (or intensity) and spatial patterns of internal population movement across the rural-urban continuum in Argentina, Chile and Mexico over a 26-month period from March 2020 to May 2022. We revealed an overall systematic decline in the level of short- and long-distance movement during the enactment of nonpharmaceutical interventions in 2020, with the largest reductions occurred in the most dense areas. We also showed that these levels bounced back closer to pre-pandemic levels in 2022 following the relaxation of COVID-19 stringency measures; however, the intensity of these movements remained below pre-pandemic levels in many areas in 2022. [add bit on net balances]

1 Introduction

The COVID-19 pandemic triggered major changes in the patterns of human population movement across the world. Nonpharmaceutical interventions to contain the spread of COVID-19, such as social distancing, lockdowns, business and school closures contributed to sharp declines in internal population movements within countries (Nouvellet et al. 2021). As the virus spread globally in early 2020, COVID-19 infection and mortality rates were disproportionately higher in large and dense metropolitan areas (Pomeroy and Chiney 2021), remote work reduced the need to commute (Nathan and Overman 2020) and diminished retail activity decreased the attractiveness and vibrancy of these areas (Florida, Rodríguez-Pose, and Storper 2021). In a gloomy prospect for urban centres, media headlines suggested the death of cities gathering anecdotal evidence on an “urban exodus”, claiming

sudden rises in the number of people moving from large cities to suburbs and rural locales (Paybarah, Bloch, and Reinhard 2020; Marsh 2020).

Empirical evidence have examined these claims focusing on two key dimensions of internal population movements i.e. its level (or intensity), and its spatial impacts on population redistribution. Existing evidence reveals a sharp reduction in levels of overall mobility, including short- and long-distance movements, and some support for an urban exodus during the early days of COVID-2019 in 2020 as the pandemic was unfolding and strict nonpharmaceutical measures were enacted [Rowe, González-Leonardo, and Champion (2023)]. Population losses through internal population movements were documented for large core metropolitan areas in Spain [González-Leonardo et al. (2022); González-Leonardo and Rowe (2022)], Germany [Stawarz et al. (2022)], Sweden [Vogiazides and Kawalerowicz (2022)], Japan [Tønnessen (2021)], Australia [Perales and Bernard (2022)], the United States [Ramani and Bloom (2021)] and Britain [Rowe et al. (2022b)]. Suburban and outer parts of metropolitan areas (as in the ‘donut effect’ noted for US cities, see Ramani and Bloom (2021)), as well as more distant rural areas, were identified as gaining population.

Yet, less is known about the extent and durability of population movements to and from large cities during the COVID-19 pandemic in the Global South and extending beyond 2020. Existing work has focused on countries in the Global North and restricted to the immediate effects of COVID-19 data during 2020. Only two studies have analysed data extending to 2021. For Spain, González-Leonardo and Rowe (2022) report continuing population losses through internal migration in large cities, such as Madrid and Barcelona. In Britain, however, Rowe et al. (2022b) record a recovery in the levels of internal movements in low and high density areas converging to pre-pandemic levels.

A major limitation to capture national-scale changes in the patterns of internal population movement across the rural-urban hierarchy in the Global South during the pandemic has been the lack of suitable data. Traditionally census and survey data are used to study human mobility patterns at such scale. But, these data systems are not frequently updated and suffer from slow releases, with census data for example being collected over intervals of ten years in most Latin American countries and with a few month lag for the release of information (CEPAL 2022). These systems thus lack the temporal granularity to analyse population movements over short-time periods (Green, Pollock, and Rowe 2021). Digital footprints (DF) left as a result of social interactions on digital platforms offer an unique source of information to capture human population movement in the unfolding data revolution (Rowe 2023). Particularly DF data from mobile phone applications have become a prominent source to sense patterns of human mobility at higher geographical and temporal resolution over in real time, and especially in data-scarce environments in less developed countries.

Drawing on Meta-Facebook users’ mobile phone location data, we aim to examine the extent and persistence of changes in the levels (or intensity) and spatial patterns of internal population movement across the rural-urban continuum in Argentina, Chile and Mexico over a 26-month period from March 2020 to May 2022. Specifically, we seek to address the following set of questions:

- How have the levels of mobility changed across the rural-urban hierarchy over time?

- To what degree have large cities experienced population loss through internal migration movements during the pandemic? What have been the main destinations for people leaving large cities?
- To what extent have the intensity and potential negative balance of population movement from large cities have persisted over time?

We focus primarily on national capital cities. In Latin American countries, these cities have dominated the national system of internal population movement since the 1930s, although they have recorded continuing balance of moderate population losses due to internal migration over the last three decades (Bernard et al. 2017; Rodríguez-Vignoli and Rowe 2018). We could expect that the magnitude of these population losses to have accelerated during the COVID-19 pandemic. We distinguish between short- and long-distance movement to identify the potential sources of the patterns underpinning observed changes in population movements during the pandemic.

Our work contributes to expanding existing knowledge by offering new empirical evidence on the impacts of COVID-19 on internal population movement. First, it provides a systemic understanding of the overall population movement system in Latin America. While prior work has focused on daily mobility or internal migration, our study provides a more complete representation analysing how short- and long-distance mobility have evolved during COVID-19. Second, we capture the evolution of the internal population movements from 2020 to 2022. Data limitations have prevented previous studies from extending their analysis to understand the patterns of internal population movements beyond 2020. Third, we contribute some of the first empirical evidence documenting the patterns of internal population movement in a set of countries in the Global South.

The rest of the paper is structured as follows. The next section provides a brief review of recent research on internal population movements during the COVID-19 pandemic, before providing an overview of the main patterns of population movements within Latin American countries. Section 3 describes the data, and Section 4 discusses the methods used in this study. Section 5 presents the key results from our analyses before they are discussed in light of the existing literature in Section 6, which also identifies key limitations and potential avenues for future work. Section 7 provides some concluding remarks.

2 Background

2.1 The impact of COVID-19 on internal population movements

Globally, there is evidence that the COVID-19 pandemic constrained both shorth- and long-distance movements within national boundaries (Nouvellet et al. 2021; González-Leonardo, Rowe, and Fresolone-Caparrós 2022; Wang et al. 2022; Rowe, González-Leonardo, and Champion 2023). Declines were documented across the Global North during the first year of the pandemic, in the United States (Ramani and Bloom 2021), some European countries, Japan and Australia (Rowe, González-Leonardo, and Champion 2023), from 2.5% in Spain to 8.5% in Australia. Drops mostly

occurred when governments implemented non-pharmaceutical interventions, such as stay-at-home requirements, travel restrictions, mobility restrictions, business and school closures. Levels of human mobility within countries, however, recovered pre-pandemic values following the elimination of lockdowns and other stringency measures. Declines on human mobility were attributed to lockdowns, increasing teleworking and restrictions of movements, but also to a loss of labour market dynamism as a consequence of the economic recession during the pandemic (Perales and Bernard 2022). In addition to evidence in the Global North, drops in internal population movements were also found in Latin American, declining by about 10% during periods of severe stringency measures (Aromí et al. 2023). The highest declines occurred in Bolivia, Ecuador and Argentina, ranging from 16% to 19%, while they did not reach 3% in Paraguay and Venezuela.

In global north countries, the COVID-19 pandemic also modified the patterns of internal population movements between large cities and areas with lower population densities (Rowe, González-Leonardo, and Champion 2023). Variations were found in the United States (Ramani and Bloom 2021), United Kingdom (Rowe, González-Leonardo, and Champion 2023; Wang et al. 2022), Spain (González-Leonardo et al. 2022; González-Leonardo, Rowe, and Fresolone-Caparrós 2022), Germany (Stawarz et al. 2022), Sweden (Vogiazides and Kawalerowicz 2022), Norway (Tønnessen 2021), Australia (Perales and Bernard 2022) and Japan Kotsubo and Nakaya (2022). Net-migration rates in large cities declined in the United States, Germany, Norway, Sweden and Japan during 2020, while they increased in their suburbs. (Ramani and Bloom 2021) called this phenomenon as “donut effect”, reflecting a decrease in population inflows to urban centers (urbanization) and a growth of movements from cities to their suburban rings (suburbanization). Nonetheless, there is no evidence of a “donut effect” in the United Kingdom, Spain and Japan, as net-flows in suburbs did not show significant changes. However, inflows to large cities also declined and counterurbanisation movements increased, reflecting unusual population gains in rural areas. In Spain, Sweden, Japan and Germany, holiday town with second homes of wealthy individuals were also found as popular destination for people leaving large cities during the pandemic. It suggests that wealthy populations and professionals who are able to work remotely seems to underpin movements from large cities to areas with lower population densities where they own second residences (Haslag and Weagley 2021; Tønnessen 2021).

Despite the above-mentioned changes to the human mobility system during the pandemic, research suggests that pre-existing macro-structures of internal population movement across the rural-urban continuum were not altered, since the majority of movements continued to occur within and between urban areas, and changes are not likely to endure (Rowe, González-Leonardo, and Champion 2023). For instance, mobility patterns returned to those registered before the pandemic after the lockdown in the United Kingdom (Rowe et al. 2022a; Wang et al. 2022). The pandemic caused minor impacts on spatial patterns of internal population movements in Australia, and variations attributed to COVID-19 disappeared in late 2020 (Perales and Bernard 2022). Urbanisation levels returned to those registered prior to the pandemic in Spain when the lockdown ended in mid-2020 (González-Leonardo et al. 2022), although unusually high levels of counterurbanisation persisted over 2021, despite decreasing over the year (González-Leonardo, Rowe, and Fresolone-Caparrós 2022). The levels and patterns of internal population movements seem to have returned to those observed prior to the pandemic in some countries, while they have not in others. Thus, the long-term effects of COVID-19 are yet to be established.

Previous work provided a good understanding on how human mobility across the rural-urban hierarchy was affected by the pandemic in the Global North. However, less is known about COVID-19 impacts on movements between cities, suburbs and rural areas in the Global South and the durability of potential changes. Anecdotal evidence, based on small surveys carried out in India (Irudaya Rajan, Sivakumar, and Srinivasan 2020) and South Africa (Ginsburg et al. 2022), pointed out that flows from large cities to less populated areas increased due to the return of workers to their hometown, while movements of labour force to cities decreased. Both surveys saw that the economic downturn caused by non-pharmaceutical interventions during the pandemic (Ghosh, Seth, and Tiwary 2020) underpinned declining inflows of workers to cities and increasing returns among people who lost their jobs. The above-mentioned anecdotal evidence suggests that vulnerable populations seem to have played a role in movements to and away from large cities during the pandemic in the Global South.

Nonetheless, a recent study demonstrated that wealthy individuals from large cities in Brazil, Colombia, Indonesia, Mexico, Philippines and South Africa moved to less populated areas during the first wave of COVID-19 (Lucchini et al. 2023). On average, residents from high-wealthy neighborhoods were 1.5 times more likely to leave cities compared to those from low-wealthy areas. This pattern was also found in Chile among high-income individuals leaving Santiago during the pandemic (Elejalde et al. 2023). Wealthy individuals have the resources to move, are able to telework and own second residences away from cities. Low-income population in the Global South however may lack resources to move. In addition, a large proportion of vulnerable populations work in the informal economy which makes leaving cities difficult for them. While there is some evidence on the mixed effects that the pandemic had on the patterns of internal population movements in some Global South countries, the magnitude and durability of these changes across the urban-rural hierarchy remain to be quantified. Here, we use a non-traditional source of mobility data to analyse the effect of COVID-19 on the patterns of internal population movements in Argentina, Chile and Mexico.

2.2 Human mobility across the rural-urban continuum in Latin American countries

Currently, Latin America has the highest urbanization rate in the world after North America, totaling 81% (Nations” 2019). It means that the population is highly concentrated across space within Latin American countries, particularly in large cities with more than one million inhabitants, where half of urban residents are settled (Pinto da Cunha 2002; A. E. Lattes, Rodríguez, and Villa 2017). High urbanization rates are due to massive levels of population redistribution from rural settlements to cities until the 1980s, mostly during the fast industrialisation period from early-1950s to late-1970s, when population gains were mainly observed in chief cities (Firebaugh 1979; A. Lattes 1995; J. Sobrino 2012). Internal population movements in Latin America have been declining since the 1980s, as rural population stocks were depleted (Chávez Galindo et al. 2016) and the industrial crisis leaded to deconcentration trends in large cities, such as Santiago de Chile [González Ollino and Rodríguez Vignoli (2006)] or Mexico City (Jaime Sobrino 2006), where long distance inflows have declined. In sum, middle size cities became more attractive to internal migrants as a consequence of increasing

domestic and foreign investment in export-oriented industries or tourism activities, leading to geographic economic dispersal (Brea 2003; Pérez-Campuzano 2013; Chávez Galindo et al. 2016). Nowadays, movements between cities dominate the internal migratory system in Latin American countries (Bernard et al. 2017; Rodríguez-Vignoli and Rowe 2018; Nations” 2019). About 80% of internal migrants moved between cities, according to the 2010-11 census round (Rodríguez-Vignoli and Rowe 2018). Medium-sizes cities from 500.000 to 1 million residents showed the highest population gains by internal migration, while large cities with more than 1 million residents registered balanced rates and small cities with less than 500.000 inhabitants lost population by internal mobility (Rodríguez-Vignoli and Rowe 2018).

Latin American cities have shown a significant growth in terms of land development in their urban peripheries. Since the 1970s, large cities, such as Santiago de Chile, Buenos Aires or Mexico City, but also middle and small cities have experienced suburbanisation (Graizbord and Acuña 2007; Chávez Galindo et al. 2016). Suburbanisation flows comprise middle- and high-class families moving from cities to auto-segregated areas in the periphery (Borsdorf 2003; Rodríguez Vignoli and Rowe 2017). Low-income individuals also settle in slums across suburbs but, in this case, in those areas where the land cost is cheaper (Janoschka 2002; Rodríguez Vignoli and Rowe 2017). Both residents in auto-segregated areas and slums commute daily to cities, mainly for work reasons (Chávez Galindo et al. 2016). Most recently, reurbanisation trends have been identified in central areas due to gentrification dynamics, although suburbanization flows continue to dominate short distance movements (J. So-brino 2012; Chávez Galindo et al. 2016). In this report, we explore COVID-19 impacts on the patterns of human mobility across the rural-urban continuum in Latin America.

3 Data

3.1 Meta-Facebook Data

The multinational technology conglomerate Meta offers a range of data products aimed for social good through their Data for Good programme, which is open to trusted partners including universities, non-profit organisations, and international institutions. The data is available at small spatial and temporal scales and has the potential to improve how we respond to real-world crises or unusual events, such as earthquakes, hurricanes, floods or pandemics (Maas et al. 2019). In particular, the Data for Good programme offers location data, gathered from Facebook app users who have the Location Services setting turned on on their smartphone. Meta uses the location data for a wide variety of applications in addition to the Data for Good programme, including providing customised services to its users such as finding nearby friends, providing information about nearby Wi-Fi hotspots, and location-relevant ads. The collected location data also enables targeting of AMBER alerts and prompts to check-in as “safe” after a hazard event.

While the raw location data remains available only to the data owners, the datasets available through Data for Good consist of anonymised and aggregated near real-time data corresponding to a period

of crisis which might extend over several weeks, months or years. The datasets also contain historical location data as a baseline period before the event (Maas et al. 2019).

We analyse human mobility during the COVID-19 pandemic using the datasets Coronavirus Disease Prevention Map of Facebook Population During Crisis (Tile Level) and Coronavirus Disease Prevention Map of Facebook Movements During Crisis (Tile Level), hereinafter Facebook Population and Facebook Movements datasets. Specifically, we analyse human movement data from four Latin American countries: Argentina, Chile, Colombia and Mexico. The former dataset allows us to analyse how the number of Facebook users changed across space during the COVID-19 pandemic. The focus of our analysis, however, is on the latter, which contains information about the evolution of spatial patterns of mobility during COVID-19.

The datasets contain data corresponding to a two-year period, starting on the 10th March 2020 and ending in mid-March 2022. Data are temporally aggregated into three 8-hour daily time windows (00:00-08:00, 08:00-16:00 and 16:00-00:00). The datasets also include data for baseline levels before COVID-19 based on a 45-day period ending on the 10th of March of 2020. The baseline data is computed using an average for the same time of the day and day of the week in the period preceding the crisis (e.g., average over all data collected on a Monday from 00:00 to 8:00 or average over all data collected on a Wednesday from 16:00 to 00:00). For more details on how the baseline values are computed, see (Maas et al. 2019).

The data is spatially aggregated into units called Tiles, according to the Bing Maps Tile System developed by Microsoft (Microsoft). This widely-used system offers a variety of world partitions, where the spatial units are square cells at various levels of resolution. The Data for Good datasets are typically generated using Bing tile levels 13 through 16, where level 13 results in tiles that are about 4.9 x 4.9 km at the Equator (Maas et al. 2019).

The Facebook Population data provides the number of mobile app users who have the Location Services setting turned on, aggregated by tile. The location of each user in a given 8-hour time window is determined by the tile where they spent most of the time within that window. The Facebook Movement data captures the number of mobile app users who have the the Location Services setting turned on moving between a pairs of tile. The origin and destination of a movement are defined as the locations where a user spent most time between two subsequent time windows (e.g., 00:00-8:00 and 8:00-16:00). In addition to the count data, both the Facebook Population and the Facebook Movement datasets include the percentage difference between the number of counts during the crisis period and the corresponding baseline level for each entry.

Prior to releasing the datasets, information on personal characteristics of users is removed and several techniques are applied to ensure privacy and anonymity. Small-count dropping is one of these techniques, whereby a data entry is removed from the data set if population or movement counts are lower than 10 during the crisis period, the baseline period or both. While this technique makes it harder to identify individual users based on their movement patterns, the removal of data entries containing locations with small counts may lead to an underrepresentation of the population in these places. Another of these techniques consists in adding a small undisclosed amount of random noise

to ensure that it is not possible to ascertain precise, true counts for sparsely populated locations. In order to produce a smooth population count surface, spatial smoothing using inverse distance-weighted averaging is also applied (see (Maas et al. 2019) for details).

3.2 COVID-19 stringency data

To understand the patterns of mobility in the context of the COVID-19 pandemic, we use the stringency index as a measure of the level of nonpharmaceutical interventions to COVID-19, such as social distancing and lockdowns. The stringency index ranges from 0 to 100, with 100 being the value corresponding to the most strict scenario. The values for the stringency index were retrieved from the COVID-19 government response tracker (<https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker>). For more information, see Hale et al. (Hale et al. 2021).

3.3 Worldpop population data

An additional data set from WorldPop was used to capture the spatial distribution of actual population in the different countries analysed here. The WorlPop poulation dataset is in raster format and contains gridded population data at 1 sqkm resolution. We processed the WorlPop population data so it is spatially aggregated according to the Bing Maps Tile System. The level of detail was chosen so it coincides with that used in the Facebook Population and the Facebook Movements data for each of the countries analysed in this study.

4 Methods

4.1 Population density classification

In this study, we aim to analyse the extent and durability of changes in internal population movements across the rural-urban hierarchy of multiple Latin American countries. Classifying the origin and destination locations of each movement accroding to their population density allows us to achieve this aim. To help characterise the population density of different locations, we consider the Worldpop population data aggregated into Bing tiles. We then use the Jenks natural breaks classification method in order to obtain 10 categories of population density, with categories 1 and 10 being the least and most dense categories respectively. This categorisation of Bing tiles, which offers a greater level of detail than the traditional binary rural/urban classification, is represented in Figure 1. In the Figure, we have included maps for the three countries in the study showing the Bing tiles coloured according to the population density category they belong to. It is possible to see from the in-set histograms that Argentina and Chile have very skewed distributions due to the strong concentration of highest-density areas in just a few tiles belonging to their capital cities, Buenos Aires and Santiago. By contrast, Mexico displays more balanced population density distributions across tiles. It is important

to note that the cut-off values for each population density category vary across countries, but we expect tiles belonging to the same category in each country to have similar functions in the urban hierarchy (e.g. the high-density tiles belonging to category 10 always correspond to major urban centres that act as socioeconomic hubs in their respective regions).

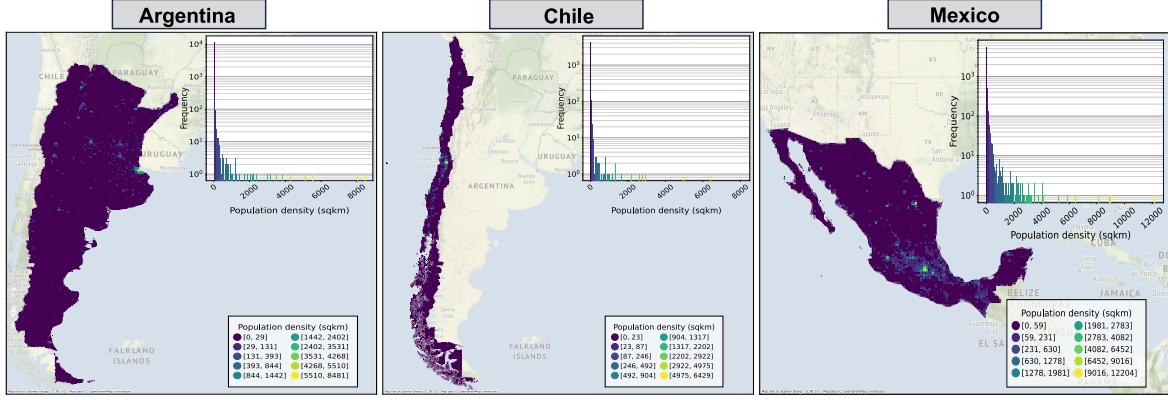


Figure 1: Population density at Microsoft Bing tile level, Argentina, Chile and Mexico.

In order to provide a better intuition of the type of areas that each population density category represents, we also include (**tab-places?**), where we give a few examples of names of places belonging to each density category.

[Table]{#tab-places}

4.2 Tile-based mobility metrics

We measured changes in the intensity of movement by computing the variation in the number of inflows and outflows by population density category, i.e. the number of people entering and leaving tiles belonging to a specific population density category. We did this across all tiles of Argentina, Chile and Mexico for two distinctive months during the course of the COVID-19 pandemic: May 2020 and March 2022. Specifically, we use the percentage change in the intensity of a population flow as provided in the Facebook Movement data sets (Maas et al. 2019). For each entry in the dataset, which represents a flow of people between an origin and a destination tile, the percentage change in the intensity of the flow is computed as:

$$Change(\%) = \left(\frac{n_{crisis}}{n_{baseline}} - 1 \right) \times 100$$

where n_{crisis} corresponds to the number of people moving and $n_{baseline}$ corresponds to the number of people that would be expected to move in the baseline pre-pandemic period at the same time of

the day, on the same day of the week and between the same origin and destination tiles. A positive value indicates an increase in the extent of population movement relative to the baseline levels. A negative score represents a decrease, while a zero score denotes no changes.

We then group the population flows according to the population density category of origin (for outflows) or destination (for inflows) during the two selected months. We generate boxplots for the percentage change variable, corresponding to each population density category. The boxplots illustrate the spread of values of percentage change in the number of inflows and outflows during a selected month for each population density category.

Furthermore, we also considered the impact of the pandemic in the mobility patterns by analysing changes in net mobility. We looked at the evolution of netflows, i.e. the difference in the number of people entering and leaving a location, throughout the whole period of the dataset. The netflows were computed as

$$\text{netflows} = \text{inflows} - \text{outflows}$$

where: *inflows* and *outflows* represent the total number of people entering and exiting a given density category in a given month. Therefore, we can obtain the netflows corresponding, for example, to August 2021 for population density category 8 or to October 2020 for population density category 3.

4.3 Local vs long-distance mobility

All the tile-based metrics described above were computed for population flows where the Euclidean distance between the origin and the destination location was greater than 0 km. Population flows for which the recorded distance was 0 km were discarded. We also split the Facebook Movement dataset into two, one considering flows where the straight line distance covered by the movement was below 100 km and the other for flows covering 100 km or more. The rationale for this stratification is that we expect the COVID-19 pandemic to affect mobility differently at different spatial scales. As highlighted in the background section, a decrease in inflows to the urban core coupled with an increase in inflows in suburban areas was observed in multiple large cities from the Global North, indicating a change in the commuting patterns. Population flows from big cities to rural areas were also observed in some Global North countries, which suggests a change in internal migration patterns in the form of an urban exodus. Given that the information contained in the Facebook Movement data set is aggregated, we are unable to infer the purpose of a movement, but analysing population flows that cover under and over 100 km separately can help us better understand whether the patterns observed in Latin American countries follow the same trends that were observed in countries from the Global North. In particular, we expect populations flows covering under 100 km to capture local travel such as commutes or day trips, and flows over 100 km to capture longer-distance multi-day trips or even internal migration.

5 Results

5.1 Changes in mobility in May 2020 and in March 2022

We analysed changes in the intensity of inflows and outflows for different population density categories across Argentina, Chile and Mexico in May 2020 and March 2022. These two months represent two pivotal points in the pandemic. May 2020 provides a good representation of the early days when a series of strong stringency measures were enacted following the WHO's declaration of COVID-19 on the 11th of March 2020 as a global pandemic. March 2022 captures the later days of the COVID-19 pandemic about six months after most of the COVID-19 restrictions had been relaxed in the countries in our analysis. Figure 2 and Figure 3 show boxplots of the distribution of the percentage change in the number of outflows by areas according to their population density for under and over 100 km, respectively. The boxplots report movements that emerge from each population density category during May 2020 and March 2022. The baseline levels are represented by the dotted line at $y = 0$. Positive values indicate increases in mobility relative to the pre-pandemic period, while negative values indicate a reduction in mobility.

Short-distance movements

Overall, in Figure 2 we observe a consistent decline in outflows across all population density categories for movements under 100 km. The decline is specially strong in the early days of the pandemic. We observe some degree of recovery in March 2022, evidenced by the fact that the boxplots appear closer to the baseline levels. Of all countries, Chile displays the lowest degree of recovery.

Furthermore, we observe a consistent trend whereby the decline in outflows becomes greater as the population density increases, so the largest drops occurred in the most densely populated areas, such as Buenos Aires, Santiago and Mexico City. This effect is stronger in May 2020, where population flows originating in tiles from the highest-density category, dropped by more than 50% in some cases. Chile displays a larger decline of outflows from population density category 10 than Argentina or Mexico. Low-density areas reported lower declines which in some cases are statistically indistinguishable from 0%.

The observed variation in mobility across population density classes is likely to be the result of a combination of the following behaviours. Firstly, this variation could emerge due to a reduction in commuter flows to, from and within cities driven by the fact that a high proportion of jobs that can be done remotely are concentrated in cities (Althoff et al. 2022). Secondly, it could be capturing an urban exodus phenomenon, i.e. people's relocation from the highest-density urban cores to lower-density areas. Particularly, a donut effect is a type of urban exodus where people relocate to lower-density areas surrounding the high-density urban core. Due to the aggregated nature of our data, we are unable to ascertain whether the decline in outflows from densely populated areas can be attributed to the first or second behaviour. In particular, we cannot determine whether we are observing the behaviour of individuals who typically commute to highly dense areas within a 100 km radius of their residence, but are now opting to stay closer to home and commute into the city less frequently, or of individuals who typically reside in highly dense areas but have relocated to lower-density regions,

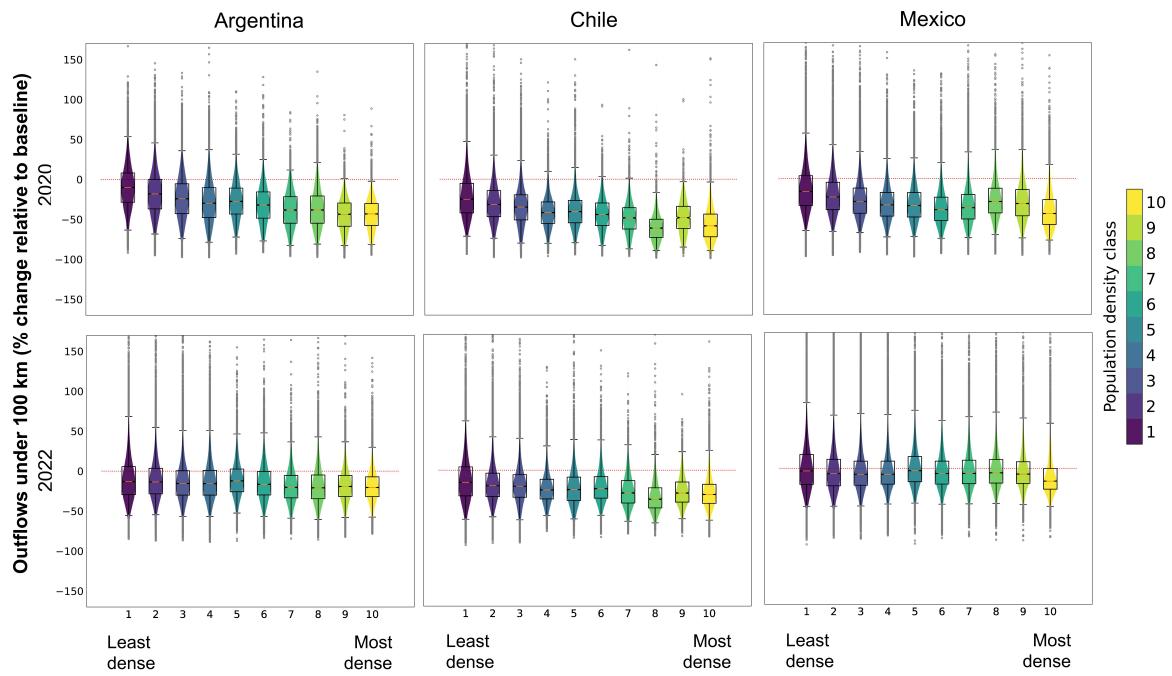


Figure 2: Changes in mobility flows during May 2020 and March 2022 by population density class, relative to baseline period. Short-distance ($<100\text{km}$) movements.

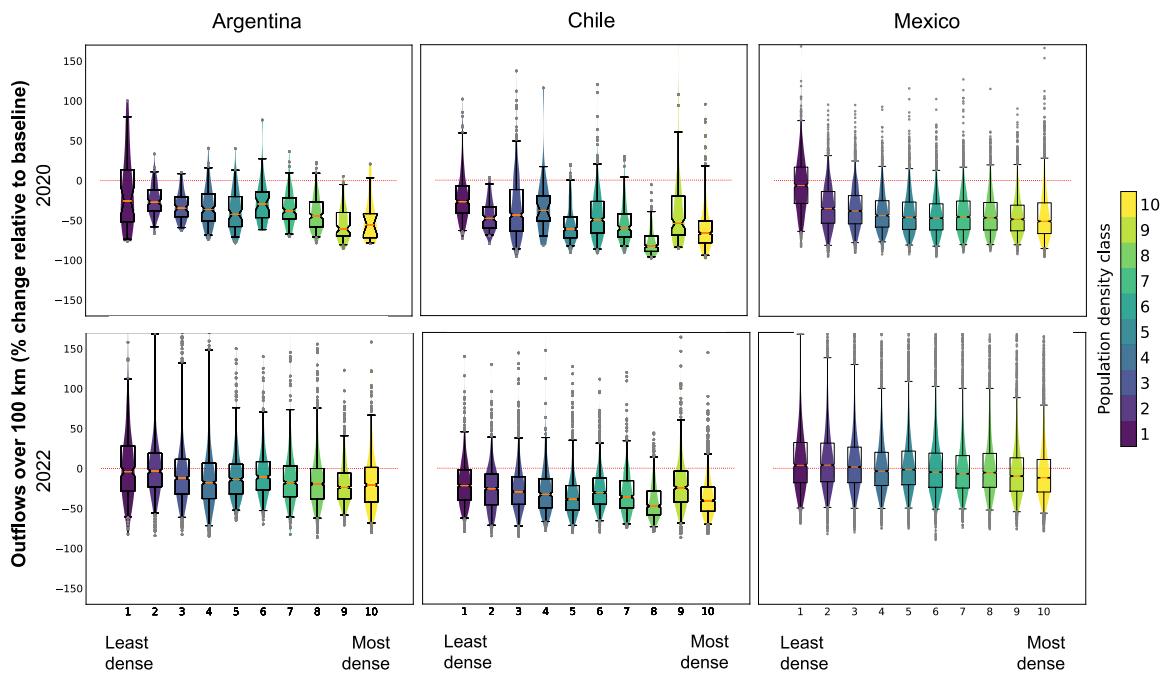


Figure 3: Changes in mobility flows during May 2020 and March 2022 by population density class, relative to baseline period. Long-distance (<100km) movements.

resulting in reduced activity in high-density zones. The analysis of net movements in the next section can help us better understand the extent to which the population of each country has redistributed across the territory.

Long-distance movements

In Figure 3, we observe very similar trends to those observed in Figure 2. Firstly, a consistent decline in outflows across all population density categories for movements over 100 km, like we did for movements under 100 km. This leads us to the conclusion, that mobility was reduced for all types of movements, regardless of the distance they cover or of the population density of the origin and destination. The decline is specially strong in the early days of the pandemic, especially for Chile, and there is some recovery by March 2022, where the number of outflows is closer to the baseline levels, especially for Argentina and Mexico.

The Figure shows the same consistent variation that we observed for short-distance movements in accordance to the population density class of the origin, i.e. the decline in outflows is greater as the population density increases, so the largest decline corresponds to the most densely populated areas. However, we identify a relatively higher level of variability in this trend, likely due to the smaller sample size of population flows covering more than 100 km.

The mobility behaviours giving rise to the patterns observed for movements covering over 100 km are likely to be the same as for short-distance movements, namely, a reduction in commuter flows and a redistribution of population to less dense areas. The latter factor, however, is likely to carry greater significance in this scenario, primarily because commutes typically occur within distances of less than 100 km.

5.2 Spatio-temporal patterns of population redistribution during COVID-19

We also analysed the spatial impact of mobility on redistributing population across the country during the COVID-19 pandemic. Specifically, we examined the evolution of changes in the net balance between mobility inflows and outflows across the rural-urban hierarchy during the pandemic. We calculated the monthly net movement balance as the difference between mobility inflows minus outflows for individual population density classes during March 2020 to May 2022. Figure 4 and Figure 5 show the changes in net balance for movements under 100km and over 100km, respectively.

Short-distance movement

Figure 4 reveals a persistent pattern of fluctuating negative net balances of movements under 100km in the highest population density areas in Argentina and Mexico for most of March 2020 to May 2022. The extent of these balances becomes more notably pronounced after July 2020, but they vary widely by country. Mexico displays the largest negative balances, probably reflecting the fact that it is the second most populated country in Latin America following Brazil. The trend of negative balances indicates that the highest population density areas in Argentina and Mexico tended to record a larger number of outward movements than inward movements over distances of less than 100km. As indicated in Section 4.1, these locations comprise highly dense metropolitan cores predominantly

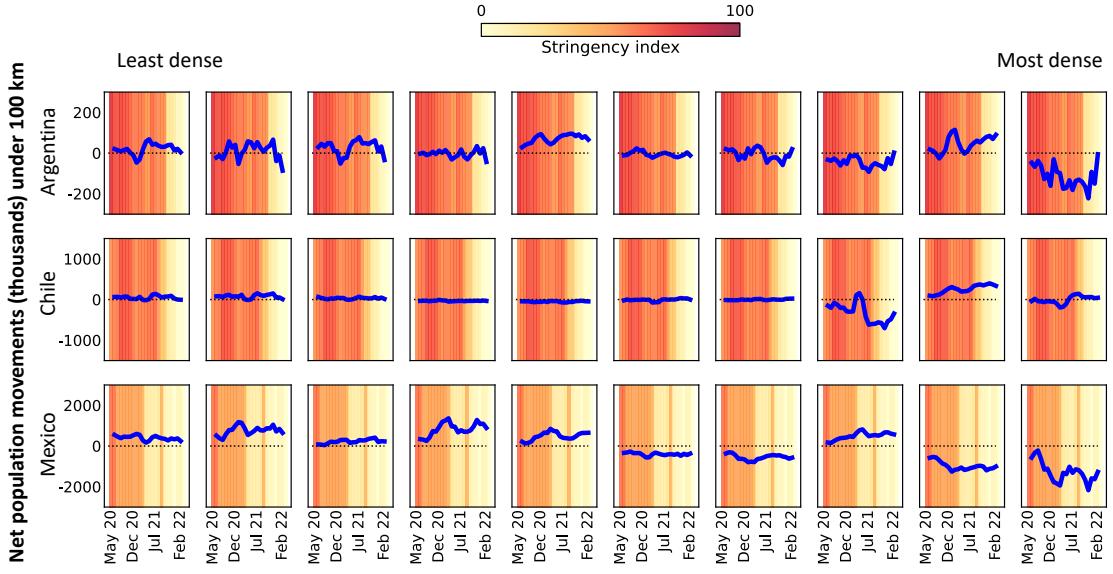


Figure 4: Total number of net movement by population density class. Short-distance (<100km) movements.

in capital cities, including the Central Business District. In Mexico, large negative net balances also occurred in areas of class 9. These areas are particularly in . The spatial concentration of negative net balances in high density areas mirrors the pattern of population loss identified in metropolitan areas in developed countries during the COVID-19 pandemic (Rowe, González-Leonardo, and Champion 2023).

At the same time, Figure 4 shows a relatively consistent positive net balance of movements in specific types of areas along the rural-urban hierarchy. Argentina records a consistent pattern of greater inward movement than outward movement in medium density areas of class 5 type, including , and a trend of irregular net positive balances in the least dense areas of class 1-3 and high density locations of class 9. Areas of class 1-3 in Argentina correspond to rural and sparsely populated regions across the country, while class 9 areas predominantly represent suburban metropolitan and large city areas. In Mexico, a pattern of consistently positive net balance of movements occurred in the range of less dense areas of class 1 to 5 and 8. These balances were particularly pronounced in areas of class 2 and 4, encompassing places such as . In Mexico, the observed patterns suggest mobility out of high density areas in Mexico City, including metropolitan core areas and suburbs, to nearby sparsely and rural areas within a radius of 100km.

Chile displays a different pattern. The most densely populated areas in the country record net balances around zero for movements under 100km. This pattern suggests limited population redistribution from and to metropolitan core areas in Santiago over short distances during the pandemic. Yet, areas

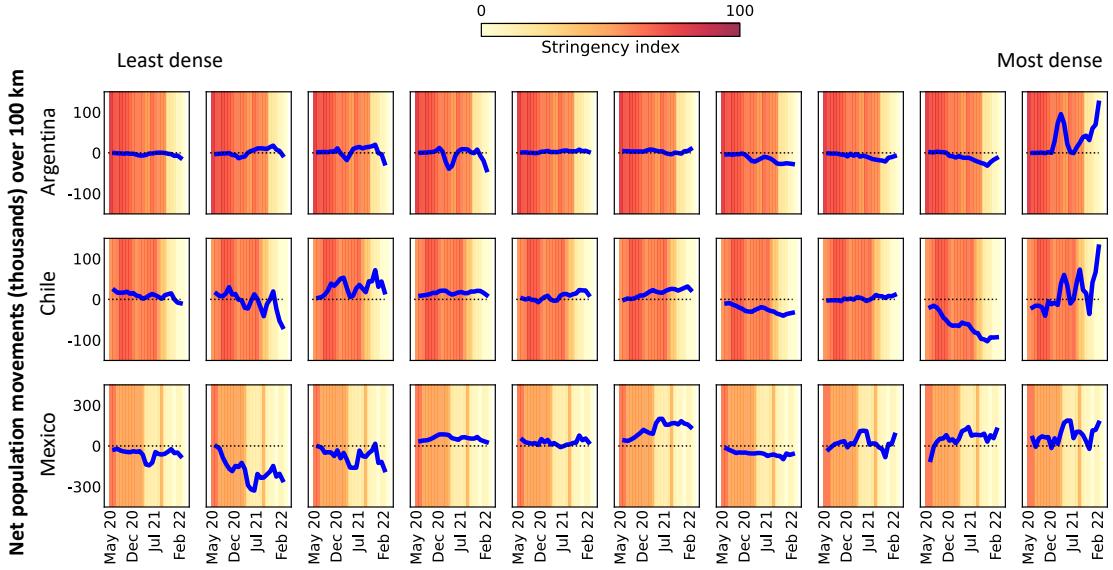


Figure 5: Total number of net movement by population density class. Long-distance (>100km) movements.

of class 8 display large net losses, particularly from July 2021 following less stringent COVID-19 restrictions. At the same time, areas of class 9 report more pronounced net gains since July 2021. These findings suggest a pattern of movement up the rural-urban hierarchy from urban areas, such as to more dense locations, such as.

Long-distance movements

Figure 5 reveals a systematic pattern of net balances across Argentina, Chile and Mexico. It shows small net balances of movements over 100km in the most densely populated areas from the start of the COVID-19 outbreak to December 2020 but sizable net gains during 2021 and 2022. The pace of these gains, however, differs across countries. Argentina and Chile report rapid a rise in net gains of long-distance movements in metropolitan core areas, while the trend of increase in positive balances in Mexican highly dense areas is less marked. These patterns seem to relate to the impact of stringency levels of COVID-19 restrictions. These impacts are particularly visible in metropolitan core areas. Limited population redistribution appears to have occurred early in the pandemic when severe COVID-19 restrictions were enacted, and enlarged as the stringency level of these measures decreased. Also, comparatively, Argentina and Chile implemented stricter restrictions and reductions in stringency levels seem to have resulted in larger expansions in the net balances of metropolitan core areas than in Mexico.

Unlike other countries, Chile displays a pattern of negative net balances of movements over 100km

in the highest density areas of the Santiago metropolitan area during the first year of the pandemic (Figure 5). These balances are not very large but suggest a steady flow of people moving away from high density areas of Santiago to destinations over 100km. Net positive balances of movements over 100km in less dense areas of class 1 to 3 indicate that these were the primary destinations of flows from the capital. Yet, the duration of these balances suggests that movements from metropolitan core areas were temporary. Figure 5 reveals an irregular pattern of large net positive balances in these areas from May 2021 as COVID-19 restrictions were relaxed. At the same time, we observed a continuous trend of negative net balances in highly dense areas of class 9, reflecting increasing net losses in areas in large cities (other than Santiago), such as .

5.3 Movements from and to capital cities

To understand better the nature of movements involving areas of population density class 10, we analysed the spatial patterns of movement of under and over 100km from capital cities. In our analysis, movements from population density class 10 areas exclusively represent mobility patterns from metropolitan core areas of capital cities. Figure 6 displays the number of movements out from metropolitan core areas in Buenos Aires, Santiago and Mexico City for March 2020 and April 2022. As anticipated, areas around the national capitals represent the main destinations for short-distance movements. In March 2020, movements away from capital were limited but had expanded in volume and geographical extent by April 2022.

Figure 6 reveals the main destinations for the movements underpinning the persistent losses of short-distance movement observed for class 10 areas in Argentina and Mexico. Our data revealed that nearby urban and suburban areas, such as Moreno, La Matanza and Tigre in Argentina and Ecatepec de Morelos, Ciudad López Mateos and Chicoapan de Juárez in Mexico absorbed over 80% of short-distance moves from Buenos Aires and Mexico City in April 2022. To a lesser extent, these moves have been directed to rural areas. Though, as we described in the previous section, these areas recorded a relatively large net balance of short-distance moves, particularly in Mexico, while short-distance movements are quite balanced in metropolitan core areas in Chile (Figure 4).

Figure 6 also reveals a similar pattern to the donut effect documented in the US with large cities hollowing out (Ranani and Bloom 2021). The maps for short-distance moves in Figure 6 show that suburban areas closer to metropolitan core areas absorbed larger counts of short-distance moves, with neighbouring rural locations and towns attracting smaller numbers. In Argentina and Chile, this pattern has been relatively uniform with areas closer to Buenos Aires and Santiago absorbing large numbers. In Mexico, areas on the west and north-west, such as Lerma, Metepec and Chiautla have tended to record the largest numbers from Mexico City.

Figure 6 identifies the destination areas underpinning the negative balance of long-distance movements in the early months of the pandemic observed for Santiago, Chile. The bottom-left map in Figure 6 reveals that key destinations were coastal areas in the province of Valparaiso and central-southern areas in the provinces of Talca, Curico and Colchagua. Movements to these destinations are thought to have been moves from affluent households, with second or holiday homes in these

a Buenos Aires, Argentina

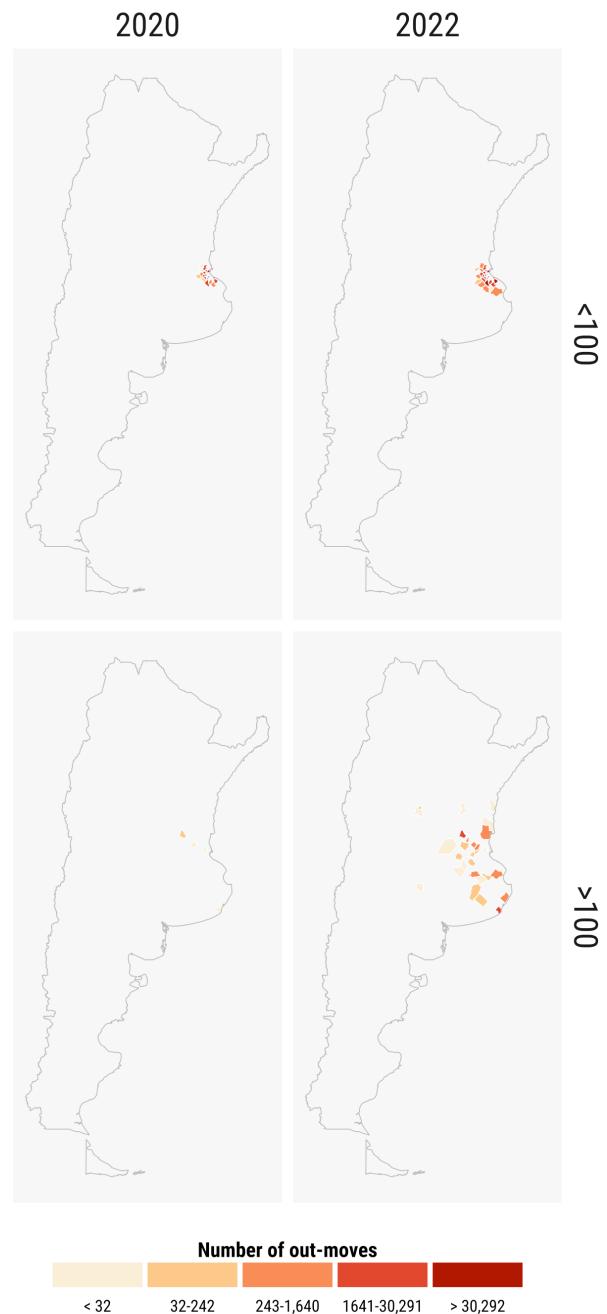


Figure 6: Short-distance (<100km) and long-distance (>100km) movements from core areas in capital cities. March 2020 and April 2022.

areas and jobs which could be done remotely. Additionally, the bottom-left map in Figure 6 for Chile shows that the provinces of Antofagasta and El Loa also attracted a relatively large number of moves. The economy of these areas suggest that these were long-distance commuting moves, rather than migratory moves.

Figure 5 showed that metropolitan core areas in the three countries in our analysis have tended to record consistent positive balances of long-distance movements. Contrary to early speculations of the death of cities, this pattern may reflect the resilience of cities to endure crises and as a key engine of economic growth, innovation and prosperity. Figure 6 revealed the

- In Argentina, Chile and Mexico, how do we explain the rise in positive net balances in 2021 and 2022

6 Discussion

6.1 Key findings

Emerging evidence has indicated that the COVID-19 pandemic resulted in a urban exodus from large cities in developed countries. Anecdotal evidence has suggested that a similar pattern occurred in Latin American countries. However, lack of access to suitable data has prevented the analysis of changes in internal population movements over the pandemic. Drawing on location data from Meta-Facebook users, we sought to analyse the extent and durability of changes in internal population movements across the rural–urban hierarchy in Argentina, Chile and Mexico during the COVID-19 pandemic from March 2020 to May 2022. We found evidence of an overall systematic decline in the level of population internal movement during the enactment of nonpharmaceutical interventions in May 2020 across all three countries. We showed that declines occurred across the rural–urban continuum for movements over both short and long distances. The largest reductions occurred in the most dense areas of Argentina, Chile and Mexico. Average levels of declines in less dense areas were less pronounced as a large number of them recorded rises mobility levels. We also revealed that the intensity of mobility bounced back closer to pre-pandemic levels in May 2022 following the relaxation of COVID-19 stringency measures. Yet, the intensity of movement remained below pre-pandemic levels in many areas.

Additionally, we presented evidence of sustained negative net balances of movements under 100km in the highest density areas of Argentina and Mexico during 2020 and 2022, particularly since July 2020. At the same time, we identified a positive net balance of movements for distances under 100km in areas of low and moderate population density. In Chile, population redistribution for movements under 100km is limited across the urban hierarchy, except for moderately high density areas. These patterns differ from those observed for movements over 100km. In all three countries, the most dense areas registered overall positive net balances of movements over 100km particularly from early 2021. Only in Chile, we found evidence of a negative net balance for movements over 100km in the hightest density areas during 2020, when COVID-19 began spreading throughout the country and

stringency measures were enforced. The patterns of population redistribution at lower levels of the urban hierarchy varied by country. In Argentina, we observed moderate negative net balances of movements over 100km in dense areas. In Chile, a pronounced and growing negative net balance for these movements occurred in highly dense areas around the Santiago Metropolitan Area and neighbouring cities. In Mexico, large negative net balances were recorded in low density areas.

6.2 Interpretation

Our findings suggest that levels of internal population movement over both short and long distances declined in 2020 and remained below pre-pandemic levels in May 2022. In Chile, seasonality in mobility patterns may prompt these conclusions as the pre-pandemic baseline coincides with the national period of summer holidays when levels of internal movements over long distances are typically higher than during the rest of the year. Yet, we argue that such seasonality produces a substitution effect by trading short-distance commuting moves for long-distance travel, rather than increasing overall levels of mobility across the country. Additionally, we argue that hybrid forms of working that emerged during the height of the pandemic may have had a continuing effect on internal population movements in the three countries in our analysis. Hybrid working may have precipitated a secular trend of internal migration decline which was in motion before the pandemic (Bell et al. 2017), and led to reduced rates of mobility in many countries during COVID-19 (Rowe, González-Leonardo, and Champion 2023). Furthermore, global analyses indicate that hybrid working has become a new future of our working life as stigma associated with working from home has diminished, large investments on working environments to enable hybrid work have been made, and working-from-home experiences in terms of productivity and work-life balance have been better than expected (Barrero, Bloom, and Davis 2021; Aksoy et al. 2022). Hybrid working is thus expected to reduce the need for daily commuting travel and living in close proximity to work places.

Additionally, our study lends some support for the theory of an urban exodus providing evidence of negative net balances of movements in the most dense areas of capital cities. These patterns are consistent with ‘the donut effect’ identified by Ramani and Bloom (2021) to describe net population losses in dense city centres in most US metropolitan areas during early stages of the COVID-19 pandemic. In Argentina, Chile and Mexico, distinct processes seem to have underpinned these patterns of negative net balances. In Argentina, sustained negative balances in highly dense areas were associated with short-distance movements, likely reflecting a pattern of suburbanisation in the metropolitan area of Buenos Aires. In Mexico, the pattern of negative balances were also associated with short-distance moves but extended to a wider set of highly dense areas around the metropolitan area of Mexico City, and generated positive balances of moves in sparsely populated areas, suggesting a pattern of counterurbanisation. In Chile, negative balances in highly dense areas of the metropolitan area of Santiago were underpinned by long-distance moves. These losses were however temporary, switching to neutral and positive balances in 2021 and 2022.

Overall, we contributed to expanding existing evidence on the impact of COVID-19 on the levels and spatial patterns of internal population movement. Existing work has focused on developed countries

and restricted to the immediate effects of COVID-19 analysing data from 2020. The cumulative evidence suggest that the levels of human mobility declined in 2020, that large cities lost population through internal migration, and that suburbs and rural areas experienced population gains. To our knowledge, only two studies have analysed data extending to 2021 for Spain (González-Leonardo and Rowe 2022) and Britain (Rowe et al. 2022b). In Spain, large cities continued to report population losses through internal migration. In Britain, low and high density areas returned to display net balances of movement similar to those observed before the COVID-19 pandemic.

We expanded the existing evidence by investigating the patterns of internal population movement in Latin America over a period stretching from March 2020 to May 2022. Our evidence suggests that negative balances of moves in highly dense areas and large cities recorded for various countries in 2020 may have persisted over 2021 and 2022, as we documented for short-distance moves in Argentina and Mexico. They suggest a structural change from a core city preference for suburban and less populated areas. Though, this seemed to be shifting back in Argentina. Alternatively, our findings suggest that population losses due to long-distance movement in highly dense areas in the metropolitan area of Santiago were short-lived, shifting to neutral and positive balances over 2021 and 2022. Contrary to the initial expectations of apocalyptic headlines - ‘empty cities’, ‘dead cities’, ‘ghost cities’, ‘deserted cities’ and ‘silent cities’ - on the media, the evidence emerging from Chile attests the attraction of cities to absorb population. Economies agglomeration in dense urban spaces are likely to continue to facilitate and foster knowledge exchange, innovation and economic growth (Storper and Venables 2004). At the same time, digital infrastructure in rural locales of Latin American countries remain deficient (Pick, Sarkar, and Parrish 2020), representing a major challenge to permanently relocate to these areas.

6.3 Limitations and future work

We distinguished between short- and long-distance moves. Typically short-distance moves are typically used to capture local residential and routine moves, and long-distance moves are used to account for more permanent and infrequent moves, such as internal migration (Owen and Green 1992). However, we cannot identify moves involving permanent changes of residential address. Our data capture these movements but also include frequent and daily travel behaviour, such as commuting and shopping trips. Future work could extend and validate our work identifying changes to moves relating permanent and temporary displacements, and triangulating alternative DFD and traditional data sources, such as censuses and representative surveys collecting information on residential location.

We focused on analysing the levels and spatial patterns of internal population movement. Available evidence from the Global North suggests systematic differences in the mobility patterns of more and less socio-economically advantaged individuals during the early stages of the pandemic (Gauvin et al. 2021; Long and Ren 2022; Santana et al. 2023). While empirical evidence is lacking, existing findings suggest that more socio-economically advantaged individuals seem to have been able to relocate more “permanently” away from large and dense urban areas during the height of the pandemic (Gauvin et al. 2021). They are more likely to have second or holidays homes and have jobs which can be done

remotely. Less socio-economically advantaged individuals were less able to relocate away from their home as they are more likely to work on less well paid service jobs requiring face-to-face interaction (Santana et al. 2023). Drawing on area-level population attributes, future work could investigate the occurrence and persistence of these patterns in Global South countries where socio-economic inequalities are more acute (Qureshi 2023).

Further research is also needed to establish the cause of the observed changes in the spatial patterns of internal population movement since the start of the COVID-19 pandemic. Understanding these causes can assist in anticipating long-term structural changes in the direction of mobility flows in the coming years. A combination of factors, including social distancing, business shutdowns, school closures, telework and unemployment, have all been cited as key forces recasting preexisting patterns of population movement in the early stages of the pandemic. While some of these factors vanished as COVID-19 restrictions were relaxed, others such as telework has endured the pandemic (Aksoy et al. 2022). Determining the extent to which firms and workers have and will continue to adopt remote work will be key to understand future residential and mobility choices within and away from large and dense urban areas.

Additionally, accessing and working with DFD to measure human mobility and migration is challenging. DFD are known to suffer from biases and issues of statistical representation reflecting differences in technology usage and accessibility (Rowe 2023). While concerted efforts to develop data services and methodological frameworks to leverage on DFD exist in the Global North [REF], limited progress has been done in Latin America. National government and statistical agencies have a prime position to promote the creation of data sharing partnerships with private companies and create the digital infrastructure to ensure equal and secure access to DFD sources for the social good. With academia, these agencies could play a major role in promoting the creation of a methodological framework for the use and analysis of DFD, setting common definitions, metrics, and standard approaches to measure and correct data biases and validate data analyses. Location data have been proven key to monitor and develop appropriate policy responses to population displacement and movement during natural disasters, wars and epidemics (Green, Pollock, and Rowe 2021). We envision resources like those created by the European Commission Joint Research Centre (2022) and the UNSD (2019), identifying sources of non-traditional data and establishing methodological guidelines for the use of mobile phone data for official mobility statistics. Existing resources have a global character, we call for initiatives with a regional focus accounting for differences in the local landscape of data availability and digital technology usage.

7 Conclusion

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