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Abstract: This paper examines the geographic factors that are associated with the spread of COVID-19 in Sweden. The country is a useful case study to examine because it did not impose mandatory lockdowns, and thus we would expect the virus to spread in a more unimpeded way across communities. A growing body of research has examined the role of factors like density, household size, air connectivity, income, race and ethnicity, age, political affiliation, temperature and climate, and policy measure like lockdowns and physical distancing among others. The research examines the effects of some of these factors on the geographic variation of COVID-19 cases and on deaths, across both municipalities and neighborhoods. Our findings show that the geographic variation in COVID-19 is significantly but modestly associated with variables like density, population size, and the socio-economic characteristics of places, and somewhat more associated with variables for household size. What matters more is the presence of high-risk nursing homes and the onset of infections with places that were hit earlier by COVID-19 cases experiencing more severe outbreaks. Still, all these variables explain little of the geographic variation in COVID-19 across Sweden. There appears to be a high degree of randomness in the geographic variation of COVID-19 across Sweden and the degree to which some places were hit harder than others.

Keywords: COVID-19, Sweden, geography, density, connectivity

JEL: I10, J19, R23

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Introduction

Why does COVID-19 hit some places harder than others? What are the characteristics of some places that leave them more vulnerable to the virus? What factors influence and shape the geographic variation in COVID-19 across places? These are big questions that a growing body of research has begun to grapple with, and which are the focus of this study.

Early in the pandemic, which hit first and hardest at large global cities like New York and London, it was speculated that density was the key factor in spread of COVID-19. A growing body of research has partly debunked this claim (Nathan, 2020; Florida et al. 2020), finding mixed evidence on the role of density, with some studies showing only a modest positive association while others find no association at all. A study of more than 900 US metropolitan counties finds COVID-19 cases and deaths to be associated with population size but not density; that county density is not significantly related to COVID-19 cases; and that higher density counties have lower death rates from COVID-19 (Hamidi et al., 2020). A London School of Economics study of US metro regions (Carozzi et al, 2020) also finds density to be associated only with the earliest outbreaks of COVID-19, but not associated with COVID-19 cases or deaths on a time-adjusted basis. In other words, large cities got hit first but not necessarily harder than smaller places over the long run. This is likely because large cities are more interconnected to other places across the globe through travel, tourism and flows of immigrants, but they tend to benefit from better health systems and are better able to implement physical distancing measures that help mitigate and contain the virus (Hamidi et al., 2020, Carozzi et al 2020).

Other studies find additional factors such as overcrowding, race, income, and age to be associated with the spread of the virus. In one study of the UK, Nathan (2020) finds COVID-19 cases to be associated with household size and public transportation usage. More importantly, he finds COVID-19 cases to be positively associated with socio-economic deprivation. A wide body of literature equally documents the disproportionate impact of COVID-19 cases and deaths on less advantaged people and communities, on racial and ethnic minorities, and on front-line workers (Nguyen et al. 2020).

Our research examines the geographic factors associated with COVID-19 in Sweden. Sweden makes a useful case study because it did not implement a lockdown or have regional variations in public health policies that might impact the spread of COVID-19 in some locations versus others. Thus, we would expect COVID-19 to be able to spread in an unimpeded way across various geographic areas of the country so that analyzing that spread would help us understand the most salient factors.

Our research looks at the effects of geographic factors on both COVID-19 cases and deaths. The data report on all 290 of Sweden's municipalities as well as 34 neighborhoods in the three largest municipalities—Stockholm, Gothenburg, and Malmö. The independent variables reflect the factors that prior research found to be most associated with COVID-19 cases and deaths, such as density, size of population, age, income, education, inequality, immigration status, air connectivity, temperature, presence and characteristics of nursing homes, timing of initial onset of COVID-19 infections, and others.

Our findings suggest that COVID-19 in Sweden is significantly related to factors like density, population size, and socio-economic disadvantage, in line with previous research. However, these variables explain little of the geographic variation in COVID-19 cases or deaths across Sweden either at the municipal or neighborhood level. More important to the geographic variation in COVID-19 in Sweden is the onset of the first infection. This leads us to believe that the geographic spread of COVID-19 across Sweden and the vulnerability of places have less to do with the density or size of places, and more to do with their connectedness to other parts of world, which led them to be exposed to the virus during the earliest stages of the pandemic.

That said, the variable most closely associated with the geographic variation of COVID-19, in particular with the death rate, is the presence of at-risk nursing homes. This variable outperforms all others in the regression analysis for COVID-19 deaths across Swedish municipalities.

Nevertheless, even with the addition of this variable, none of these models can fully explain the geographic variation in COVID-19 cases or deaths across Sweden. Ultimately, it appears that the spread of COVID-19 in Sweden simply has a high degree of randomness.

The remainder of the paper proceeds as follows. The next section describes the variables, data, and methodology used in the analysis. The third section provides background on the geography of COVID-19 in Sweden. The fourth section summarizes the findings in our analysis of COVID-19 cases and deaths across Swedish municipalities. The fifth section summarizes the results for the analysis of COVID-19 cases across neighborhoods within cities. The concluding section highlights the key findings and discusses their relationship to prior research and what we know about the geography of COVID-19 generally.

Variables, Data, and Methodology

This section describes the variables, data, and methodology for our analysis. The data on COVID-19 cases are based on weekly data released by the Public Health Agency of Sweden (Swe: Folkhälsomyndigheten) on the number of confirmed infections. The data cover the period February 3, 2020 to August 2, 2020, which is the 25-week time period with the most COVID-19 cases in the country.

The data on COVID-19 deaths come from the National Board of Health and Welfare (Swe: Socialstyrelsen). The definition of a COVID-19 related death in Sweden is if (1) a person is reported dead by a medical doctor via SmiNet (the database system used to report by law notifiable infectious diseases) or by the health care sector via the regional infectious restraints, or if (2) a person dies within 30 days after a confirmed COVID-19 test has been taken. The data cover all deaths up until the first week of August by municipality; however, at the neighborhood level, the data on deaths is not available on a weekly basis but is known for the entire period.

The analysis covers two levels of geography. The first is the municipal level. Swedish municipalities are similar to US counties and cover jurisdictional units that responsible for public services such as schools, emergency services and more general physical planning. Sweden consists of 290 municipalities, which together cover all its geographical area. The most populated municipality is Stockholm (Stockholms stad), with approximately 975,000 inhabitants. The least populated is Bjurholm with approximately 2,400 inhabitants. Population density differs significantly across municipalities. The highest density is Sundbyberg, a suburb to Stockholm, with approximately 6,000 inhabitants per square kilometer. The lowest density is in Arjeplog, in the northern parts of Sweden, with 0.2 inhabitants per square kilometer.

The second level of geography studied is at the neighborhood level. This analysis is able to cover 34 neighborhoods in Sweden’s three largest cities—Stockholm, Gothenburg and Malmö, neighborhoods for which data on COVID-19 cases is available from the Swedish Health Agency. However, the agency does not disclose the exact number of COVID-19 cases if the total number of infections (over time) is below 15. In these instances, we extrapolate the value s and add a dummy variable to control for the weeks where this data is not available. This primarily covers the earliest weeks of the pandemic when mainly smaller municipalities reported a limited number of cases.

The analysis combines these data on COVID-19 cases and deaths with data on a range of explanatory variables identified by the previous research as possible factors related to geographical spread and outbreaks of COVID-19. Most of the data for these variables is from Statistics Sweden, unless otherwise noted below.

Dependent Variables:

COVID-19 Cases: These variables come from the Public Health Agency of Sweden and are the cumulative number of reported of infections They are reported on a weekly basis over the 25 weeks and are available for all Swedish municipalities and 34 neighborhoods in Stockholm, Gothenburg or Malmö. We examine total reported cases and cases on a per capita basis. When using this cumulative value, a dummy variable for week of the observation is added, since values by definition will be higher during later stages of the pandemic.

COVID-19 Deaths: This variable comes from the National Board of Health and Welfare and is the total number of COVID-19 deaths per municipality. We use total reported deaths and deaths per capita.

The data for COVID-19 cases and deaths is available on a daily basis at the national level. Data at the municipal and neighborhood level is more limited. The number of cases is available at a weekly level, but the number of deaths is only available for the overall time period.

Independent Variables:

Population Size: Previous studies find an association between population size and COVID-19 cases and deaths. This variable captures the population size of each area.

Density: There has been considerable debate over the role of density in the spread of COVID-19. We measure density as people per square kilometer.

Air Connectivity: Previous research finds that more connected places have been hit earlier and harder by the virus. We include a variable for airport access based on the distance to the nearest airport, the time it takes to go there in combination to the number of passengers trafficking the airport (for the accessibility calculation methodology, see Johansson et al., 2003). This variable is calculated based on data from the Swedish Transport Agency (Swe: Transportstyrelsen).

Age: Age has been found to be a key factor in COVID-19 severity and death. Approximately 90 percent of those who died from COVID-19 in Sweden have been 70 years or older. We include variables for the share of the population in an area above 70, above 80, and also for the average age in that locale.

Income: Income has also been found to be associated with COVID-19, with lower income people and places being more vulnerable to the virus. We employ two different measures of income to capture both absolute and relative income: disposable 1000 SEK income per person, which includes wage income, transfers and capital income, and relative income which is the average income in the neighborhood (or municipality) divided by the average income in the municipality (or nation).

Income Inequality: Income inequality has been found to be positively associated with COVID-19. Our variable is based on the Gini coefficient for disposable income. This variable is available only for municipalities, not for neighborhoods.

Household Size: Several studies have found overcrowding to be associated with COVID-19 (Nathan, 2020; Hamidi et al., 2020). We include two variables for overcrowding: the average number of individuals in the households, and the share of single (one-person) households.

Multi-Generational Households: COVID-19 has been found to spread faster in multi-generational households. Our variable captures the share of households that includes both older (older than 70 years of age) and younger (under 15 years age) individuals.

Immigration Status: Research has found places with higher shares of immigrants to be more vulnerable to the virus. This may be because they are characterized by greater overcrowding and higher rates of multi-generational households, have lower incomes, work in more front-line occupations, or lack language skills to understand the information from health authorities. For example, early reports from late March suggested that a reason the Somali community was hard hit had was due to a lack of public health information available in the Somali language (Swedish Television, 2020a). We employ two variables to capture immigration status: the share of the population born outside of Sweden, and the share of the individuals who are either foreign born or who are native born but with one or two parents who are foreign born.

Education: Education has been shown to be associated with COVID-19. We include a variable for the share of the labor force with a BA or above.

Occupation: Occupation has been shown to affect vulnerability to COVID-19, with frontline workers being far more likely to be exposed to the virus. We thus include a variable for the share of frontline workers. This is based on their place of residence, not place of work.

Unemployment: We include a variable for the share of the individuals aged 20-64 who are unemployed.

Temperature/Climate: It has been suggested that warmer weather mitigates the spread of the virus. In Sweden, the temperature differs significantly from north to south. We include a variable to capture the average yearly temperature by municipality. This variable comes from the Swedish Meterological and Hyderological Institute (Swe: SMHI).

Nursing Homes: In Sweden, as in many parts of the world, a disproportionate number of COVID-19 deaths occurred in nursing homes, among older people with pre-existing health conditions or co-morbidities. Even before the pandemic, the Health and Social Care Inspectorate (Swe: IVO) warned that poor Swedish language skills among the employees could be a risk factor in the care of elderly (Health and Social Care Inspectorate, 2018). We employ two variables to capture possible low language skill levels among the employees: (1) average education level; and (2) foreign born share of the individuals who work in a nursing home in the municipality or neighborhood. Since approximately 70 percent of all deaths in nursing homes were in only 40 municipalities, IVO also conducted an evaluation of more than 1,700 nursing homes' routines across the country during the pandemic. We employ a dummy variable if the municipality is one of those on IVO's list (Health and Social Care Inspectorate, 2020a. 2020b; Swedish Television, 2020b, c).

Week of First Infection: Research documents that places that got hit first by the virus also got hit harder. We include a variable to capture the first week with a registered infection case in that neighborhood or municipality. The data comes from the Public Health Agency of Sweden.

We conduct both a correlation and a regression analysis of COVID-19 cases and deaths. We perform cross-section regressions since only the dependent variable varies over time, while the explanatory variables reflect annual data that are not possible to estimate in a panel FE framework.

Background of COVID-19 in Sweden

Sweden developed a unique response to the COVID-19 crisis, over which there has been considerable controversy (see e.g. Paterlini, 2020: Goodman, 2020; Karlsten, 2020; Howard, 2020). In contrast to most other countries, Sweden did not impose a mandatory lockdown at neither the national nor regional level. Based on guidance from its public health authorities, the country implemented a “trust-based” strategy for staying open while protecting the old and vulnerable. The policy left schools, childcare centers, restaurants, bars, and retail shops open, but encouraging workers and citizens to take proper precautions. The policy depended on information and trust to guide its response to COVID-19. People were advised to physically distance by keeping six feet apart rather than wearing face masks, to avoid crowds with more than fifty people, and to wash their hands frequently. Companies transitioned to remote work, with primarily professional and knowledge workers working from home. Young children were allowed to attend day-care and elementary school, but high schools and universities were closed, with classes conducted remotely. Gyms were closed temporarily, and travel across regions was discouraged. The strategy was far from perfect. Sweden suffered from a considerably higher fatality rate than its Scandinavian neighbors, with a disproportionate share of deaths occurring in its nursing homes.

The efficacy of the Swedish approach is beyond the scope of this paper and awaits further research. What is relevant to our study is that because the country did not implement a lockdown, Sweden provides a useful case to study geographic variation in the spread of COVID-19, since one would expect that the virus would spread naturally without policy impediments associated with a lockdown.

The official COVID-19 data in Sweden starts on the 4th of February 2020 (Week 6 in year 2020), and this date forms the starting point of our analysis. However, the first case was actually registered the week before, on the 31st of January in the region of Jönköping and the infected individual had been on a visit to China. The individual was quickly isolated at the local hospital and most likely did not spread the virus to anyone else. The next registered infection case was on the 26th of February (Week 9), followed by a number of other cases that same week, primarily in Stockholm, but also in Västra Götaland (Gothenburg), Uppsala (close to Stockholm) and one additional case in Jönköping.

Sweden's COVID-19 crisis reached separate peaks for cases versus deaths. In terms of death rate, the crisis peaked in Weeks 15 and 16 (beginning of April). In terms of reported cases, the peak came in June (Weeks 24 to 26). The case peak may be a result of more extensive testing across a larger population group. Initially, primarily individuals at risk and in the health care sector got access to COVID-19 infection tests. Testing then became available more broadly later, which may create a certain bias in the case numbers. Figure 1 plots cases and deaths per day over time. Note the earlier peak and sharp fall-off for deaths, and the larger sustained peak and later fall-off for cases.

(Figure 1 about here)

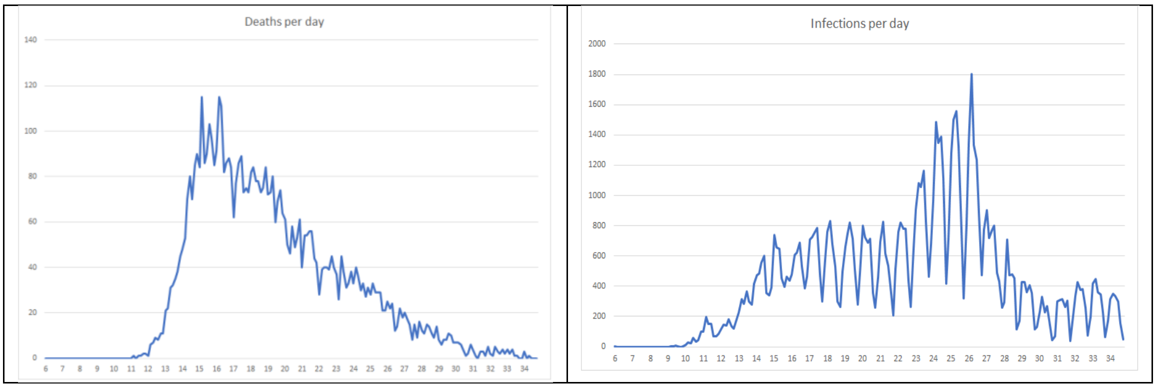


Figure 1: Timeline of COVID-19 Cases and Deaths in Sweden

Figure 2 is a scatter plot of the relationship between COVID-19 cases and deaths. Even though the registered peaks are at different points in time, we still find a relationship between the two. The correlation between the total number of infections per capita and the number of deaths per capita in the 290 Swedish municipalities as per Week 32 (first week in August) is 0.571.

(Figure 2 about here)

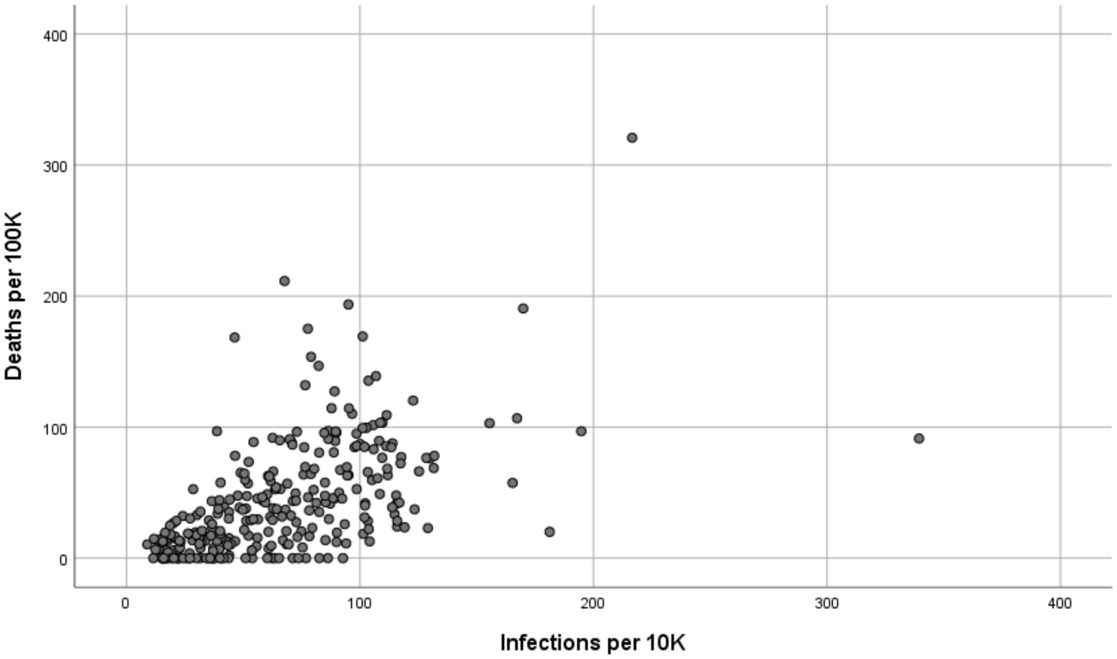


Figure 2: Relationship between Total infections and Deaths Per Capita

Note: As of the first week of August 2020.

Geographic Variation in COVID-19 by Municipality

We now move on to our analysis of the geographic variation in COVID-19 across Swedish municipalities. The geography of COVID-19 cases is highly uneven across Sweden. Table 1 lists the Swedish municipalities with the highest absolute numbers and per capita rate of COVID-19 cases.

There is a significant difference in the number of cases per capita across Swedish municipalities. In week 32 of the pandemic, the most impacted municipality had 40 plus times as many cases as the least affected municipality.

(Table 1 about here)

Table 1: COVID-19 Cases per Capita across Swedish Municipalities

Municipality	COVID-19 Cases	Municipality	COVID-19 Cases Per Capita
Stockholm	10,587	Gällivare	339.4
Göteborg	7,623	Munkfors	216.6
Uppsala	2,582	Töreboda	194.8

Jönköping	2,333	Gislaved	181.2
Västerås	1,687	Bräcke	169.9
Örebro	1,535	Tibro	167.3
Borås	1,418	Jönköping	165.4
Linköping	1,307	Gnosjö	155.5
Huddinge	1,221	Söderhamn	131.8
Södertälje	1,215	Göteborg	131.6

Note: Cases as of Week 32.

On an absolute basis, COVID-19 cases tend to track population. There are exceptions, however. For example, Malmö, the third most populated municipality in Sweden, ranks 13th in the absolute number of cases.

When we look at cases on a per capita basis, smaller municipalities move higher up the list. Four of the municipalities high on the per capita list were also reported by the Health and Social Care Inspectorate (Swe: IVO) not to have proper routines in place in nursing homes during the pandemic.

Figure 3 presents scatterplots of COVID-19 cases and deaths by population size. The correlations are 0.55 for total cases and 0.26 for total number of deaths.

(Figure 3 about here)

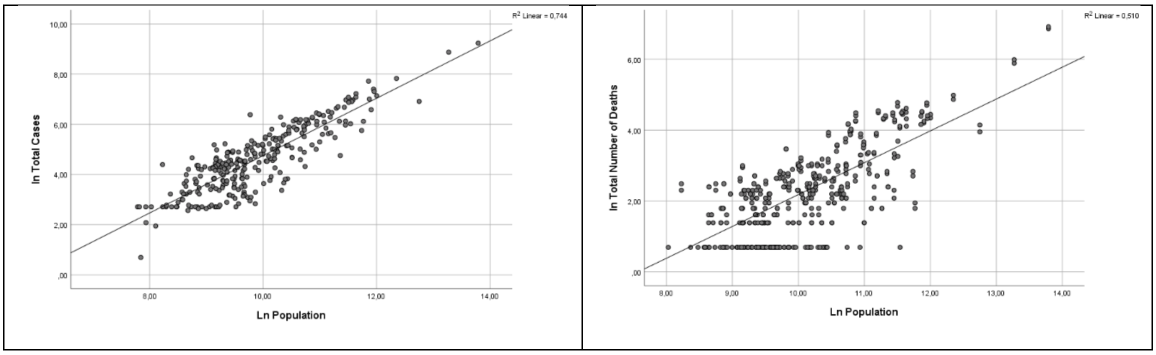


Figure 3: Relationship between Population and Number of Cases and Deaths for Swedish Cities

Note: As of Week 30.

We next map infections on a per capita basis. These data are available on a weekly basis from the start of the pandemic. In Figure 4, we map three points in time: Week 10 (first week of March), Week 20 (second week of May), and Week 30 (third week of July) to show the geographic spread of cases.

(Figure 4 about here)

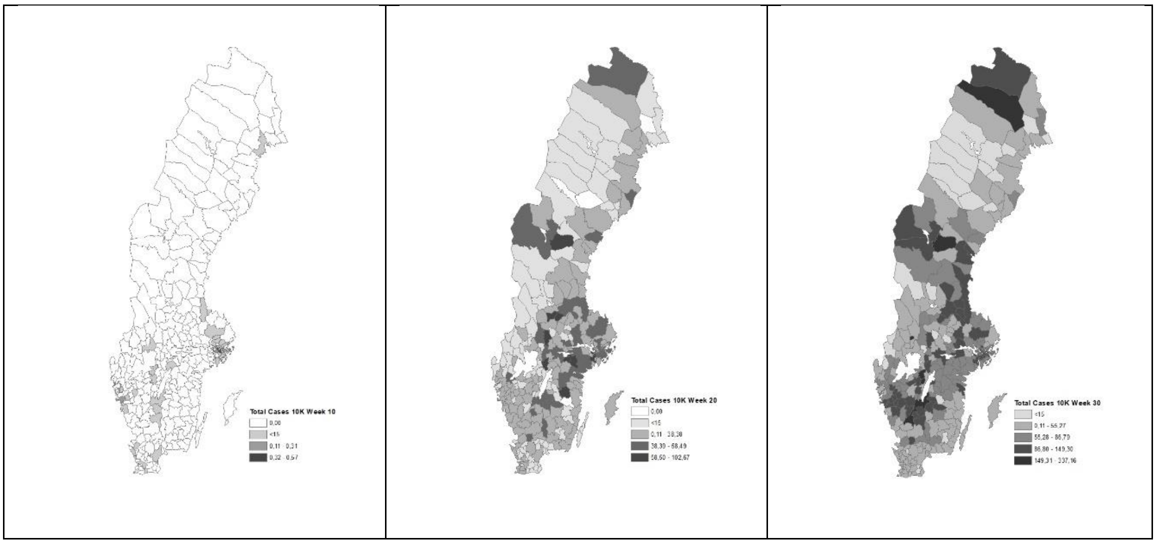


Figure 4: The Geography of COVID-19 Cases per Capita for Swedish Municipalities

Note: COVID-19 Cases per 10,000 people as of Weeks 10, 20, and 30

As Figure 4 shows, the geographic pattern of COVID-19 in Sweden changed somewhat over time. Following a pattern seen in other nations, the crisis hit larger municipalities first and then spread to smaller places across the country. Up to Week 10, larger municipalities like Stockholm, Gothenburg, and Malmö bore the disproportionate bulk of COVID-19 cases. By Weeks 20 and 30, the pattern had partly shifted to smaller municipalities. The correlation between cases per capita and population size was 0.23** in Week 10, 0.20** in Week 2, and 0.20** in Week 30.

Correlation Results for Swedish Municipalities

Table 2 provides the results of a partial correlation analysis for COVID-19 cases per capita on a weekly basis (from Week 6 to Week 32) controlling for week, and a bivariate correlation analysis for COVID-19 deaths per capita by Week 32 (the first week of August).

(Table 2 about here)

Table 2: Correlation Analysis for COVID-19 in Swedish Municipalities

	Partial Correlation	Bivariate Correlation
	Cases per Capita	Deaths per Capita
Population (ln)	0.145**	0.121*
Density (ln)	0.125**	0.192**
Average Age	-0.163**	-0.122*
Over 70 Years of Age	-0.172**	-0.128*
Over 80 Years of Age	-0.155**	-0.126*
Income	0.073**	0.061
Income Inequality	0.076**	0.074
Average Household Size	0.117**	0.093
Intergenerational Households	0.071**	0.045
Single Households	-0.020	0.074
Foreign-Born	0.123**	0.228**
First or Second-Generation Foreign-born	0.144**	0.232**
Education (BA and above)	0.086**	0.019
Frontline Workers	-0.141**	-0.093
Unemployment	-0.158**	0.003
Average Education in Nursing Homes	0.019	-0.106
Share Foreign Born Employees in Nursing Homes	0.189**	0.260**
Nursing Home Problems IVO	0.284**	0.572**
Average Temperature	-0.037**	0.007
Air Connectivity	0.125**	0.137*
Week of First Case	-0.189**	-0.152**

Notes: Partial correlation controlling for week of the pandemic. Cases per capita is based on weekly data. Deaths per capita is based on total deaths by the first week of August**.**

The variables for population size and density are positively associated with COVID-19 cases and deaths. Those results are partly skewed by the Stockholm region, which was hit hard early in the pandemic. The results also show that the average number of individuals per household is positively and significantly associated with COVID-19 cases. There is also a positive and significant association between the variable for multi-generational households and COVID-19, though neither of these variables is strongly associated with COVID-19 deaths. This is partly in line with other research which finds overcrowding and multi-generational households to be factors in COVID-19 transmission

(Hamidi, 2020). There is no significant association between the share of single households and COVID-19 cases and deaths.

Age has been found to be a key factor in vulnerability to COVID-19, with those over age 70 experiencing significantly higher rates of serious complications from the infection and death. In contrast, in this study, the coefficients for age-related variable correlations are mainly negative and significant. This result may seem counter-intuitive given the fact that people over 70 are at much higher risk from serious COVID-19 complications. However, these results may reflect a population-size effect, due to the fact that bigger, denser cities have much larger concentrations of younger demographic cohorts.

In many nations across the world, a significant share of COVID-19 deaths has been concentrated in nursing homes. Roughly three-quarters (73 percent) of COVID-19 deaths in Sweden have been among individuals who either have lived in nursing homes (47 percent) or who have been in need of special help in their own homes (26.5 percent). The variable for the presence of high-risk nursing homes (based on 40 municipalities that accounted for the largest share of nursing home deaths) is positive and significantly associated with both cases and deaths. The variable for the share of foreign-born workers in nursing homes is also positively associated with COVID-19 cases and death. This seems in line with the earlier suggestion from Swedish health authorities (Swe: IVO) that limited Swedish language skills among nursing home employees could have increased the risk factor. Journalistic reports suggest that information about COVID-19 in minority languages took time to be provided (Swedish Television, 2020), which in turn could have affected the ability for these communities to learn about and take steps to prevent the virus spread. That said, we do not find any significant association for the average education level for workers in nursing homes.

The coefficient for air connectivity is also positive and significant, suggesting that the connectivity of large places may have played a role in their being hit earlier and harder by the pandemic. This is line with the findings of Carozzi et al. (2020). We also find a positive and significant correlation between places that got their first infections during the first weeks of the pandemic and overall COVID-19 cases and deaths.

We now turn to the variables for income, education, and occupation. Prior studies note that COVID-19 cases and deaths have disproportionately concentrated among less advantaged groups and communities and front-line workers who have more frequent contact with other workers and the general public. In Sweden, for example, the most vulnerable occupations are taxi drivers, bus drivers, and pizza makers with a risk 4 to 5 times greater that of the average worker (Swedish Public Health Agency, 2020). Our findings for these variables are counter-intuitive. The variables for income and education are both positively and significantly associated for COVID-19 cases. Even more counter-intuitively, there is a negative and significant association between the variable for front-line workers and COVID-19 cases. These results may be artifacts of a "big-city" effect, where larger places, which are also more affluent and educated, were harder hit by the virus. This is also suggested by the correlation for income inequality and COVID-19 cases which is positive and significant. Here we note that the data are municipal averages and as such do not account for potentially significant within-municipality differences of neighborhood levels of income or education – a subject we will cover in the neighborhood-level analysis. The correlations for both income and income inequality are insignificant with COVID-19 deaths. Unemployment is negative and significant with COVID-19 cases. This may reflect that fact that Sweden remained open with more workers continuing to go to work, which may have resulted in more employed workers contracting the virus wherever unemployment levels are low.

The correlation between temperature and COVID-19 cases is also positive and significant, which suggests that warmer regions experienced higher cases. This is not necessarily a temperature or climatic effect; it simply could reflect the fact that the vast majority of Sweden's population live in the relatively mild southern parts of the country where the virus hit earlier and spread more extensively early on.

As we have seen, several of the results of the correlation analysis are counter-intuitive. To gain better insight into the connection between these variables and COVID-19, we turn to a regression analysis.

Regression Findings for Swedish Municipalities

We now present the findings of our regression analysis for Swedish municipalities. Recall municipalities in Sweden include cities and their outlying urban areas. The regression analysis enables us to better deal with the fact that many of the variables in the analysis essentially reflect and capture similar underlying elements of city-regions. The analysis excludes explanatory variables that are insignificant in the correlation analysis. Furthermore, when there are several variables that capture similar dimensions of cities, we exclude the ones which showed weaker associations in the correlation analysis. The regression analysis covers both COVID-19 cases and deaths, on a per capita basis.

Table 3 summarizes the results of the regression analysis. We report both the unstandardized/standardized β-coefficients to shed light on the relative importance of the variables. Since only the dependent variable varies over time, while the explanatory variables are yearly data, it is not possible to estimate in a panel with fixed effects. The data is constructed in a panel framework with a traditional OLS estimation where we control for the week of the pandemic. Columns 1 and 2 provide the estimations for cases per capita and deaths per capita. Column 3 is a Probit estimation based on an extension of the deaths per capita regression where we estimate the likelihood of being listed as one of the municipalities with a nursing home at risk.

(Table 3 about here)

Table 3: Regression Analysis for COVID-19 Cases and Deaths

	Cases per Capita*	Deaths per Capita	At-Risk Nursing Homes
Population (ln)	-	-	-
Density (ln)	2.27**/0.116 (0.409)	2.334/0.092 (2.11)	0.293** (0.028)
Average Age	-	-	-
Over 70 years of Age	-62.62**/-0.062 (15.71)	183.88/0.141 (100.27)	-2.838* (1.278)
Over 80 Years of Age	-	16.80/0.039 (34.40)	-
Income	0.061**/0.085 (0.014)	9.17/0.027 (30.28)	-0.017** (0.001)
Income Inequality	44.88**/0.044 (15.63)	-	17.508** (1.209)
Household Size	-7.88**/-0.067 (1.69)	-	-
Intergenerational Households	174.31/0.011 (131.58)	-	53.477** (11.774)
Single Households	-	-	0.414 (1.004)

Foreign Born	-	-	-
First or Second-Generation Foreign-born	44.65**/0.133 (6.00)	9.169/0.574 (6.894)	-1.298* (0.535)
Education (BA and above)	-90.29**/-0.197 (7.20)	-	-6.523** (0.651)
Frontline Workers	40.51**/0.041 (13.19)	-	-
Unemployment	-217.20**/-0.189 (15.79)	-	-18.443** (1.458)
Nursing Home:			
Avg Education	-	-	-0.013 (0.140)
Share Foreign-born Employees	-3.01/-0.011 (4.24)	9.260/0.027 (30.28)	5.152** (0.363)
Nursing Home Problems IVO	12.83**/0.131 (0.83)	73.04**/0.574 (6.894)	-
Average Temperature	-3.21**/-0.115 (0.370)	-	-
Airline Connectivity (ln)	-1.75**/-0.112 (0.227)	-1.81/-0.092 (1.020)	-
Week of First Case	-1.39**/-0.101 (0.119)	-1.63/-0.092 (1.020)	-
Week Dummy	YES	-	-
N	7803	290	290
R2	0.614	0.346	

Notes: Cases are based on weekly data. Deaths are as of the first week of August 2020. Column 3 shows the results for a Probit regression which controls for the presence of high-risk nursing homes. Standard errors within brackets.
* a control is added for values that are extrapolated, primarily in smaller regions during the beginning of the pandemic. When we exclude this dummy, the relative strengths of the coefficients remain more or less constant.

The variable for density is positive and significant for COVID-19 cases, but not for deaths. The variable for average household size is now negative and significant, which may be a multicollinearity effect since overcrowding is more common in the densest places. The correlation between household size and population density is 0.600 and significant. The variable for multi-generational households is now insignificant. Here, we note that multi-generational households are relatively uncommon in Sweden, making up a very small share of all households.

The results for age remain counter-intuitive. The variable for the share of population below the age of 70 is positive and significant, meaning the smaller the share of people in this cohort, the greater the number of COVID-19 cases per capita. This may reflect the fact that in Sweden's open environment, with the absence of a hard lockdown, younger age cohorts were more likely to be out and about and thus more likely to be exposed to the virus. The association between this age variable and COVID-19 deaths is insignificant.

The variable for the presence of high-risk nursing homes is positive and significant both for COVID-19 cases and for deaths. It is by far the strongest variable in the analysis of COVID-19 deaths, outperforming all others, explaining approximately 35 percent of the variation in COVID-19 deaths per capita across municipalities. Furthermore, when we include the variable for the municipal presence of high-risk nursing homes, we find no additional association between COVID-19 cases and deaths and foreign-born employees of nursing homes.

The variable for frontline workers is now positively and significantly related to COVID-19 cases, which is in line with previous research (Nguyen et al. 2020).

The education variable is positively related to COVID-19 cases, which is somewhat counter-intuitive. This may reflect the fact that this group is over-represented in the biggest, more dense municipalities in Sweden.

The unemployment variable is negative and significantly associated with COVID-19 cases, which is also counter-intuitive. Here again, this may reflect that fact that Sweden remained relatively open, enabling more workers to interact in person and come into contact with the virus in municipalities where unemployment rates are lower.

The variables for immigration status are positive and significantly associated with COVID-19 cases but not deaths. This is in line with the suggestion (Dagens Nyheter, 2020; Swedish Television, 2020b, c) that marginalized regions with higher shares of first- and second-generation immigrants were harder hit by the pandemic in Sweden.

The variable for timing of first infection is negative and significantly associated with COVID-19 cases. In other words, places that were exposed in an earlier week to the virus also tended to have more infection cases later on. That said, this variable is not significantly associated with COVID-19 deaths.

The regression for COVID-19 cases generates an R2 value of 0.614. It is worth noting that the weekly control-variable alone generates an R2 value of 0.5. This means that the included variables that are significant explain relatively little of the overall distribution of COVID-19 across Swedish municipalities.

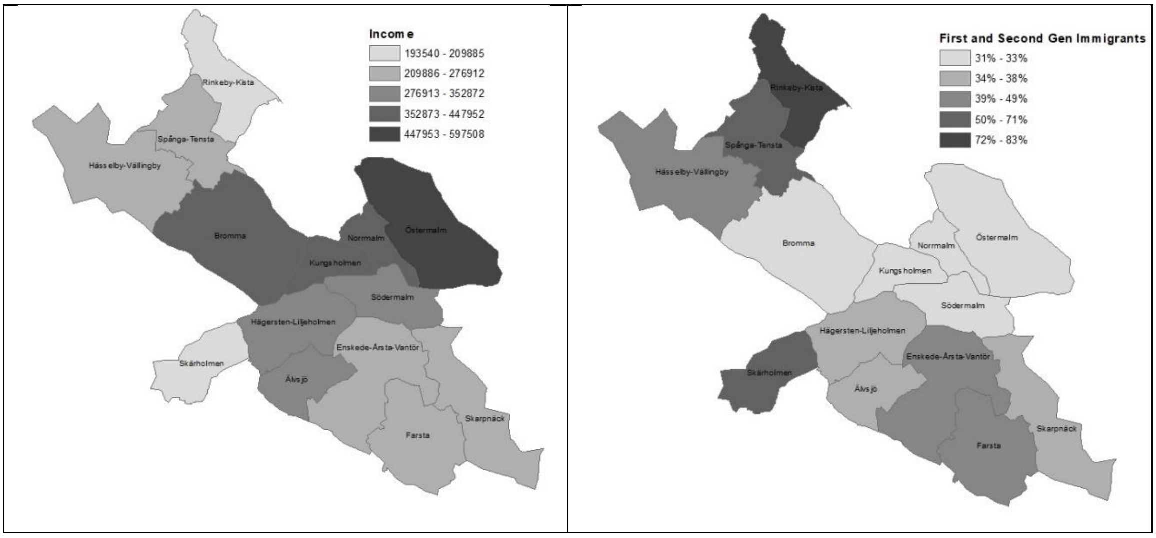
Given the strength of the variable for municipalities with at-risk nursing homes and COVID-19 deaths, we conducted an additional Probit regression (column 3, Table 3) to see if any of our included explanatory variables are significantly related to being a municipality at risk, and thereby indirectly related to the number of deaths per capita. The results from this indicate that municipalities with the presence of high-risk nursing homes are also denser, with a smaller share of individuals under age 70, more multi-generational households, have lower incomes, lower levels of educational attainment, lower levels of immigrants and unemployment, and higher levels of income inequality.

Findings for Neighborhood-Level Analysis

COVID-19 not only varies across city-regions or municipalities; it varies considerably within them. Neighborhoods within cities may be sorted and segregated by income, education, age, family size and status, nationality, and other factors. Prior research has found these factors to be associated with patterns of COVID-19 cases and deaths. To get at this, we examine COVID-19 cases across Swedish neighborhoods. (Data on COVID-19 deaths is not publicly available for Swedish neighborhoods). As noted above, this neighborhood data is available for COVID-19 cases on a weekly basis for Sweden's three largest cities: Stockholm, Gothenburg, and Malmö. These cities are home to nearly one-fifth (18.4 percent) of the total population of Sweden.

Figures 5, 6, and 7 compare the concentration of COVID-19 cases at two time points in the pandemic (weeks 15 and 30) to the geographic patterning of income and immigrants in Stockholm, Gothenburg, and Malmö respectively.

(Figure 5 about here)



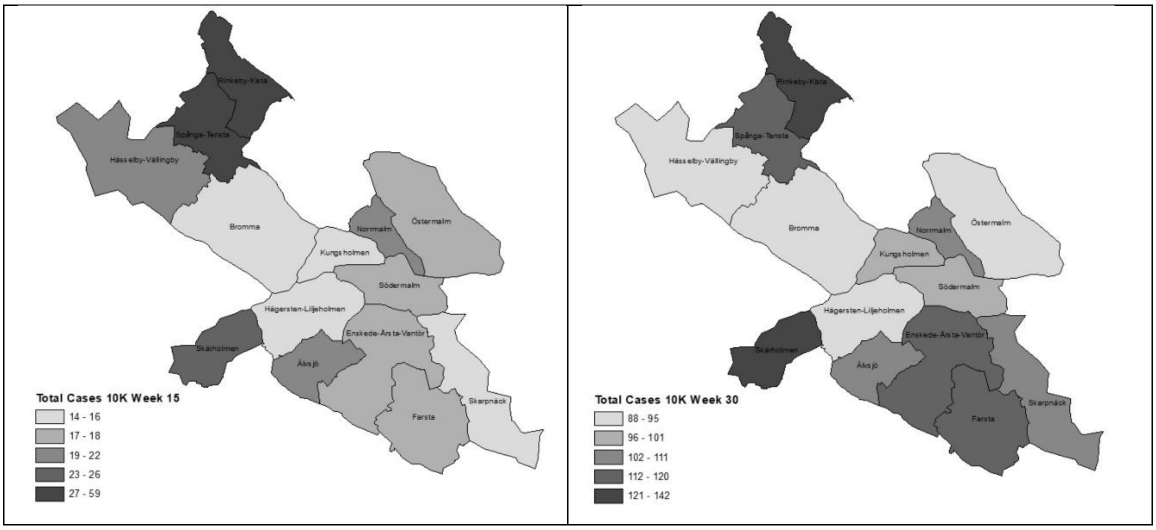


Figure 5: COVID-19 Cases across Stockholm Neighborhoods

Note: For Weeks 15 and 30

In Stockholm, the neighborhoods with the lowest incomes and highest shares of immigrants (e.g., Rinkeby-Kista, Spånga-Tensta and Skärholmen) had higher concentrations of COVID-19 at both time periods.

(Figure 6 about here)

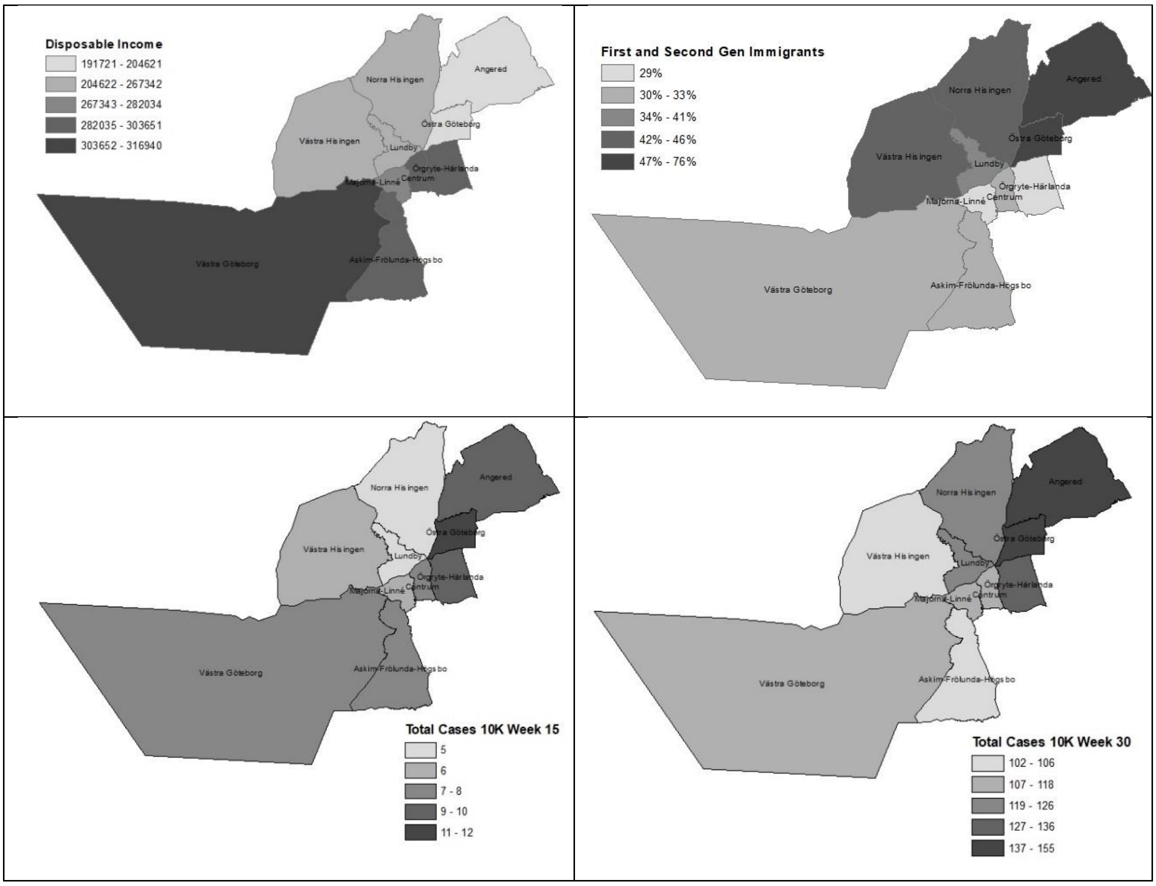


Figure 6: COVID-19 Cases across Gothenburg Neighborhoods

Note: For Weeks 15 and 30

A similar pattern is visible in Gothenburg, where COVID-19 cases are higher in neighborhoods with lower incomes and higher concentrations of immigrants (Angered, Östra Göteborg, but also Norra and Västra Hisingen), with the exception of one neighborhood, Västra Hisingen, where COVID-19 cases were relatively lower.

(Figure 7 about here)

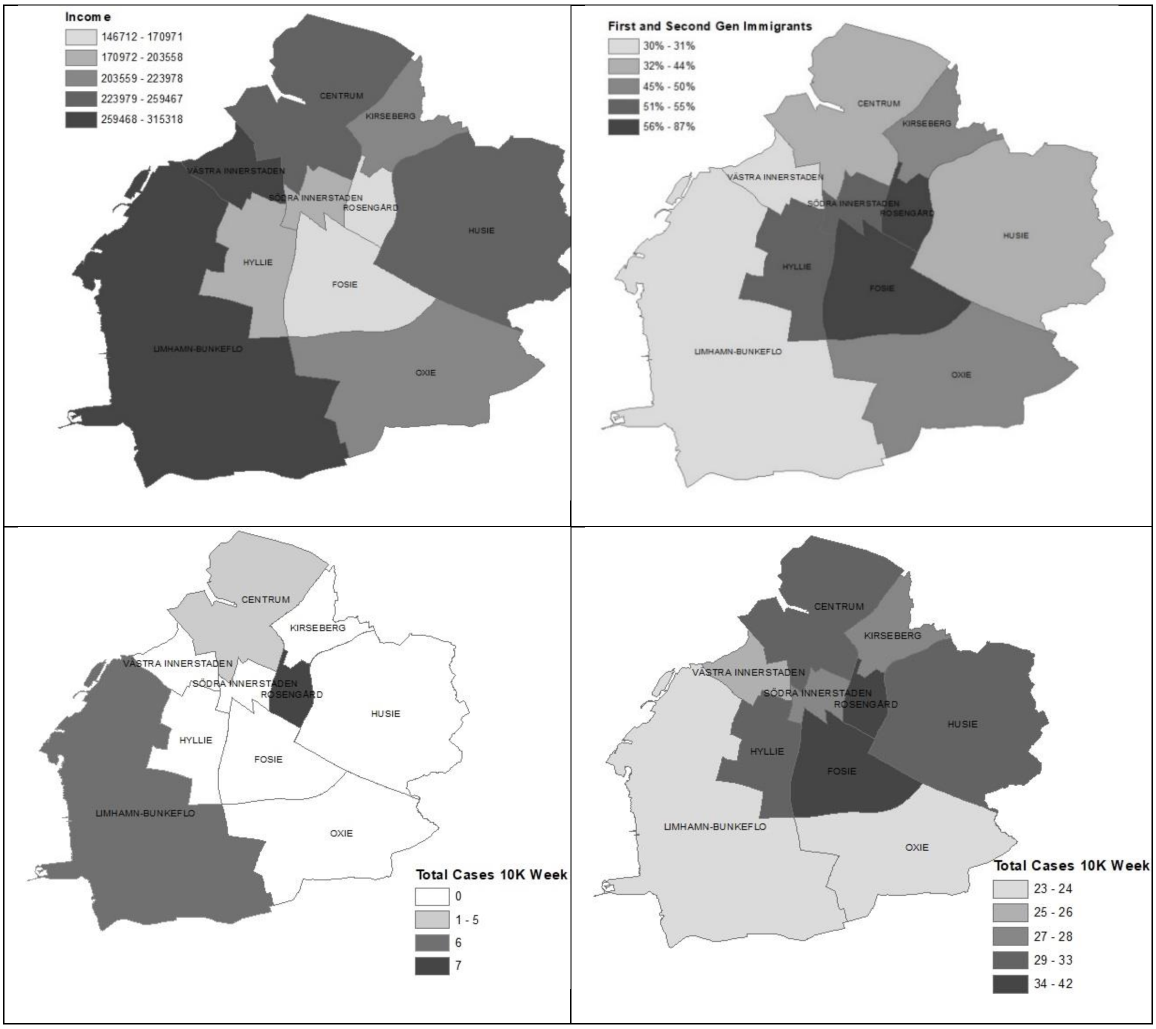


Figure 7: COVID-19 Cases across Malmö Neighborhoods

Note: For Weeks 15 and 30

The results in Malmö follow a somewhat different pattern. In the initial stages of the pandemic, both high- and low-income neighborhoods were hit relatively hard, as can be seen in the examples of Limhamn-Bunkeflo which has high incomes and low shares of immigrants, and Rosengård, a disadvantaged and marginalized neighborhood. But by the later stages of the pandemic, the geography of COVID-19 in Malmö is more similar to that of Stockholm and Gothenburg where COVID-19 is disproportionately concentrated in less advantaged neighborhoods.

To better understand the geography of COVID-19 at the neighborhood level, we turn to the findings of our correlation and regression analyses.

Neighborhood-Level Correlation Findings

Table 4 reports the results of a partial correlation for COVID-19 cases. It covers per capita cases on a weekly basis, controlling for the week data was registered and the municipality. The variables are similar to the analysis for municipalities as presented in the above sections, with the following exceptions. We use a variable for relative income that compares neighborhood income to city income to capture income inequality. We also exclude the air connectivity variable, since this will not vary for neighborhoods within cities.

(Table 4 about here)

Table 4: Results of Neighborhood-Level Correlation Analysis

	Partial Correlation
	COVID-19 cases per Capita
Population (ln)	0.188**
Population Density (ln)	-0.134**
Average Age	-0.149**
Over Age 70	-0.144**
Over Age 80	-0.162**
Income	-0.076*
Income Inequality (Relative Income)	-0.212**
Average Household Size	0.221**
Multigenerational Households	0.244**
Single Households	-0.030
Foreign Born	0.160**
First and Second Generation Foreign Born	0.163**
Education (BA and above)	-0.121**
Frontline Workers	0.209**
Unemployment	-0.075*

Avg Education in Nursing Homes	-0.007
Share Foreign Born of Nursing Homes Employees	0.184**
Week of First Case	-0.315**

Note: Based on weekly data and controlling for week during the pandemic.

First off, population size at the neighborhood level remains positively and significantly related to COVID-19 cases, but we now see the correlation coefficient for density is negative and significant. However, it is important to note that the density variable does not reflect the entire area of the neighborhood, but only the parts where people live or work excluding areas of parks, open space, and parking. Still, this might suggest that density is not necessarily a factor in the spread of COVID-19 cases across neighborhoods within cities.

COVID-19 cases at the neighborhood-level are positively and significantly related to our variable for average household size and for multigenerational households, in line with prior research that finds overcrowding to be a greater factor in COVID-19 than density per se.

The findings for income, education, and occupation are different from the municipal analysis and more in line with prior research. The variable for income is negative and significant, indicating that COVID-19 cases are concentrated in the less advantaged neighborhoods. In addition, the coefficient for our measure of inequality (relative income) is even stronger, highlighting the connection between lower relative income and COVID-19 cases. The variable for educational attainment is also negative and significant. In contrast to the municipal-level results, the variable for frontline workers is positive and significant, again in line with prior research and intuitive expectations (Nguyen et al. 2020). The variables for frontline workers and educational attainment reflects place of residence, not place of work.

The result for immigration status is also positive and significant, in line with prior research. The variable for foreign-born employees of nursing homes is also positive and significantly associated with COVID-19 cases.

The result for the variable for age remains counter-intuitive. COVID-19 cases at the neighborhood-level are negatively and significantly correlated with age. In other words, there are more COVID-19 cases in neighborhoods with a relatively younger population. This likely reflects the fact that the average age is lower in disadvantaged neighborhoods. It may also reflect the fact that Sweden remained relatively open, allowing younger people who are at lower risk to interact more with one another.

By far the strongest association in this analysis is the variable for the weekly onset of first infection. As with municipalities, timing matters: Neighborhoods that got hit first in general got hit harder.

Neighborhood-Level Regression Findings

The neighborhood-level regression analysis covers 34 neighborhoods in Stockholm, Gothenburg and Malmö for which data is available. The data cover COVID-19 cases per week, from week 6 to week 32. Given that some of the variables are closely related to one another, we use a factor analysis to reduce the variables related to neighborhood characteristics. The factors generated essentially group variable characteristics together as related factors. In this way, the factor analysis helps to reduce problems with multicollinearity. The nursing home variables are based on workplace location and are therefore kept as separate variables.

(Table 5 about here)

Table 5: Factor Analysis Results for Residential Neighborhood Characteristics

	Factor 1	**Factor 2**	**Factor 3**
Population (ln)	-0.612	-0.251	-0.088
Density (ln)	-0.353	-0.683	0.255
Average Age	-0.319	0.896	0.098
Over 70 Years of Age	-0.315	0.873	0.250
Over 80 Years of Age	-0.194	0.824	0.466
Income	-0.834	0.140	-0.384
Relative Income	-0.817	0.286	-0.174
Household Size	0.869	0.262	-0.366
Intergenerational Households	0.732	0.263	-0.446
Single Households	-0.533	-0.728	0.347
Foreign-Born Share	0.931	-0.175	0.034
First and Second Generation Foreign-Born	0.927	-0.203	0.015
Education (BA and above)	-0.947	-0.214	-0.106
Frontline Workers	0.846	0.112	0.333

Unemployment	0.829	-0.095	0.213

Table 5 shows the results from the factor analysis, which generates three separate factors. Factor 1 reflects more disadvantaged neighborhoods – those with lower incomes, lower relative income, lower educational attainment, more front-line workers, higher levels of unemployment, bigger households, and higher levels of multi-generational households.

The other two factors mainly reflect the age structure of the neighborhoods. Factor 2 primarily reflects somewhat older neighborhoods, where the average age is higher and there is a larger share of the population aged 70 and above. These neighborhoods also have lower densities. Factor 3 primarily reflects much older neighborhoods, with a higher share of population aged 80 and above, and fewer multi-generational households.

We use Factors 1 and 2 in the regression analysis relating neighborhood-level characteristics to COVID-19 cases. We add an additional regression to capture two additional key variables: timing of first infection (Regression 1) and nursing home characteristics (Regression 2). Both regressions add a dummy variable to control for municipality. Table 6 summarizes the key findings from the regression analysis.

(Table 6 about here)

Table 6: Neighborhood-Level Regression Analysis for Infections per Capita

	Regression 1	Regression 2
Residential Characteristics:		
Factor 1	6.401**/0.119	1.876/0.035
	(0.967)	(0.990)
Factor 2	-3.667**/-0.068	0.732/0.014
	(0.945)	(0.911)
Nursing Home Characteristics:		
Average Education in Nursing Homes	-	0.773/0.002
		(7.306)
Share Foreign Born Emp in Nursing Homes	-	121.495**/0.266
		(7.306)
Other Variables:		
Week of First Case	-3.177**/-0.037	-0.600/-0.007
	(1.816)	(1.377)
Municipality Dummy	YES	YES
Week Dummy	YES	YES
N	917	917
R2 Adj	0.721	0.775

Regression 1 finds a significant association for Factor 1. COVID-19 cases are thus associated with less advantaged neighborhoods, i.e., those with lower incomes, lower relative incomes (a measure of inequality), lower levels of education, more front-line workers, and more immigrants.

Factor 2, which captures the age structure of neighborhoods, is negative and significant, but of lower magnitude than Factor 1. The standardized β-coefficient is -0.068 for Factor 2, compared to 0.119 for Factor 1. Here is it important to remember that the analysis covers only COVID-19 cases not deaths. The Swedish strategy has been to have risk groups such as those in older age groups to remain isolated with limited contact with others. And because Sweden remained relatively open, young people were more likely to come into contact with the virus. The results from Regression 1 also suggests that neighborhoods that were hit early on had more infection cases during the pandemic.

Although these neighborhood-level characteristics factors are significant, they explain relatively little of the variation of COVID-19. In fact, the dummy variables for Week and the Municipality Dummy explain substantially more of the variation, approximately 70 percent, compared to just 3 percent for the variables for neighborhood characteristics.

This limited explanatory power of the variables for neighborhood characteristics is also clear once we control for nursing home characteristics. When this variable is added to the model, both the neighborhood-level factor and the variable for onset of infection become insignificant. This variable adds an additional 5 percent explanatory power to the regression model, which still is relatively low. Taken together, the results indicate that while neighborhood disadvantage is associated with COVID-19 cases, neighborhood characteristics do not explain a lot of the variation across these neighborhoods.

Conclusion

This research has examined the geography of COVID-19 in Sweden. Sweden is a good case to consider to understand both the spread of COVID-19 and the key factors associated with it, because it is did not impose lockdowns either nationally or on a regional basis. Thus, we would expect COVID-19 to spread in a relatively unimpeded way across Swedish cities and neighborhoods.

The research examined the role of factors identified by previous studies as associated with COVID-19 (measured as both cases and deaths per capita) such as density, population, household size, age, air connectivity, income, education, front-line worker status, immigration, nursing home populations, and temperature, among others. It explored the salience of these factors across all Swedish municipalities and in neighborhoods in the nation's three largest cities.

Our results are generally in line with some of the findings of prior research but are more mixed and at times counter-intuitive. For example, we find that density is associated with COVID-19 cases across municipalities, but not directly with deaths. Density is also not associated with COVID-19 cases across neighborhoods where it is likely to vary more. Similarly, population size is weakly associated with COVID-19 cases but not deaths, and it is not associated with COVID-19 across neighborhoods.

Our correlation findings suggest several factors may be more important than either density or population to explain the spread and deadliness of COVID-19. For example, household size is positive and significant in relation to infections at both the municipal and neighborhood levels. This finding is in line with prior research which identifies overcrowding as a factor in the transmission of COVID-19.

The timing of COVID-19 outbreaks also seems to have mattered. Municipalities and neighborhoods that were hit earliest by the pandemic experienced more extensive outbreaks. Nursing homes are found to be a key factor in the spread of COVID-19 across both municipalities and neighborhoods. Indeed, the presence of high-risk nursing homes was found to be among the strongest factors in COVID-19 deaths across municipalities.

However, other factors are weaker than expected in our findings, and even counter-intuitive in light of both academic research and conventional wisdom. At the individual level, age has been identified as a key factor in the vulnerability of people to the virus, with people over age 70 being much more likely to be hospitalized and to die from COVID-19. But at the municipal, aggregated level, we find COVID-19 cases and deaths to be negatively associated with the variables for age, including the average age of places, and the percent of people over the age of 70 and over the age of 80. This likely reflects the fact that younger people were free to have contact with one another because

Sweden did not impose any lockdowns, while older and more vulnerable people were more likely to isolate and physically distance.

The findings for indicators of socio-economic status are also mixed and in some cases counter-intuitive. For example, the variables for income and education are positively related with COVID-19 cases at the municipal level, which seems counter-intuitive. However, as in other studies, the variable for income inequality is positively associated with COVID-19 cases across municipalities, as expected. These findings may reflect a more general result for city size, as bigger cities tend to be more affluent and educated but also more economically unequal. The factor for disadvantaged neighborhoods is modestly associated with COVID-19 cases in the neighborhood-level analysis.

The findings for frontline workers are also mixed. This variable generates mixed results at the municipal level but was positively and significantly related to COVID-19 cases in the neighborhood-level analysis. The variables for immigrants are positively and significantly associated with COVID-19 cases but not deaths. This may provide additional evidence for the association between COVID-19 and disadvantaged neighborhoods, as immigrants in Sweden are generally concentrated in less advantaged neighborhoods.

Overall, our findings suggest that the geographic variation of COVID-19 across Swedish municipalities is only weakly related to variables for density, population size, immigration status, and even fewer of these variables are significantly directly related to deaths from COVID-19. The neighborhood-level analysis finds the geographic variation in COVID-19 cases to be associated with the factor for neighborhood disadvantage. But again, this factor explains relatively little of the infection rates on a weekly basis during the pandemic.

The variable that is by far most closely associated with COVID-19 across Swedish municipalities is the presence of at-risk nursing homes. This variable outperforms all others in the regression analysis for COVID-19 deaths across Swedish municipalities.

A key factor that seems to matter to the spread of COVID-19 across Swedish municipalities and neighborhoods is the timing of first infection. Swedish cities and neighborhoods that were hit earlier by the virus seem to have been hit harder – a finding which is in line with previous research **(**Carozzi et al., 2020**).**

That said, all these variables explain only a small amount of the geographic variation of COVID-19 across Sweden—in fact, roughly only ten percent of the variation in COVID-19 cases across municipalities and just three precent across neighborhoods. A couple of factors may bear on this. Differences in testing of COVID-19 across places may be skewing the data on cases. It may also be that the effect of variables that matter at the individual level may be muted when we aggregate up to the level of neighborhoods or municipality.

Still, perhaps the biggest takeaway from this study is that the geographic variation in COVID-19 and the vulnerability of certain places to it appear to have relatively little to do with their own characteristics. Analysis shows that the spread of COVID-19 per capita across municipalities and neighborhoods in Sweden seems to reflect a great deal of randomness. In a country that did not impose a lockdown, i.e., one in which we would expect unimpeded spread, we find that it is not so much place-based characteristics that mattered to the spread of COVID-19 but rather randomness and bad luck.

These findings should be interpreted as interim results. The pandemic remains ongoing and its geographic pattern and determinants continue to evolve and are far from fixed. It is important to continue to track the geographic spread of COVID-19 and the factors associated with it. We encourage further research on the factors associated with the spread of COVID-19 across cities and neighborhoods. Understanding of the geographic variation of COVID-19 will evolve alongside the evolution of the virus itself.

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