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Covid 19 vaccination: Accessibility or literacy? Israel as a case study

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ABSTRACT

Israel is ranked as the leading country in terms of prevalence of vaccination against SARS-COV-2 virus (persons vaccinated divided by total population). Based on updated data as of January 19, 2021, the objective of the current study is to assess the relationship between the prevalence of vaccination and population density. A-priori, given the better infrastructure of health services (more physicians and nurses per 1000 persons), one would anticipate a higher level of vaccination in denser cities. Surprisingly, the outcomes demonstrate an opposite relationship: a lower level in the per capita level of vaccination with higher population densities from 0.2144 for 2 persons per sq. Km. to a minimum of 0.007191 for 16,642 persons per sq. Km. Given the relatively good accessibility to vaccination centers and high spread of clinics and health centers in Israel, research findings thus stress the major importance of promoting the benefits of vaccination (vaccination literacy) to diversified populations.

1. Introduction

Coronavirus 2019 (COVID-19) is a declared global pandemic with multiple risk factors (WHO report: coronavirus). As of October 31, 2021, the official accumulated Covid-19 cases are 247,376,970 and deaths worldwide are approx. 5 million persons [1]. A vaccine against the SARS-COV-2 virus became available as of December 20, 2020.

In this context, Israel is an interesting case study. It is a country with a high per capita income along with an advanced health system and offers universal health-care insurance by law. To address inequalities in availability and access to health care, legislation providing for universal health-care insurance for all Israeli citizens was passed in 1995 [2]. This law provides a broad basket of high-quality preventive, curative, and rehabilitation health-care services.

Israel is ranked as the leading country in terms of prevalence of vaccination against SARS-COV-2 virus (persons vaccinated divided by total population). This, despite the cultural and ethnic diversity of Israel’s population, and the existence of pockets of “vaccine hesitancy” [3]. From a public policy perspective, the maintenance of high levels of vaccine coverage (in Israel and globally) is necessary to avert a decline in herd immunity, which in turn prevents a reoccurrence of diseases that otherwise might be on the verge

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of extinction [3].

Muhsen et al. [4] mention the large extent of independent programs, initiated by the various health plans, to reduce inequalities in health by a combination of policies. These include lowering copayments, focusing on at-risk populations, and adapting intervention measures to language, culture, literacy, and comprehension levels. Similar public-relation promotion programs were applied by the Israeli Ministry of Health to accelerate the COVID-19 vaccination campaign (e.g., Ref. [5]).

Israel is also considered to be a highly urbanized nation. According to the Israel Central Bureau of Statistics [6] (Israel in Figures – Selected Data from The Statistical Abstract of Israel, 2019), in 2018 a total of 88.9% of the Israeli population, consisting of 8,967,600 inhabitants, lived either in cities (74.2%) or municipalities (14.7%) (page 30). Between 1975 and 2014, life expectancy in Israel steadily grew and is currently above the average life expectancy for the Organization for Economic Co-operation and Development (OECD) countries [7]; available at: https://www.taubcenter.org.il/en/pr/why-is-mens-life-expectancy-so-high-in-israel/; [4]. On the eve of the COVID19 pandemic, life expectancy in Israel was 84.7 years for women, and 81.0 for men [8]; available at: https://www.statista.com/statistics/970780/life-expectancy-at-birth-in-israel-by-gender/).

An interesting related debate is the role of development density in the spread of pandemics. Dense 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 [9,10]. At the same time, dense areas tend to enjoy superior health and educational systems that are more prepared to handle pandemics, leading to higher recovery rates and lower mortality rates [11]. Densely developed areas also have the infrastructure to put in place more effective measures that foster social distancing, thus reducing actual rates of infection. Density also might make it easier to provide services for citizens in need at the time of social distancing orders [12]. [13]; 1–2 [14];

Based on updated data as of January 19, 2021, the objective of the current study is to assess the relationship between the prevalence of vaccination and population density. According to Dagan et al. [15]; until February 1, 2021 (12 days after the date of our cross-sectional study - January 19, 2021), at least 1,503,216 persons, consisting of 16.26% of the Israeli population (\(=\frac{1,503,216}{9,246,000}\)), and 24.11% of the Israeli population without children \((=\frac{1,503,216}{6,742,804})\), have been vaccinated in two doses. A-priori, given the better infrastructure of health services (more physicians and nurses per 1000 persons), one would anticipate a higher vaccination likelihood in denser cities.

Surprisingly, the outcomes demonstrate an opposite relationship: a lower level in the per capita level of vaccination with higher population densities from 0.2144 for 2 persons per sq. Km. to a minimum of 0.007191 for 16,642 persons per sq. Km. Given the relatively good accessibility to vaccination centers and high spread of clinics and health centers in Israel, research findings thus stress the major importance of promoting the benefits of vaccination (vaccination literacy) to diversified populations.

The remainder of this study is organized as follows. Section 2 provides the background. Section 3 describes the methodology, and sections 4 and 5 present the results and discussion. Finally, Section 6 concludes and summarizes.

2. Background

Israel is a high-income country with an advanced health system and offers universal health-care insurance by law. To address inequalities in availability and access to health care, legislation providing for universal health-care insurance for all Israeli citizens was passed in 1995 [2]. This law provides a broad basket of high-quality preventive, curative, and rehabilitation health-care services. Overall, the health status has improved steadily over recent decades. Between 1975 and 2014, life expectancy in Israel steadily grew and is currently above the average life expectancy for the Organization for Economic Co-operation and Development (OECD) countries [4].

In the context of COVID19 vaccinations, several researchers have raised concerns regarding COVID19 and vaccine literacy among different populations, and the need to elevate public awareness in an effort to optimize vaccine uptake [20,21]. Mcaffery demonstrated that compared with Australians with adequate health literacy, those with inadequate health literacy had poorer understanding of COVID-19 symptoms (49% vs 68%; \(p < 0.001\)), were less prone to adopt appropriate behaviour to prevent infection (59% vs 72% \(p < 0.001\), and experienced more difficulty finding information and understanding government messaging about COVID-19. In addition, people with inadequate health literacy were less likely to rate social distancing as important (6.1 vs 6.5; \(p < 0.001\)) and reported more difficulty with remembering and accessing medicines since lockdown (3.6 vs 2.7; \(p < 0.001\)). People with lower health literacy were also more likely to endorse misinformed beliefs about COVID-19 and vaccinations (in general) than those with adequate health literacy. The same pattern of results was observed among people whose primarily language at home was not English.

Health literacy in the Israeli context is directly related to both health care and public health and is operationally defined as: “the...
development of the cognitive and social skills which determine the motivation and ability of individuals to gain access to, understand and use information in ways which promote and maintain good health” [22]. Levin-Zamir and Baron-Epel [3] define ‘vaccine hesitancy’ as a situation in which parents decide to partially vaccinate their children. Parents may decide to permit their child to receive a portion of the recommended vaccines, while rejecting others, delay the age of a child’s immunization, or may even categorically refuse to participate [23]. demonstrate that parents with high levels of communicative and critical health literacy are less likely to vaccinate their children.

Similarly, Muhsein et al. [4] mention the large extent of independent programs, initiated by the various health plans. The aim of these programs was to reduce inequalities in health by a combination of policies. These include lowering copayments, focusing on at-risk populations, and adapting intervention measures to language, culture, literacy, and comprehension levels. For example, Ethiopian cultural mediators were integrated in clinics in neighborhoods with large numbers of Ethiopian immigrant residents. In Arab villages, personal nurses were introduced into local clinics as case managers for diabetes patients.

Fig. 1 gives the scatter diagram, where the vaccinated-population ratio is given at the vertical axis and the population density is given at the horizontal axis. The graph is based on 169 Israeli Local Authorities (cities and towns), covering 80.11% of the Israeli population,7 As the figure demonstrates, between 0 and 5000 persons per sq. Km. the spread of vaccinated-population ratio is high. The spread becomes lower with higher population densities. This reversed heteroskedacity may be corrected by running a weighted least square, namely, giving different weight to each Local Authority, where $a_j = \frac{1}{\sqrt{POP_j}}$ (the square root of Local Authority population).

Israel is also considered to be a highly urbanized nation with almost 90% of the population living in urban areas. Appendix A1 displays the map of Israel stratified by population density The total area of the nine statistical regions in the country, including East Jerusalem and the Golan Heights, is 22,072 sq. Km., and if lakes are excluded, the total area is reduced to 21,643 sq. Km. (Israel CBS: Israel in Figures, 2019).

The spatial distribution of population is highly non-uniform, and there is high variability in population densities across regions, as shown in the table in Appendix A2. While most of the southern parts of Israel are sparsely populated (fewer than 100 persons per sq. km.), population density becomes higher with a shift to the north; until it reaches a peak of 6276–12,385 persons per sq. Km. in the Tel Aviv District, (one of the most densely populated regions world-wide). Shifting further to the central west and the northern parts of Israel, population densities become lower to 1000–2999 persons per sq. Km. in the Haifa, Nazerath and Karmiel and Nahariya sub-districts [24], available at: https://www.cbs.gov.il/he/publications/doclib/2019/2.shatonpopulation/02_01e.pdf.

As the map in Appendix A2 demonstrates, the urbanization patterns vis-à-vis the spread of the COVID19 pandemic may pose a challenge to health policy. This is because dense areas facilitate more intensive human interaction and might lead to higher exposure to the infection, which make them the potential epicenter of the pandemic crisis [9,10]. On the other hand, dense areas tend to enjoy superior health and educational systems that are more prepared to handle pandemics, leading to higher recovery rates and lower mortality rates [11]. Densely developed areas also have the infrastructure to put in place more effective measures that foster social distancing, thus reducing actual rates of infection. Density also could make it easier to provide services for citizens in need at the time of social distancing orders [12]. [13]; 1–2; [14].

In terms of COVID19 vaccinations, as of January 24, 2021 Israel was global leader for vaccinations, with 41.8 vaccinations per 100 persons (see the figure in Appendix A4). Second place is held by the United Arab Emirates with only 25.1 vaccinations per 100 persons.

3. Methodology

Consider the following estimated maximum likelihood objective function of the fractional probit model (e.g. Ref. [25],: 1484; Papke and Wooldridge [26]; Johnston and Dinardo [27]: 61–63,7 424–426; Wooldridge [28]):

$$\ln L = \sum_{j=1}^{N} a_j y_j \ln \left\{ G(x_j \beta) \right\} + \sum_{j=1}^{N} a_j (1-y_j) \ln \left\{ 1 - G(x_j \beta) \right\}$$

(1)

$$G(x_j \beta) = \Phi(x_j \beta)$$

(2)

where $j$ is the index for each Local Authority ($j = 1, 2, 3, \ldots, 169); a_j = \frac{1}{\sqrt{POP_j}}$ (the square root of Local Authority population); $y_j = \text{vaccine rate}_j = \frac{\text{vaccine}_j}{\text{population}_j}$, where $0 \leq y_j < 1; x_j$ is a matrix whose dimensions are $169 \times 4$ ($x_{j4} = 1$ for the constant term; $x_{j2} = \text{Population Density}$, in square kilometers; $x_{j3} = \text{Population Density}_j^2$; and $x_{j4} = \text{Socio Economic ranking}$ of the Local Authority, which ranges between 1 = the lowest, to 10 = the highest). Finally, $\Phi$ is the cumulative normal distribution function; and $\beta$ is a column vectors of the parameters with up to four rows.

The fractional probit model was pioneered and has been extensively used in biometrics applications [25]: 1484 [27]: 413. It belongs to the family of discrete choice models. Biologists (medical researchers) employ this sort of model to measure the relationship

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6 Local Authorities, for which either: 1) information about population density was unavailable; 2) vaccinated-population ratio was greater than 1, were excluded from the sample. Nevertheless, we are left with a sample of 169 local authorities, covering 80.11% of the Israeli population.

7 The likelihood function of the model: $Y_i = a + \beta x_i + u_i$ may be defined as $L(\alpha, \beta, \sigma^2; Y_i)$. The maximum likelihood estimators (MLE) $\hat{\alpha}, \hat{\beta}, \hat{\sigma}^2$ maximize the probability of obtaining the sample values that have actually been observed [27]: 61–63. The method gained a widespread popularity due to a range of desirable large sample asymptotic properties, including: consistency, asymptotic normality and efficiency [27]: 143–145.
between survival of an insect = 1; otherwise = 0 (patients recovery = 1; non-recovery = 0) and the dosage of insecticide (drugs). Consequently, it seems plausible to employ this model in a micro-individual level sample, where the limited dependent variable equals 1/0 if the person was vaccinated/not-vaccinated.

4. Results

Based on a sample of 169 local authorities, covering 80.11% of the Israeli population, Table 1 reports the regression outcomes obtained via the fractional, probit and logit models. Given the difficulty of direct interpretation of parameters, Fig. 2 gives the projected probabilities of vaccination rates from the population (obtained from column (1) of Table 1) as a function of population density squared and population density.

The outcomes demonstrate that projected likelihood of vaccination becomes lower from 0.2144 for a population density of 2 persons per sq. Km. (the minimum) to 0.007191 for a population density of 16,642 persons per sq. Km. Above this population density, projected likelihood of vaccination becomes slightly higher until 0.03268 for the maximum population density of 26,510 persons per sq. Km.

The outcomes in Table 1 also show that the coefficients of the socio-economic ranking variable is statistically insignificant (p = 0.407–0.408). Given that COVID19 vaccinations in Israel are given free-of-charge, personal level of income apparently plays no role. In line with Amit-Aharon et al. [23] and Levin-Zamir, and Baron-Epel. [3]; it is possible that people in Local Authorities with a higher Socio-Economic Index, with elevated medical literacy, are more prone to refuse to get vaccinated. This might be driven from the likelihood of suffering from vaccine complications, which may overpowers the expected benefit of the vaccine, according to the risk perception of vaccine hesitants (Lorini et al., 2021).

5. Discussion

Israel is considered to be a highly urbanized nation. According to the [6]; in 2018 a total of 88.9% of the Israeli population, consisting of 8,967,600 inhabitants, lived either in cities (74.2%) or municipalities (14.7%) (page 30).

An important advantage of dense cities is a better infrastructure of health care services (more physicians and nurses per 1000 persons – according to the [18], which, in turn, may promote large-scale COVID19 vaccination in big cities. Surprisingly, the outcomes demonstrate a lower level of anticipated likelihood of vaccination with higher population densities when socio-economic status is controlled. A possible interpretation of this outcome is vaccine hesitation due to reliance on the better health infrastructure in big cities and fear from adverse effects of vaccinations.

Additional results demonstrate insignificant difference in the projected likelihood to get vaccinated based on socio-economic status of the city or town. A possible interpretation is elevated medical literacy with higher socio-economics status, which, in turn, raises the awareness to adverse effects of vaccinations. This may prevail over the expected benefit of the vaccine, according to the risk perception of vaccine hesitants. Referring to children vaccinations against diseases such as measles, these points were demonstrated in Lorini et al. [29] and Levin-Zamir, and Baron-Epel [3].

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As noted, Local Authorities, for whom either: 1) information about population density was unavailable; 2) vaccinated-population ratio was greater than 1, were excluded from the sample.

The fractional logit model yields a similar graph. Referring to the outcomes obtained from the Linear Probability model (LPM) – available upon request – for population densities of between 10,000 and 22,850 persons per sq. Km., projected probabilities to become vaccinated are negative.

According to Lorini et al. [29]: “the relationship between health literacy and vaccinations seems to be driven by risk perceptions and by the likelihood of getting sick or suffering from complications in the short term. When these possibilities are high, health literacy positively predicts vaccination uptake; when they are low, health literacy negatively predicts vaccination uptake or shows no effect” (page 486).
The implication from the outcomes reported in this article might be that medical literacy is more important than accessibility. Despite the fact that denser cities have better accessibility to health care centers, where vaccinations are given, compared to peripheral towns, fewer persons arrive to these centers to get vaccinated. Consequently, more effort should be given to the provision of medical information regarding the benefits and costs of COVID19 vaccinations by medical professionals. This information should be given in simple terminology that could be understood by the broad public who lack medical training and education.

6. Summary and conclusions

Israel is ranked as the leading country in terms of prevalence of vaccination against SARS-COV-2 virus (persons vaccinated divided by population), and vaccinations are given free-of-charge. Based on updated data as of January 19, 2021, the objective of the current study is to assess the relationship between the prevalence of vaccination and population density. A-Priori, given the better infrastructure of health services (more physicians and nurses per 1000 persons), one would anticipate a higher vaccination likelihood with denser cities. Surprisingly, the outcomes demonstrate an opposite relationship: a lower level of anticipated likelihood of vaccination with higher population densities from 0.2144 for 2 persons per sq. Km. to a minimum of 0.007191 for 16,642 persons per sq. Km.

Based on our study, several public policy recommendations may be derived. First, given the reduced tendency of people in denser cities to get vaccinated, city planners should include in their consideration for the design new cities ways avoiding pandemic spreads, such as, lower densities and more open spaces.

Second, referring to existing cities, municipalities should develop emergency plans to address future pandemics. These plans may include publication and enforcements of guidelines, such as: 1) hygienic behaviour; 2) reduction in activity hours; 3) reduction of public transportation; 4) promotion of online trading.

Finally, research findings emphasize the major importance of promoting vaccination literacy to diversified populations. Particularly, different publication strategies should be implemented based on socio-economics status of the city. More effort should be given to the provision of medical information regarding the benefits and costs of COVID19 vaccinations by professional medical doctors.

### Table 1

Regression outcomes.

| VARIABLES                     | (1) Fractional Probit                        | (2) Fractional Logit                      |
|------------------------------|---------------------------------------------|------------------------------------------|
| rate_vaccine × √POP          |                                             |                                          |
| Population_Density² × √POP   | 6.08 × 10⁻⁹*** (0.00168)                   | 1.23 × 10⁻⁹*** (0.00285)                 |
| Population_Density × √POP    | −0.000201*** (4.62 × 10⁻⁴)                 | −0.000419*** (7.44 × 10⁻⁴)               |
| Socio_Economic_Index × √POP  | 0.0290 (0.408)                             | 0.0566 (0.407)                           |
| Constant × √POP              | −0.933*** (1.13 × 10⁻⁶)                    | −1.469*** (9.61 × 10⁻⁶)                  |

Notes: Estimation outcomes are based on the fractional probit and logit regressions, where population weights (√POP) are included. Robust p-values are given in parentheses. *p < 0.1,**p < 0.05,***p < 0.01.

![Fig. 2. Vaccination Rate 19 January 2021. Notes: The figure is based on the outcomes of the fractional probit model (column (1) in Table 1).](image-url)
might convince those who are “vaccine hesitants” with higher medical literacy in high income cities. In all cities, this information should be given in simple terminology that could be understood by the broad public who lack medical training and education.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A1. Population Densities in Israel

Appendix A2. Population Densities of Selected Areas:

| Area Number | Population Density (persons per sq. km.) |
|-------------|-----------------------------------------|
| Negev Desert (South) | <100 |
| Northern Negev | 612–621 | 100–249 |
| Beer Sheba Sub-District | 623 | 258 |
| Ashkelon Sub-District | 614 | 472 |

(continued on next page)
Appendix A3. A Map of COVID-19 Infection Rates in Israel, December 31, 2020. Source: https://clear-map.com/il

Appendix A4. Cumulative COVID-19 vaccination doses administered per 100 people. Source [30]: Available at: https://ourworldindata.org/covid-vaccinations
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