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Do COVID19 infection rates change over time and space? Population density and socio-economic measures as regressors

Yuval Arbel \textsuperscript{a, *}, Chaim Fialkoff \textsuperscript{b}, Amichai Kerner \textsuperscript{c}, Miryam Kerner \textsuperscript{d}

\textsuperscript{a} Sir Harry Solomon School of Economics and Management, Western Galilee College, Derech Hamichlala, P.O. Box 2125, Acre 2412101, Israel
\textsuperscript{b} Institute of Urban and Regional Studies, Hebrew University of Jerusalem, Mt. Scopus, Jerusalem 9190501, Israel
\textsuperscript{c} School of Real Estate, Netanya Academic College, 1 University Street, Netanya 4223587, Israel
\textsuperscript{d} The Ruth and Bruce Rappaport Faculty of Medicine, Technion, Israel Institute of Technology, Israel

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\textbf{ABSTRACT}

The COVID19 pandemic motivated an interesting debate, which is related directly to core issues in urban economics, namely, the advantages and disadvantages of dense cities. On the one hand, compact areas facilitate more intensive human interaction and could lead to higher exposure to the infection, which make them the potential epicenter of the pandemic crisis. On the other hand, dense areas tend to provide superior health and educational systems, which are better prepared to handle pandemics, leading to higher recovery rates and lower mortality rates. The objective of the current study is to test the relationship between COVID19 infection rates (cases\div population) as the dependent variable, and two explanatory variables, population density and socio-economic measures, within two timeframes: May 11, 2020 and January 19, 2021. We use a different methodology to address the relationship between COVID19 spread and population density by fitting a parabolic, instead of a linear, model, while controlling socio-economic indices. We thus apply a better examination of the factors that shape the COVID19 spread across time and space by permitting a non-monotonic relationship. Israel provides an interesting case study based on a highly non-uniform distribution of urban population, and diversified populations. Results of the analyses demonstrate two patterns of change: 1) a significant rise in the median and average infection-population ratio for each level of population density; and 2) a moderate (a steep) rise in infection rates with increased population density on May 11, 2020 (January 19, 2021) for population densities of 4000 to 20,000 persons per square kilometer. The significant rise in the average and median infection-population ratios might be as attributed to the outcome of new COVID19 variants (i.e., the British and the South African mutants), which, in turn, intensify the virus spread. The steeper slope of infection rates and the rise in the standard deviation of the infection-population ratio may be explained by non-uniform spatial distribution of: dissemination of information in a variety of language; different levels of medical infrastructure in different parts of the country; varying levels of compliance to social distancing rules; and strict (limited) compliance to social distancing rules. The last factor of limited compliance might be the outcome of premature optimism due to extensive scope of the vaccination campaign in Israel, which is located in first place globally.

\textbf{1. Introduction}

Coronavirus 2019 (COVID-19) is a declared global pandemic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), with multiple risk factors (WHO report: coronavirus). Particularly, the dissemination rate of the British variant could be greater than 70\% of cases in the UK compared to the normal SARS-CoV-2 virus, with an R index growth of 0.4 (Conti et al., 2020). The COVID19 pandemic motivated an interesting debate, which is related directly to core issues in urban economics, namely, the advantages and disadvantages of dense cities. On the one hand, compact areas facilitate more intensive human interaction and could lead to higher exposure to the infection, which make them the potential epicenter of the pandemic crisis (Eubank et al., 2004; Glaeser, 2011). On the other hand, dense areas tend to provide superior health and educational systems, which are better prepared to handle pandemics, leading to higher recovery rates and lower mortality.

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\textsuperscript{*} Corresponding author.

\textit{E-mail addresses:} YuvalAr@wgalil.ac.il (Y. Arbel), kerneram@netvision.net.il (A. Kerner), Miryamke@clalit.org.il (M. Kerner).

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rates (Dye, 2008). Compact planning also promotes greater physical activity and less likelihood of obesity, heart disease, cancer prevalence (Arbel, Fialkoff, & Kerner, 2020; Ewing, Meekins, Hamidi, & Nelson, 2014; Sallis et al., 2016), higher life expectancy (Hamidi, Ewing, Tatalovich, Grace, & Berrigan, 2018) and consumption of healthier food (Hamidi, 2020). Given the growing criticism against compact planning design in California for potentially facilitating the spread of future viruses (Kahn, 2020), new empirical evidence might prove to be important in providing a firmer theoretical basis for policy formulation.

The objective of the current study is to test two dimensions of the SARS-CoV-2 virus spread in Israel: across time and space (e.g., Appendix 1). We examine the relationship between infection-population ratio and population densities on May 11, 2020 and January 19, 2021. We use a different methodology to address the relationship between COVID19 spread and population density by fitting a parabolic, instead of a linear, model, while controlling socio-economic indices. We thus apply a better examination of the factors that shape the COVID19 spread across time and space, and by permitting a non-monotonic relationship. We are unaware of any previous study that employs this methodology. Moreover, the literature addressing the relationship between the COVID19 virus spread and population density in denser urbanized environments around the world is rather limited (e.g., Hamidi, Ewing, & Sabouri, 2020). Consequently, the current study adds to the body of knowledge by providing new evidence while employing a different methodology.

Israel is considered a densely populated country (e.g., Appendix 2). In 2018, 88.9% of the Israeli populations lived in urban areas, (ICBS report: Israel in Figures – Selected Data from The Statistical Abstract of Israel, 2019) compared to 55.3% of the world’s population in mid-2018 (United Nation: World Urbanization Prospects File 1: Population of Urban and Rural Areas at Mid-Year (thousands) and Percentage Urban, 2018). This settlement pattern, in turn, is expected to promote virus spreading (Eubank et al., 2004; Glasser, 2011).

The outcomes of this study provide some support to previous findings from other countries. Referring to 1165 metropolitan counties at the US statewide level and after controlling for metropolitan size and other confounding variables, Hamidi et al. (2020) found that county density leads to significantly lower infection rates and lower death rates. Yet, studies referring to the spread of the 1918 influenza pandemic in USA, UK and Japan provided mixed results (e.g., Chowell, Bettencourt, Johnson, Alonso, & Viboud, 2008; Garrett, 2010; Mills, Robins, & Lipsitch, 2004; Nishiura & Chowell, 2008).

Given the non-monotonic design of the empirical model, on the one hand, our findings demonstrate an anticipated rise in COVID19 infection rates for population densities of below 20,000 persons per square kilometer, which becomes steeper with the COVID19 spread. On the other hand, results show an anticipated drop in COVID19 infection rates for population densities of between 20,000–25,000 persons per square kilometer.

The remainder of this study is organized as follows. Section 2 reports the background and descriptive statistics. Section 3 describes the methodology and Section 4 presents the results. Finally, Section 5 concludes and summarizes.

2. Descriptive statistics

Fig. 1 compares the histograms of the infection-population ratio in each Local Authority for May 11, 2020 and January 19, 2021. This comparison clearly demonstrates the rise in the infection-population ratio. On May 11, 2020 the average infection-population ratio is 63 cases per 1000 persons and the median is 5.66779%. The 6.24972% mean difference is statistically significant at the 1% significance level. The calculated t-value with 423 degrees of freedom is 26.0739 compared to the 1% critical t-value with 423 degrees of freedom of 2.5875.

To strengthen this conclusion, we also ran a median test. Unlike the mean, the median of the distribution is unaffected by outliers. This nonparametric test is based on four components: 1) generating a pooled sample of the two dates and calculating the median of the pooled sample (0.24828%); 2) counting the number of cases, which are above/below the median of the pooled sample for each date separately; 3) calculating the Pearson Chi statistics with one degree of freedom; 4) comparing the calculated value to the critical value. The results of this analysis clearly demonstrate a rejection of the null hypothesis of equal medians. While the calculated Pearson Chi² with one degree of freedom is 335.5037, the 1% critical value with one degree of freedom is only 3.841. These consistent outcomes for the two central measures of location (mean and median) indicate the spread of the British variant, which, according to Conti et al. (2020) is responsible for 70% of the new COVID19 cases in the UK.

Another interesting feature of the distribution is an increase of the spread around the mean. The standard deviation (SD) on May 11, 2020 is 0.18345% and on January 19, 2021 is 3.69318%. A formal statistical test clearly supports the conclusion that these standard deviations are not equal. The null hypothesis, according to which SD(January 19, 2021) = SD(May 11, 2020) = 1 is clearly rejected. The calculated F-Value with 187 degrees of freedom in the numerator and 237 in the denominator is 405.3101, compared to the 1% critical F-value with the same degrees of freedom of 1.3778115.

Given that within the two measured points in time (May 11, 2020 and January 19, 2021) population densities and the socio-economic measures remain unchanged, these differences in the spread of the disease indicate a non-uniform spatial distribution in three distinct areas: 1) medical literacy, namely, limited awareness of different populations and the socio-economic structure in cities in the central versus the peripheral regions of the country measured, for example, as the number of medical staff per 1000 persons; 2) resilience of the Israeli community and limited compliance to social distancing rules (preserving a distance of two meters, wearing masks, hygienic practices); 3) premature optimism due to extensive scope of vaccinations campaign in Israel. 1

3. Methodology

Consider the following estimated maximum likelihood objective function of the fractional probit model (e.g., Papke and Wooldridge (1996); Johnston and Dinardo (1997): 61–63, 424–426; Wooldridge (2010)):

\[ \ln L = \sum_{i=1}^{n} \omega_{ij} \ln \left( G \left( x_{i} \beta \right) \right) + \sum_{j=1}^{\kappa} a_{ij} \left( 1 - y_{j} \right) \ln \left( 1 - G \left( x_{ij} \beta \right) \right) \]

(1)

\[ G \left( x_{ij} \beta \right) = \Phi \left( \frac{x_{ij} \beta}{\sqrt{\sigma^{2}_{j}}} \right) \]

(2)

where \( j \) is the index for each Local Authority (for the model applied to May 11, 2020 \( j = 1, 2, 3, \ldots, 238 \) and for the model applied to January 19, 2021 \( j = 1, 2, 3, \ldots, 187 \); \( \omega_{ij} = \sqrt{\text{POP}_{j}} \) (the square root of Local

1 Since January 1, 2021 (the starting date of the vaccination campaign) Israel is located in the first place globally in terms of number of vaccinated against SARS-CoV-2 virus per 100 persons (34.01 persons on January 19, 2021 and 71.59 on February 12, 2021 – see, for example, World Health Organization. Statistics and Research: Coronavirus (COVID-19) Vaccinations Available at: https://ourworldindata.org/covid-vaccinations).

2 The likelihood function of the model: \( Y_{ij} = \alpha + \beta X_{ij} + u_{ij} \) may be defined as \( L \left( \alpha, \beta, \sigma^{2}_{j} \right) \). The maximum likelihood estimators (MLE) \( \hat{\alpha}, \hat{\beta}, \hat{\sigma}^{2}_{j} \) maximize the probability of obtaining the sample values that have actually been observed (Johnston & Dinardo, 1997: 61–63). The method gained a widespread popularity due to a range of desirable large sample asymptotic properties, including: consistency, asymptotic normality and efficiency, (Johnston & Dinardo, 1997: 143–145).
\[ y_j = \text{Infection rate}_j = \frac{\text{Infection}_j}{\text{POP}_j} \]

where \( 0 \leq y_j < 1 \).

\( x'_j \) is a matrix whose dimensions are 238 \( \times \) 5 or 187 \( \times \) 5 (\( x'_{j1} = 1 \)) for the constant term; \( x'_{j2} = \text{Population Density}_j \) in square kilometers; \( x'_{j3} = \text{Population Density}_j^2 \); \( x'_{j4} = \text{Gini Index}_j \) (a measure that ranges between 0 = perfect equality and 1 = perfect inequality) and \( x'_{j5} = \text{Socio-Economic ranking of the Local Authority} \), which ranges between 1 = the lowest, to 10 = the highest.

Finally, \( \Phi \) is the cumulative normal distribution function; \( z'_{j} = x'_{j2} \), \( x'_{j4} \) and \( \beta \) and \( \gamma \) are column vectors of the parameters with up to four rows.

To test statistically the differences between the two timeframes, we estimate the pooled sample (425 observations = 238 + 187) with interaction variables by substituting:

\[ \beta = \beta_0 + \beta_1 \text{Dum}_{January,11,2021} \]  

(3)

and

\[ \gamma = \gamma_0 + \gamma_1 \text{Dum}_{January,11,2021} \]  

(4)

where \( \text{Dum}_{January,11,2021} \) equals 1 for the data in January 11, 2021 and 0 otherwise. Consequently, the base category is May 11, 2020.

4. Results

Table 1 reports the outcomes obtained from the empirical model. Based on the pooled model, Fig. 2 demonstrates the difference between infection-population ratio as a function of Population Density on May 11, 2020 and January 19, 2021. The upper part of Fig. 2 exhibits a moderate (a steep) rise in infection rates with increased population density on May 11, 2020 (January 19, 2021) for population densities of 4000 to 20,000 persons per square kilometer (sq. km.). The lower part of Fig. 2 exhibits the 99% confidence interval for the difference between the two dates and each population density. It may be readily verified that for each population density, this confidence interval is above zero, where the minimum difference is about 5% for a population density of 4000 persons per sq. km. and the maximum difference is above 12% for a population density of 20,000 persons per sq. km.

Fig. 3 shows the rate of change \( \Delta \text{Proj Rate Infected} / \Delta \text{Population Density} \) (vertical axis) for each level of population density (horizontal axis) and separately for May 11, 2020 and January 19, 2021. The graph demonstrates a steeper rise in
The outcomes demonstrate that, on the one hand, for population densities of below 20,000 persons per square kilometer, the disadvantage of urbanization economies may overpower the advantages, particularly with the COVID19 spread at a later stage of the pandemic evolution. Differently put, denser environments facilitate human interaction (Glaeser, 2011; Hamidi, 2020), which, in turn, may lead to higher infection rates. On the other hand, the “balance of power” reverses for population densities of between 20,000–25,000 persons per square kilometer.

5. Summary and conclusions

The objective of the current study is to test two dimensions of the SARS-CoV-2 virus spread in Israel: across time and space. We examine the relationship between infection-population ratio and population densities on May 11, 2020 and January 19, 2021. We use a different methodology to address the relationship between COVID19 spread and population density by fitting a parabolic (instead of a linear) model, while controlling socio-economic indices. We thus apply a better examination of the factors that shape the COVID19 spread across time and space by permitting a non-monotonic relationship. We are unaware of any previous study that employs this methodology. Moreover, the literature addressing the relationship between the COVID19 virus spread and population density in denser urbanized environments around the world is rather limited (e.g., Hamidi et al., 2020). Consequently, the current study adds to the body of knowledge by providing new evidence while employing a different methodology.

The steeper slope of infection rates and the rise in the standard deviation of the infection-population ratio may be explained by non-uniform spatial distribution of: dissemination of information in a variety of languages; different levels of medical infrastructure in different parts of the country; varying levels of compliance to social distancing rules; and strict (limited) compliance to social distancing rules. The last factor of limited compliance might be the outcome of premature optimism due to extensive scope of the vaccination campaign in Israel, which is located in first place globally.

Given the importance of this issue to urban planners and economists, it would be of interest to replicate this methodology and apply this non-monotonic design of the empirical model to other cities and regions around the world.

Declaration of competing interest

As a corresponding author and on behalf of all the authors I declare that:

1) None of the authors have relevant or material financial interests that relate to the research described in this paper.
2) None of the authors have potential conflicts of interest, financially or non-financially, directly or indirectly related to this work.
3) This research does not require an IRB approval since it does not involve any experiment or manipulation of subjects.
4) All authors contributed equally to the study conception and design, data collection and analysis, the first draft and comments on previous versions of the manuscript. All authors read and approved the final manuscript.

Table 1

| Variables                              | Pooled rate_infected | May 11, 2020 rate_infected | Jan 19, 2021 rate_infected |
|----------------------------------------|----------------------|----------------------------|---------------------------|
| population_density_sq                  | -3.85 × 10^{-9}***   | -1.28 × 10^{-5}**          | -2.36 × 10^{-9}***        |
| dum_January_2021 × population_density_sq | 1.61 × 10^{-9}***    |                            |                           |
| population_density                     | 0.0000202***         | 0.000103***                | 0.000112***               |
| dum_January_2021 × population_density  | -9.30 × 10^{-5}***   |                            |                           |
| Gini                                   | 2.454***             | 2.924***                   | 0.709**                   |
| dum_January_2021 × gini                | -1.759***            |                            |                           |
| socio_economic_ranking                 | -0.0726***           | -0.183***                  | -0.0701***                |
| dum_January_2021 × socio_economics_ranking | -0.00127           |                            |                           |
| dum_January_2021                       | 2.280***             |                            |                           |
| Constant                               | -3.876***            | -4.050***                  | -1.602***                 |
| Insignia (population density)          | -6.54 × 10^{-5}***   | -1.90 × 10^{-5}**          | -7.05 × 10^{-5}***        |
| Insignia (socio_economic_ranking)      | 0.00935***           | 0.0335***                  | 0.00847                   |
| Observations                           | 425                  | 238                        | 187                       |

Notes: Estimation outcomes are based on the fractional probit regressions, where heteroskedasticity and population weights (\sqrt{POP}) are included. Robust p-values are given in parentheses.

* p < 0.1.
** p < 0.05.
*** p < 0.01.
Fig. 2. The difference between infection-population ratio as a function of population density on May 18, 2020 and January 19, 2021. Note: The bottom part reflects the difference between January 19, 2021 and May 18, 2020 for each level of population density.
Fig. 3. Rate of change in projected infection-population ratio as a function of population density on May 11, 2020 and January 19, 2021.

Notes: The graph shows the rate of change $\frac{\Delta \text{Proj Rate Infected}}{\Delta \text{Population Density}}$ (vertical axis) for each level of population density (horizontal axis) and separately for May 11, 2020 and January 19, 2021. The graph demonstrates a steeper rise in projected probability to become infected with increased population density on January 19, 2021 for population densities of 2000–20,542 persons per square kilometer.
Appendix 1. COVID19 infection rates in Israel, December 31, 2020

Source: https://clear-map.com/il.
Appendix 2. Population densities in Israel

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