No. of research proposal

442-2020

Abstract

Scientific background: Measures employed to combat COVID-19 included public lockdowns and vaccination campaigns. Israel’s extensive public health system produced data which showed the real-world results of these measures.
Objectives: 1) Evaluation of the health and economic outcomes of the measures to cope with Covid-19. 2) Discover the method that provides reasonable cost-effectieness.
Methodology: Publicly available datasets from the Israeli Ministry of Health were used to model the mortality, infection rates, vaccination rates and additional parameters of the pandemic in Israel. Additional data from global sources were examined as well including data from the Oxford Blavatnik School of Government COVID-19 Government Response Tracker, which was used for quantitative data on government policies. Data on the Israeli economy were taken from the Central Bureau of Statistics. Disparate datasets were cleaned, processed, and combined. Various exploratory analysis techniques from visualizations to complex regressions were applied.
Findings: Our models demonstrate that the first lockdown prevented 1,022 Covid-19 deaths at a cost 36.4-38.6 Billion NIS. The second lockdown prevented 1,970 Covid-19 deaths and cost 18-21 Billion NIS. These lifesaving effects were observed with a time lag from the declaration of lockdown. The massive vaccination campaign cost 1Billion NIS and prevented 4,750 Covid-19 deaths. Therefore, the cost per prevented death is 10-36 million NIS with a national lockdown versus 210,000 NIS with massive vaccination.
Conclusions: Both lockdowns and vaccination campaigns were effective at lowering Covid-19 deaths. The cost to avoid one Covid-19 death is with massive elderly vaccination is 50-180 lower than with a lockdown.
Policy recommendations: Policies which target the elderly population for vaccines are both lifesaving and cost-effective.

No. of research proposal

442-2020

Section 3: Hebrew Abstract

כותרת מלאה של המחקר

הערכת עלות/מועילות של האמצעים השונים להתמודדות עם מגיפת הקורונה

חוקרים: **שם מלא ושיוך מוסדי**

ד"ר רונן ארבל, מכללת ספיר.
פרופ' יוסף פליסקין, אונ' בן גוריון בנגב

מילות מפתח

עלות/מועילות, תמותה קורונה

תקציר

תקציר שאורכו עד **200 מילים**, אשר יכלול כותרים אלה:)1(רקע)2(מטרות)3(שיטה)4(ממצאים עיקריים)5(מסקנות)6(המלצות / השלכות לקובעי המדיניות

)1(רקע
האמצעים שננקטו בישראל להתמודדות עם הקורונה ב2020)בעיקר סגר כללי ממושך(בוצעו ללא ניתוח עלות/מועילות. קמפיין ההתחסנות מסיבי של האוכלוסייה החל מ2021, עשוי להיות בעל יחס עלות/מועילות טוב משמעותית.

)2(מטרות
א. הערכת ההשפעה הכלכלית של צעדי מדיניות שונים בטיפול במגיפה אל מול תוצאי הבריאות שהושגו בישראל.
ב. איתור שיטה שתאפשר שיפור משמעותי של יחס העלות/מועילות של האמצעים לטיפול במגיפה.

)3(**שיטה**
א. ארגון בסיס נתונים הכולל את תוצאי הבריאות, מדדי סגר, ועלויות.
ב. מידול ההשפעה של האמצעים השונים לטיפול במגיפה על מדדי התמותה מקורונה.
ג. השוואת העלות למניעת מוות מקורונה בין האמצעים השונים)סגר מול חיסון(

)4(**ממצאים עיקריים**
א. הסגר הראשון מנע 1,022 מקרי מוות מקורונה, והסגר השני מנע 1,970 מקרים. קמפיין החיסונים מנע 4,750 מקרי מוות בחציון הראשון של 2021.
ב. עלות הסגר הראשון מוערכת ב36.4-38.6 מיליארד ,₪ והשני ב18-21 מיליארד .₪ לעומתם עלות החיסונים מוערכת ב1 מיליארד .₪
ב. העלות למניעת מקרה מוות אחד ע"י סגר היא בין 10-36 מיליון ,₪ לעומת ₪210,000 בלבד באמצעות חיסונים.

)5(**מסקנות**
א. הטלת סגר מלא הינו אמצעי שחורג מכל אמות המידה של עלות/מועילות.
ב. הקפדה על רמת חיסוניות גבוהה באוכלוסייה בסיכון)כדוגמת מתן הבוסטר(, הינו האמצעי המועיל והכלכלי ביותר למניעת מוות קורונה.

)6(**המלצות / השלכות לקובעי המדיניות**
לאור התמשכות מגפת הקורונה, הקפדה על רמת חיסוניות גבוהה של האוכלוסייה באופן רציף, תאפשר למנוע תמותה מהמחלה בעלות סבירה.

Section 4: Executive Summary- Hebrew

רקע

רקע רפואי

מגפת הקורונה התפשטה במהירות לכדי מגפה כלל-עולמית בתחילת 2020. המגיפה יצרה שיעורי תחלואה ותמותה קשים בחלק ממדינות העולם. ישראל נקטה במגוון אמצעים לטיפול במגיפה ונדמה כי הצליחה לשפר באופן משמעותי את תוצאי הבריאות של האוכלוסייה.

רקע כלכלי

למגפה יש השפעה הרסנית על הכלכלה העולמית לרבות המשק הישראלי. נטען כי האמצעים שננקטו בישראל להתמודדות עם המגיפה (לרבות סגר כללי ממושך) בוצעו ללא התחשבות מספקת במשמעויות הכלכליות שלהם והשלכות בריאותיות מעבר לקורונה. עקב כך נוצר נזק כלכלי עצום למשק שחלקו לפחות היה יכול להימנע, תוך פגיעה מינימלית בתוצאי הבריאות של האוכלוסייה.

האמצעים שננקטו בישראל להתמודדות עם הקורונה ב2020 (בעיקר סגר כללי ממושך) בוצעו ללא ניתוח עלות/מועילות. קמפיין ההתחסנות מסיבי של האוכלוסייה החל מ2021, עשוי להיות בעל יחס עלות/מועילות טוב משמעותית.

מטרות

א. הערכת ההשפעה הכלכלית של צעדי מדיניות שונים בטיפול במגיפה אל מול תוצאי הבריאות שהושגו בישראל.

ב. איתור שיטה שתאפשר שיפור משמעותי של יחס העלות/מועילות של האמצעים לטיפול במגיפה.

שיטה

א. ארגון בסיס נתונים ייעודי הכולל את תוצאי הבריאות, מדדי סגר, ועלויות, על בסיס מקורות ציבוריים.

ב. מידול ההשפעה של האמצעים השונים לטיפול במגיפה על מדדי התמותה מקורונה.

ג. השוואת העלות למניעת מוות מקורונה בין האמצעים השונים (סגר מול חיסון).

ממצאים עיקריים

א. הסגר הראשון מנע 1,022 מקרי מוות מקורונה, והסגר השני מנע 1,970 מקרים. קמפיין החיסונים מנע 4,750 מקרי מוות בחציון הראשון של 2021.

ב. עלות הסגר הראשון הוערכה ע"י משרד האוצר ב5.1 עד 5.4 מיליארד ₪ לשבוע. הסגר הראשון ארך 50 יום ,ולכן עלותו הכוללת מוערכת ב36.4-38.6 מיליארד ₪.

ג. עלות הסגר השני הוערכה ע"י משרד האוצר ב3 עד 3.5 מיליארד ₪ לשבוע. הסגר השני ארך 42 יום, ולכן עלותו הכוללת מוערכת ב18-21 מיליארד ₪.

ד. עלות קמפיין החיסונים בחציון הראשון של 2021 מוערכת ב1 מיליארד ₪.

ה. העלות למניעת מקרה מוות אחד ע"י סגר היא בין 10-36 מיליון ₪, לעומת 210,000 ₪ בלבד באמצעות חיסונים.

מסקנות

א. הטלת סגר מלא הינו אמצעי שחורג מכל אמות המידה המקובלות של עלות/מועילות.

ב. הקפדה על רמת חיסוניות גבוהה באוכלוסייה בסיכון (כדוגמת מתן הבוסטר), הינו האמצעי המועיל והכלכלי ביותר למניעת מוות מקורונה.

המלצות / השלכות לקובעי המדיניות

לאור התמשכות מגפת הקורונה, הקפדה על רמת חיסוניות גבוהה של האוכלוסייה באופן רציף, תאפשר למנוע תמותה מהמחלה בעלות סבירה.

מקורות (לא יותר מ-4).

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2. Rosen, B., Waitzberg, R., & Israeli, A. (2021). Israel's rapid rollout of vaccinations for COVID-19. *Israel Journal of Health Policy Research*, *10*(1), 1–14. https://doi.org/10.1186/s13584-021-00440-6.

3. How many lives do COVID vaccines save? Evidence from Israel. Ronen Arbel, Candace Makeda Moore, Ruslan Sergienko, Joseph Pliskin. medRxiv 2021.10.27.21265591; doi: https://doi.org/10.1101/2021.10.27.21265591.

4. Division of Chief Economist in the Treasury. Effect of Corona virus on the product, the deficit and, the dept. Retrieved December 1, 2020, from https://www.gov.il/BlobFolder/reports/development-and-income-forecast-corona/he/development-and-income-forecast-corona_files_forecastupdate_macro_april2020.pdf

Section 5: Comprehensive scientific report - English

1. Scientific background

Clinical aspects

Over the past century, humans suffered from several pandemics that impacted the entire world and shaped many policies. The Spanish flu in 1918 caused a loss of 40-50 million lives, HIV in 1981 that caused a loss of 25 million lives thus far, and the Swine flu in 2009 that is estimated to have taken 200,000 lives (1). Coronavirus disease 2019 (COVID-19), caused by the novel coronavirus (SARS-CoV-2), is the most recent pandemic which poses a global public health emergency. It first appeared in China in the last quarter of 2019, and it rapidly spread. It was declared a pandemic by the World Health Organization (WHO) in March 2020. According to the WHO situation report-77 published on April 6, 2020 (2), the number of globally confirmed cases exceeded 1.2 million, and more than 69,000 people had lost their lives. As of November 2021, over 250 million cases and 5 million deaths have been confirmed (3). The transmission of the novel coronavirus SARS-CoV-2 occurs via close contact with infected individuals' respiratory droplets (4). On March 16, 2020, Israel employed various means of coping with the epidemic, including declaring a nationwide lockdown that lasted a month and successfully improved the population health outcomes (5). A second lockdown was enforced on September 18, 2021 and lasted 30 days. The weekly number of deaths caused by COVID-19 following these measures' enforcement is presented in Figure 1. A national lockdown is defined by an Oxford Stringency Index (OSI) that exceeds 80% (6).

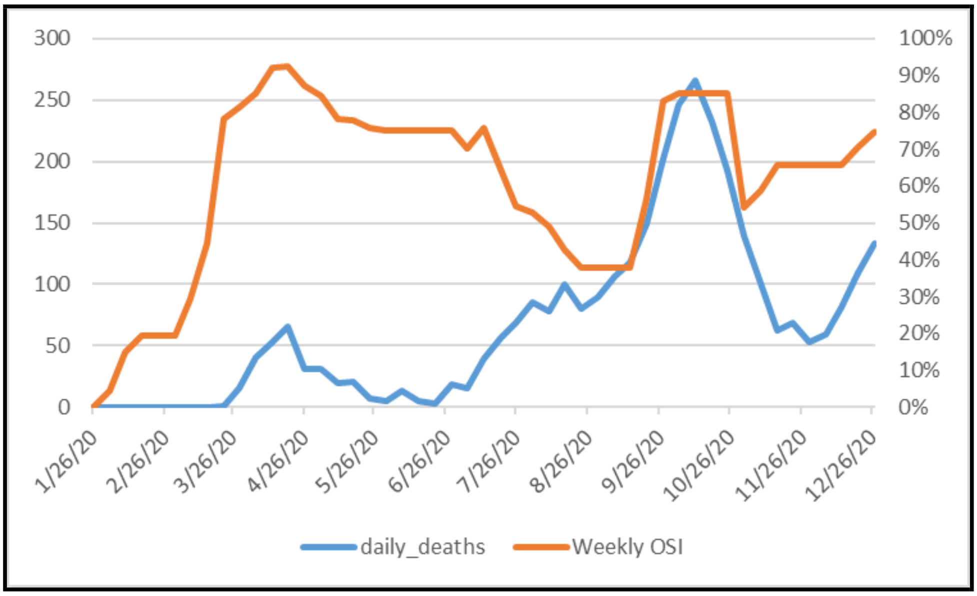


Figure 1. The weekly number of deaths caused by COVID-19 in Israel and the corresponding OSI level for the same week.

Economic aspects

COVID-19 imposes an economic burden in every country, including Israel. At the end of April 2020, the Division of the Chief Economist in the Treasury of Israel stated that while the growth rate of 2020 was estimated to be 3% before COVID-19, it was expected to be -5.4% in the aftermath (7). According to the Bank of Israel's financial stability report for the first half of 2020, the governmental policy's sole objective was saving lives. The measures taken to reduce the spread of COVID-19 caused a dramatic decrease in economic activity and affected economic stability. The expected economic forecast for the year 2020 changed in Israel and worldwide from favorable growth rates to negative ones, far more significant than in the global economic crisis in 2008-2009 (8). The gross domestic product (GDP) for the second quarter of 2020 was estimated to decrease by an annual rate of 28% (9). The World Bank (10) revealed that the pandemic will significantly impact emerging markets and developing countries that rely heavily on external financing, commodity exports, and tourism.

Health policies implemented to cope with COVID-19 spread around the world

Non-pharmaceutical interventions (NPIs) such as social distancing are crucial in reducing infection and spikes in COVID-19 cases, according to Prem et al. (11). The authors implemented an age-specific Susceptible-Exposed-Infected-Removed (SEIR) model to simulate the outbreak in Wuhan, China. The authors concluded that through NPIs, the magnitude of infections could be reduced, and the importance of this is mainly to reduce the pressure on health care systems. In the absence of treatment or vaccine, NPIs effectively contain the disease's spread. Countries that experienced recent infectious disease outbreaks, such as China, Taiwan, The Republic of Korea, and Singapore, were more prepared than the western countries (12). Lockdowns are an NPI measure, but not the only one; testing and contact tracing is an NPI measure applied in the Asian countries mentioned, which has helped limit spread.

Most western countries were not prepared for this kind of outbreak. Therefore, the most used NPI was lockdown; only after developing testing and tracing capabilities, governments started softening the lockdowns and implementing NPIs with less economic impact. Research by Barro et al. (13) estimated the loss of real GDP caused by influenza-related mortality to be between 6 to 8 percent in specific countries.

Many health policies have been implemented around the world with varying stringency of enforcement. According to Brodeur et al. (1), most countries have implemented external border restrictions and school closures. Cheng et al. (14) developed a Policy Activity Index and determined that the costliest policy to implement is school closure; social distancing, and mandatory business closure are the second most costly.

Methods used to measure the benefits and costs of the different means implemented to cope with the COVID-19 plague.

The subject of measuring the means implemented to cope with COVID-19 is still under development. Greenstone and Nigam suggested (15) to calculate the benefits in terms of preventing mortality cases. They first estimated the number of mortality cases prevented and then monetized the prevented cases. The estimated number of mortality cases was based on the Ferguson study (16) that used two scenarios: the first scenario included a mitigation scenario that combines home isolation of suspected cases, home isolation for individuals living in the same house of the suspected cases, and social distancing of elderly and individuals at high risk; and the second scenario was a no policy scenario. The prevented cases were then divided into nine age groups and then monetized using the United States (US) Government's Value of a Statistical Life - VSL (individuals' willingness to pay to reduce the risk of death) adjusted for age. Following this approach, the authors found that 1.7 million mortality cases could have been avoided in the US mitigation strategy. The authors have monetized this clinical benefit to an economic benefit to the extent of 8 trillion US dollars. This approach's main limitation was that the economic burden associated with these mitigation strategies was overlooked, specifically, their effect on the labor market, private consumption, and GDP.

Broek-Altenburg and Atherly (17) evaluated such measures' benefits in terms of quality-adjusted life-years (QALYs). Firstly, the authors used the median age of death caused by COVID-19 in Italy at 80.5 and used American citizens' life expectancy at that age. Secondly, they estimated the cost of implementing a moderate social distancing policy as the federal incentive package's value in the US valued at 1 trillion US dollars. According to their calculations, the value per QALY in the US was estimated to be between $75,000 and $650,000.

Kim and Neumann (18) compared those two approaches and pointed out the importance of assessing all the benefits and costs in implementing the means used to cope with COVID-19. These include health outcomes, healthcare costs, labor market, consumption, legal/crime justice, education, and environment. The authors emphasized that research in this area should detail which costs and benefits were considered and excluded from the analyses.

Thunström et al. (19) compared the benefits and costs from 'flattening the curve' in the US through social distancing policies defined as the avoidance of gathering of 10 or more people and travel restrictions that resulted in a temporary closure of schools, universities, and public events. They defined benefits as the number of lives saved due to social distancing. They monetized them using the average willingness to pay for a reduction in mortality risk. The costs were defined as the difference in GDP loss' present value with and without social distancing. The outcome was the benefit-cost ratio between the value of lives saved and the total GDP loss. They reported a net benefit of $5.16 trillion from social distancing. The study had several significant limitations, including using a single policy package, ignoring the distributional impact of such measures on different groups within the society, and the probability of a second wave due to preventing herd immunity through social distancing.

Miles et al. (20) conducted a cost-benefit analysis of the UK lockdown and compared the results with European countries with similar healthcare resources and income. The lockdown's economic impact was measured as a percentage loss in GDP and the benefits as gain in life expectancy adjusted for poor health and quality of life. To monetize the lockdown's health benefits, they applied a value of £30,000 per QALY, the maximum NICE threshold. The significant finding of this cost-benefit analysis was that no matter how many lives are saved, even at the high estimate of 400,000 lives saved, the cost always exceeded the benefits. The authors also applied multiple one-way scenario analyses of GDP loss from 9% to 25%, resulting in a net benefit of -£125 billion to -£475 billion at 400,000 lives saved. This cost-benefit analysis concluded that the lockdown policy implemented in the UK was not beneficial since the costs exceeded the benefits and recommended targeted restrictions on groups at high risk instead of the whole population.

2. **Research objectives**

1. To evaluate the effectiveness of various measures on Covid-19 mortality.
2. To discover the most cost-effective method for reducing Covid-19 mortality.

3. Methodology

Study population

The entire Israeli population.

Study design and perspective

An exploratory economic evaluation was conducted, using a decision-analytic model to investigate the cost-effectiveness of the measures to manage the COVID-19 outbreak. The design was from the perspective of the Israeli government.

Strategies

The measures to cope with COVID-19 in Israel that were be analyzed in the study are as follows:

- Nationwide lockdowns, defined by an Oxford Stringency Index of 80% or higher (21), which included school closure, workplace closure, cancelation of public events, restriction on gatherings, closure of public transport, requirements to stay at home, restriction on internal movement and traveling, and international traveling control.
- Limited public restrictions, defined by an Oxford Stringency Index <80 but with some limitations on full public life which typically included closure of some public events. The first examples of limited restrictions occurred in March 2020; on March 10, 2020, Israel began enforcing the closure of public spaces and restrictions on gathering and on March 16, 2020, Israel enforced workplace closures.
- Mass vaccination campaigns, defined as efforts to vaccinate the general adult population.

The time horizon for economic evaluation

In this research, the time horizon for the economic evaluation was usually held at three months due to the apparent impact of lockdown on mortality.

Discount rate

Due to the short time horizon (3 months), cost and benefit estimates were not discounted.

Outcomes

Primary outcome: Cost per COVID-19-related mortality case prevented.

Data sources, collection, and encoding method

For the study, several dedicated databases were constructed. All the clinical and economic data from the sources detailed in Table 1 were integrated in these databases. The variables analyzed are only those obtained from a reliable and publicly available data source.

Table 1. Clinical and economic data included in the analyses

	Variables	Description	Source
Clinical variables	Daily mortality due to COVID-19, age, sector, gender, death date		Ministry of Health (22)
Policy-related variable	Overall Stringency Index value (0-100%)	Uses 17 indicators categorized into four categories: 1. Containment and closure policies 2. Economic policies 3. Health system policies 4. Miscellaneous policies Values range 0-100%	Oxford University (6)
	Number of daily tests		Ministry of Health (23)
	Number of daily vaccinations		Ministry of Health (23)
Economic variables	Quarterly value of GDP for the years 2020, 2021	GDP values and economic forecast	Central Bureau of Statistic (8, 24)

Data Organization

All data were extracted, analyzed, cleaned, and organized into several unique databases, which we made public. The code for the data processing is available publicly on our Github site (https://github.com/maxcorlabs/Corona_Cost_Effectiveness).

The following datasets were published publicly on Zenodo (badges of the DOIs for several groups of datasets are hyperlinked below).

COVID-19 vaccination data in Israel by age over time until August 2021:
DOI 10.5281/zenodo.5625487

Four tabular datasets which are derived from publicly available Israel Ministry of Health data but processed for analytics about uptake in different age groups over time are included on this DOI. They cover the mass vaccination campaign for COVID-19 until August 2021.Three of the datasets are of a specific ordinal vaccination, i.e., datasets of only first, second or third doses.

Data on COVID-19 in Israel:
DOI 10.5281/zenodo.4715552

A dataset created from processing various official Israel Ministry of Health datasets and the Oxford Stringency Index for Israel by MaxCor labs from the start of the pandemic until April 1, 2021, is included in this DOI. Hospital data on patients, testing result data, vaccination data and OSI are all in one dataset.

MaxCor Labs COVID-19 in Israel Datasets on COVID-19 from 2020 to April 2021:
DOI 10.5281/zenodo.4741933

Three separate datasets which built on data made from processing various official Israel Ministry of Health datasets and the Oxford Stringency Index for Israel along with a code notebook of the calculations, and written document explaining calculations are included on this DOI. Hospital data on patients, testing results data, vaccination data and OSI are included, summed for daily, weekly, and monthly datasets.

COVID-19 symptoms over time, Israel:
DOI 10.5281/zenodo.5638497

This dataset was created by processing a larger dataset from the Israeli Ministry of Health of symptoms reported to testing centers. The dataset is for only COVID-19 positive testing patients. The dataset has been organized on a daily basis.

Visualizations from the data were made public in the lab's public Tableau available at the following link:

[**https://public.tableau.com/app/profile/maxcor3014**](https://public.tableau.com/app/profile/maxcor3014)

Measurement of effectiveness

The primary outcome of this research is the health benefits from implementing differing health policies in Israel. This outcome was primarily measured by the total number of deaths avoided due to the implementation of health policies according to the stringency index and within time frames of approximately 3 month periods.

Prediction Models

We developed several prediction models to calculate the number of deaths avoided from the measures implemented in Israel. Our simplest models were based on various naïve time series models and other simpler models included curve fitting and polynomial regressions. Other models used multiple data inputs in more complex machine learning models, e.g., random forest regressions. All models used real world observational data as inputs.

We approximate lives saved by lockdowns by the formula:

$$ {}_{M=y}^{M=\ y+90} Dm + C \ - \ {}_{N=x}^{N=\ x+90} Dn + C' \ . $$

Dm denotes daily deaths without a lockdown, summed from the first day of the period without lockdown (y) until y+90. Dn denotes daily deaths with a lockdown, summed for each day N from the first day of lockdown (x) until x+90. C denotes the mortality rate when entering the lockdown, calculated as the mean number of daily deaths in the first 30 days of the lockdown. C' is the adjustment of C to mortality rates outside of Israel.

Measurement of costs

The cost of implementing the measures was defined as the loss in GDP in new Israeli shekels for the policy's period.

To monetize the primary outcome, we divided the loss in GDP by the total number of mortality cases prevented, resulting in the cost per mortality case prevented.

Study model rationale and assumptions

The variables presented in Table 1 have been chosen to meet two conditions:

1. The variables are core costs or benefits indicators that are commonly used to evaluate the cost-effectiveness of measures implemented to cope with COVID-19.
2. The variable has a reliable and publicly available data source.

Only measures implemented in Israel were included in this study. We did not consider the impact of the measures to cope with COVID-19 spread on the sectors presented in Table 2 since they do not meet the two conditions mentioned above.

Table 2. The implication of health policy measures that are excluded from our analyses

Sector	Type of impact on the sector
Legal/Criminal justice	**Positive Impact** • Impact on motor-vehicle accidents due to reduced road traffic
	Unknown Impact • Impact on crime rates due to restricted social engagement
Education	**Unknown Impact** • Impact on student education attainment through online learning
Environment	**Positive Impact** • Reduced air pollution due to reduced road traffic

The association between OSI and daily mortality

Distributional lag model – Since the effect of OSI on mortality is not limited to the time observation, we used a time-series based model to assess the relationship between OSI and mortality rate, and ultimately a distributional lag model (assuming a 30-day lag between lockdown and effect on mortality)

The association between OSI and daily infections

Distributional lag model – Since the effect of OSI on infection rate was not limited to the time observation, we used a distributional lag model to assess the relationship between OSI and infection rate.

Scenario analyses

Multiple scenario analyses were completed by changing the variables vaccination counts, and government stringency.

Identifying possible biases and methods to reduce their impact:

Human-caused MOH reporting data errors were addressed using data published 30 days before the last update. Where appropriate, data was smoothed or examined on a weekly basis in order to avoid bias caused by different reporting patterns on weekends and holidays. In addition, to eliminate loss or gain caused by specific events such as holidays, we compared quarterly values of GDP of previous years.
Moreover, the study does not address all the economic implications of the strategies to cope with COVID-19, including crime/legal, environment, and education, because this data is not publicly available. Thus, the conclusions are drawn only regarding the data available, which is acknowledged. Finally, the definition of COVID-19 related mortality may have undergone changes and thus affected the number of deaths recorded.

4. Findings

Initial Analysis- First wave

Due to the urgency for decision-making in the first wave of COVID-19 in Israel, we conducted a preliminary analysis in the first weeks of the study. We estimated the cost to avoid one Covid-19 death at 39 million NIS. The results were distributed to the professional public health community and the COVID-19 committee of the Israeli parliament. The report (in Hebrew) is attached as an appendix. Figure 2 depicts our analysis:

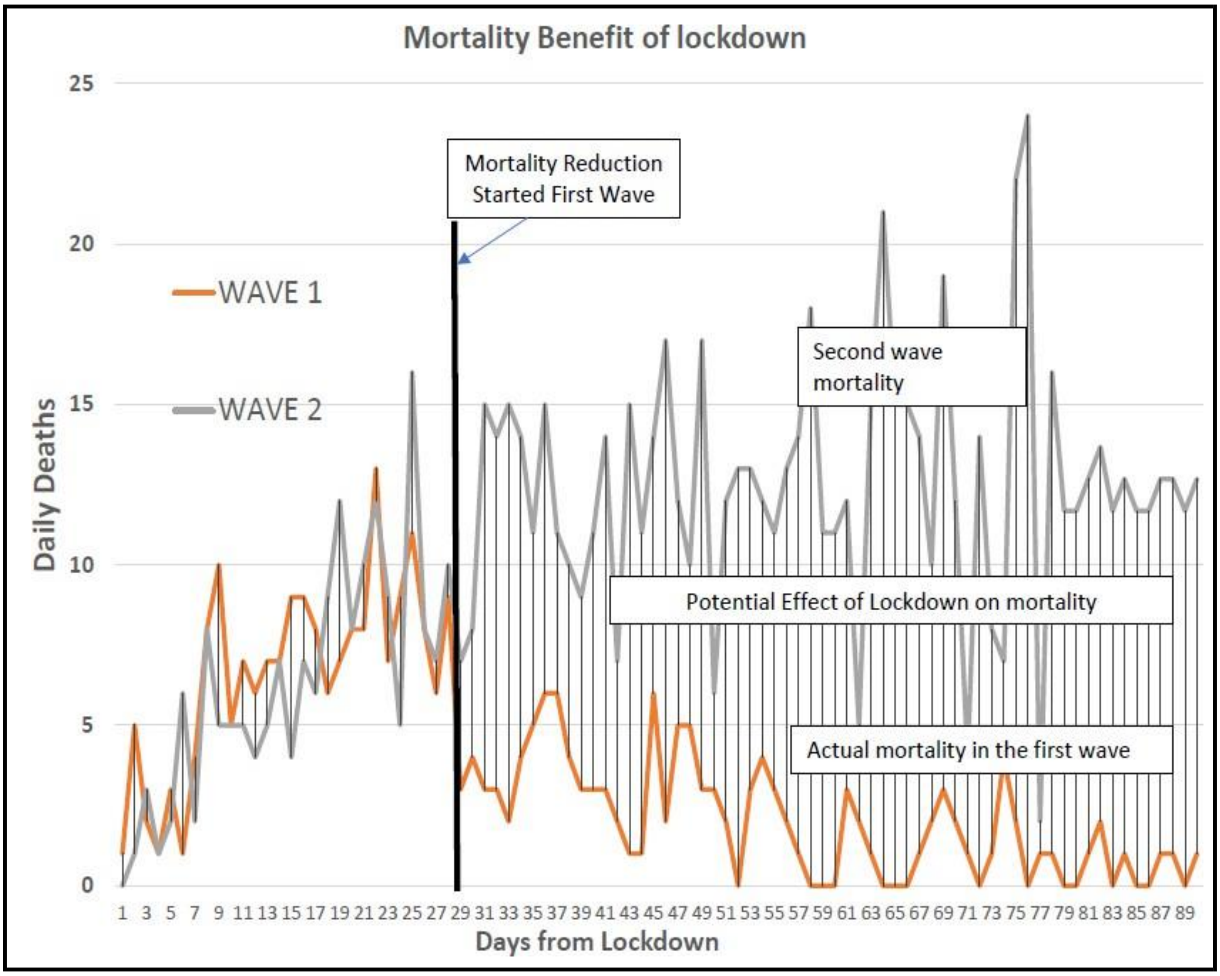


Figure 2: Mortality Benefit of the First Lockdown

The graph depicts our analysis: The orange graph depicts the actual mortality during the first wave. The grey graph depicts mortality rates in the second wave without lockdown. The integral of the differences between the two graphs is an estimation of the Covid-19 deaths avoided by the lockdown, using the formula described in the methods.

OSI and lock-downs

Government stringency did affect the spread of the disease, but with some time lag. The reproductive rate R and government stringency numbers are visualized over time in Figure 3.

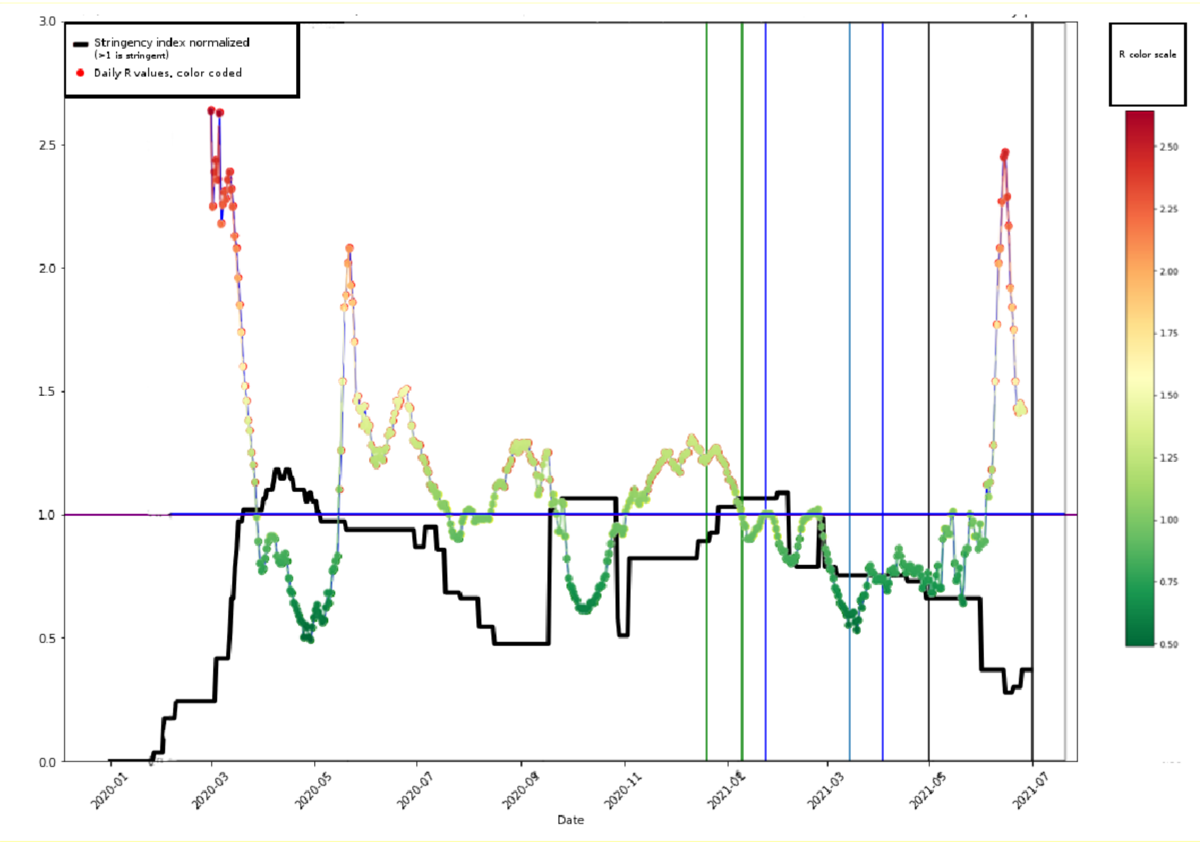
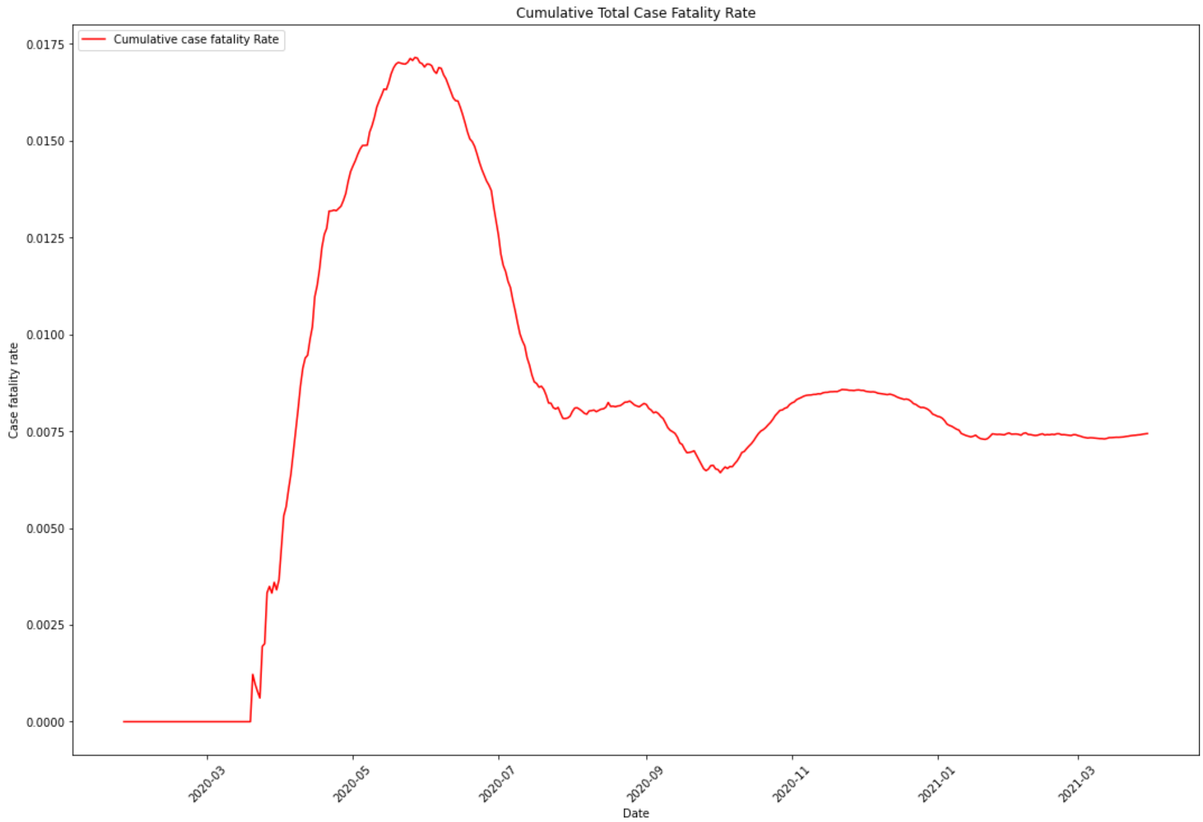


Figure 3: Normalized government stringency and R in Israel

Using Spearman's correlations with computational methods of modeling time shifts, we determined that the most significant correlation between government action before the vaccination campaign and R occurred 9 days after government action. Using the data before the vaccine campaign, the correlation for this time lag was negative 0.59. To put this finding in plain language when the government raised stringency, the R began dropping, and when the government lowered stringency the R rose, but these effects were maximal at about nine days after government action. The inverse correlation between government action and R was not maintained after very significant numbers of people were vaccinated. As vaccinations rose, government stringency dropped, but R remained relatively low until the Delta variant appeared at the end of June 2021.

Infections did not translate into deaths at the same rate throughout the epidemic. Case fatality actually fell significantly after the start of the pandemic as seen in Figure 4.



<u>Figure 4: Cumulative case fatality rate in Israel over time from the start of the epidemic</u>

Despite changing case fatality rates (, effects of government actions were observed to be carried through to affect deaths as well. Lockdowns were correlated with dropping deaths with a time lag of a couple of weeks before deaths had dropped substantially. Through various methods of computational modeling, a life-saving effect was verified.

This effect can be illustrated by examining models without lockdown, as illustrated in Figure 5:

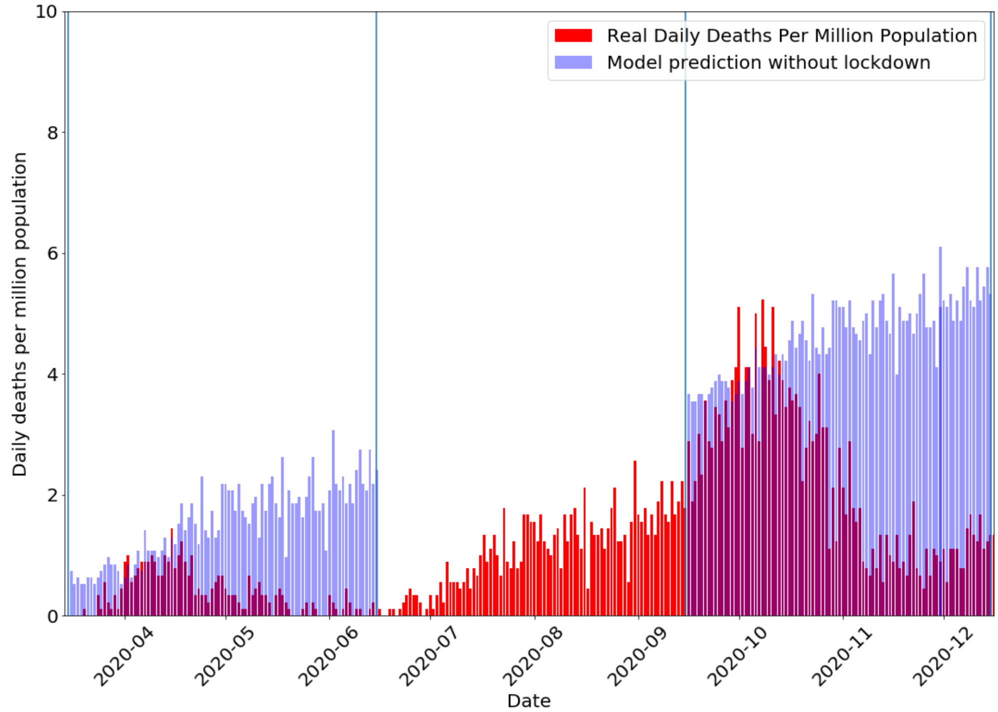


Figure 5: Real daily deaths from COVID-19 per million population in red, quarters with lockdown include modeling of deaths without lockdown based on real deaths in quarter without lockdown in blue

The Israeli lockdowns began on Mar 15 and Sept 15, 2020, and were imposed for 50 and 42 days, respectively. C (the mortality rate when entering the lockdown) for the first and second Israeli lockdown were 4.6 and 31.9 and saved 1,022 and 1,970 covid-19 deaths, respectively.

Cost of National Lockdowns and associated cost per avoided death

The cost of the first national lockdown was estimated at 5.1 to 5.5 billion NIS for each week. Therefore, the total cost of the first lockdown was 36.4-38.6 billion NIS. With an estimated 1,022 covid-19 deaths avoided, the cost per avoided death is 35,644,395-37,741,124 NIS.

The cost of the second national lockdown was estimated at 3 to 3.5 billion NIS for each week, as it was implemented during the holiday period. Therefore, the total cost of the second lockdown was 18-21 billion NIS. With an estimated of 1,970 covid-19 deaths avoided, the cost per avoided death is 9,137,056 - 10,659,898 NIS.

Massive Vaccinations

The real-world data reflects that the Israeli vaccination campaign proceeded as planned in terms of targeting older age groups first (26,27). Deaths were lowered by the vaccination campaign. In fact, there were even fewer than predicted deaths (28) given no changes in government policy. This finding is substantial because the government policy actually loosened measures against the disease, and the vaccination campaign still led to dropping death rates. The distribution of infections was not balanced with the younger population groups making up more cases before and after the vaccination campaign, but the distribution of deaths changed. Case and death distributions are shown in Figure 6 for two periods before 90% of the 70+ population was vaccinated and one period after, until the end of June.

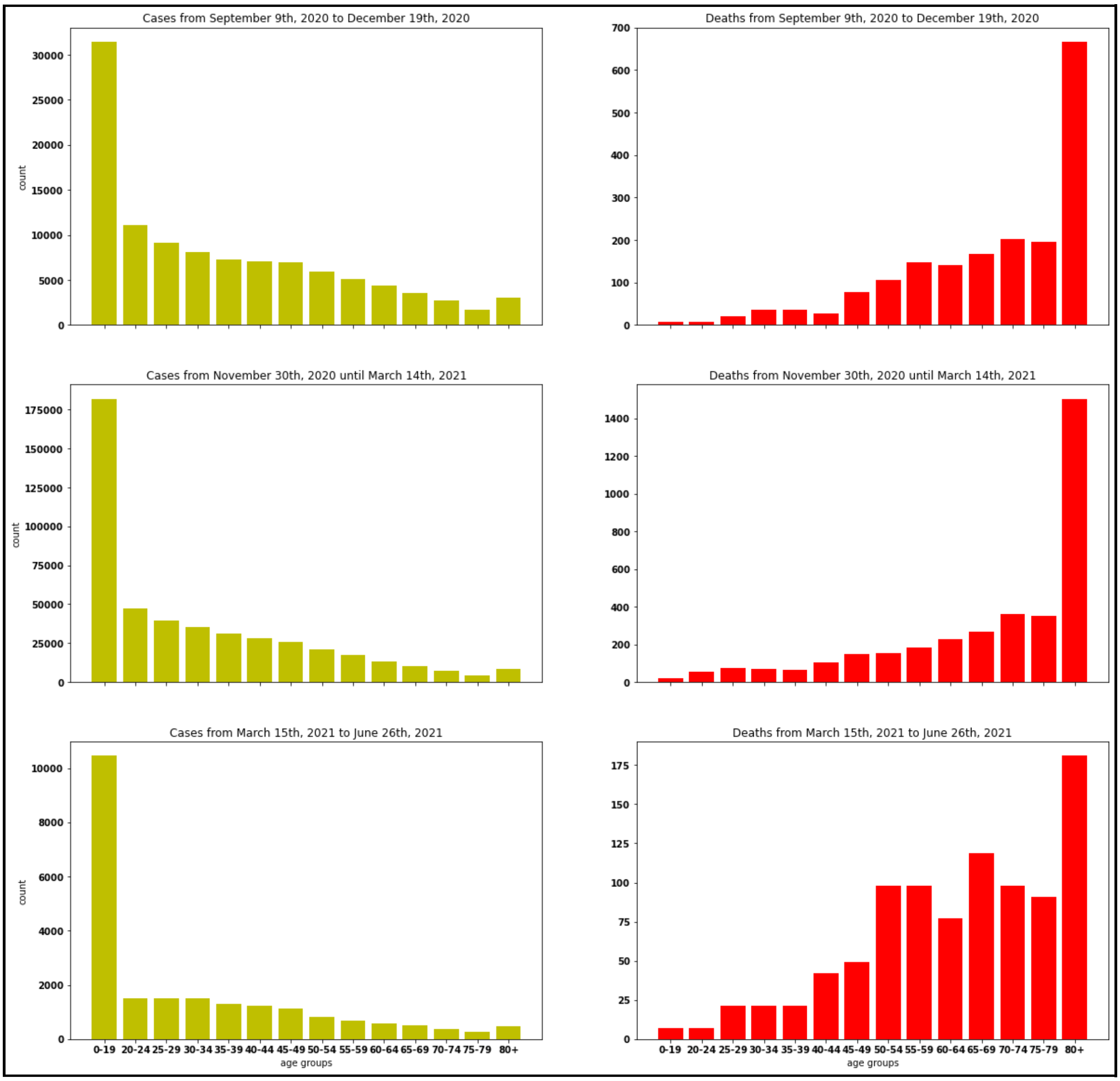


Figure 6: Selected case and death distributions in periods before during and after mass vaccination campaigns.

Without any vaccines, all other things being equal, including the lowered government stringency, the expected number of deaths in the period after the mass vaccination campaign had vaccinated most of the vulnerable population would have been 5,120 in the population over 70 by our modeling (which modeled the period until the Delta variant became predominant at the end of June 2021). This older population made up 61% percent of deaths before vaccination and about 40% of deaths afterwards. Therefore, a conservative estimate would put deaths without the vaccination campaign and the same government policy of lowering stringency at around 10,000. The confirmed deaths were 370 in the elderly population and 930 overall, resulting in the estimated prevention of 4,750 Covid-19 deaths.

Cost of Vaccinations and associated cost per avoided death

The cost of the first primary vaccination campaign during early 2021 was estimated at 1 billion NIS. With an estimated of 4,750 covid-19 deaths avoided, the cost per avoided death is 35,644,395-37,741,124 NIS.

The cost of the second national lockdown was estimated at 3 to 3.5 billion NIS for each week, as it was implemented during the holiday period. Therefore, the total cost of the second lockdown was 18-21 billion NIS. With an estimated of 4,750 covid-19 deaths avoided (28), the cost per avoided death is 210,256 NIS.

5. Discussion and Conclusions

Both lockdowns and vaccination campaigns were effective in lowering infections and deaths. Vaccination campaigns were a more cost-effective approach to COVID-19 containment once the cost on the overall economy of lock-downs was factored in. While the vaccination campaigns have lowered deaths among the old, older people still made up a disproportionate percentage of deaths from COVID-19 in Israel at the end of summer 2021.

The most pressing additional findings of the Maxcor lab's various studies are that the virus in Israel is changing towards more infectious variants.

6. Policy Implications and Recommendations

Health Data Policy Recommendations:

The Israeli Ministry of Health has done a laudable job providing much data publicly during the present unforeseen crisis caused by COVID-19. However, there are a few specific practices which this ministry and other government bodies could improve in terms of managing data not only for COVID-19 but also for other future epidemics.
At the beginning of the crisis, it was unclear which datasets were of record, and would remain locked. As disease tracking has become more routine, it appears that

information available on the dashboard is up to date, but not necessarily stable, and information available in datasets on data.gov is more stable.

We suggest that in addition to the dashboard, the Israeli Ministry of Health publish more stable datasets in more developer friendly formats and increase database administration personnel.

Unfortunately, an effort to create more accessible databases such that research groups could directly query them to produce tabular data might have unacceptable risks in terms of patient privacy and cyber-security. On the other hand, the limited data publicly available from the Israeli Ministry of Health is tabular data which required significant processing, sometimes had only Hebrew text, and sometimes presented approximations where precise data could have been published, e.g., "<15" for a number of vaccinations in an age group per day. New computational methods used by Maxcor and other advanced research groups including various forms of machine learning are better served with precise numerical data where available. In order to avoid discrepancies in data, more collaboration between the Ministry of Health and research labs such as Maxcor should be incentivized.

At present, not only is very limited data available, but researchers including those at the Ministry of Health are often de-incentivized from sharing data publicly or even with other research groups. We recommend at least two interventions: financial bonuses for collaboration and data sharing, and dedicated database management personnel who help circulate data. A targeted intervention of financial bonuses for collaboration and data sharing between research groups might lead to more data sharing, which would allow more research groups more possibilities in terms of research on COVID-19 related data. Dedicated additional database administrators who works only as liaisons between the Israeli Ministry of Health and legitimate infectious disease, public health or health policy research groups could allow research groups to attain datasets formulated to help answer their research questions. Such personnel should also work as a liaison with the Central Bureau of statistics, the army, and possibly other public institutions to integrate datasets. Database management capable staff are in high demand (thus exceptionally well renumerated) and cannot be easily produced through class-room education as the job requires skills learned through practical experience. Thus, it is highly recommended to add additional staff in this area to prepare for future epidemics and pandemics.

Public Health Policy Recommendations

In striving to create the best possible public health outcomes for the Israeli public, policy makers must weigh the financial effects of health policy carefully. Measures against other epidemic in Israel have not led to such negative financial consequences as the initial emergency measures against COVID-19 which involved lockdowns of public life. The results of such financial consequences will be seen for decades to come in every area of life including public health.

Although the mass vaccination campaign was successful, as the Delta variant appeared, deaths began to rise in spite of high vaccination rates. Scientific debate about to what extent this rise was due to vaccinations wearing off, and to what extent the Delta variant was less preventable with the current vaccination regime continues. Nonetheless, we expect more variants of variable sensitivity to the present vaccines to appear in Israel. If new variants are more infectious as the Alpha variant was (reference our Alpha pub), we expect them to become dominant strains causing the majority of infections.

Based on our measures of the economic impacts of various strategies we recommend that actions which exclude public lockdowns should be used against the epidemic as it unfolds including education campaigns, increased research and mass vaccination campaigns before public lockdowns are considered. We also recommend that targeted closure measures are undertaken before complete lockdowns are instituted. Our data analysis shows that increasing stringency has an inverse effect on disease spread whether or not the stringency is high enough to be considered a complete lockdown.

An additional measure in the fight against COVID-19 which we recommend is increased surveillance with specificity for mutations in the virus. As our group's research has explored, new strains of COVID-19 may be more infectious, more deadly or both. We therefore recommend continued surveillance of virus strains as the virus continues to evolve paired with continued research on the real-world effects. This surveillance should be integrated with similar surveillance efforts in the occupied Palestinian territories. Our research has shown that there has been a change in presenting symptoms of the disease over time (32), thus we recommend continued tracking of symptoms, and funding research which examines the correlations between new symptoms, newly predominant symptoms, and new strains.

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Supplement 1: Preliminary Analysis, before the first lockdown in Israel

הערכת עלות/מועילות של האמצעים השונים להתמודדות עם מגיפת הקורונה

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(מחקר במימון המכון הלאומי לחקר שירותי הבריאות ומדיניות הבריאות 20/442)

תקציר ממצאים ראשוניים

רקע

מגפת הקורונה התפשטה במהירות לכדי מגפה כלל-עולמית בתחילת 2020. המגיפה יצרה שיעורי תחלואה ותמותה קשים בחלק ממדינות העולם. ישראל נקטה במגוון אמצעים לטיפול במגיפה ונדמה כי הצליחה לשפר באופן משמעותי את תוצאי הבריאות של האוכלוסייה במהלך הגל הראשון. אולם, האמצעים שנקטו בישראל להתמודדות עם המגיפה (לרבות סגר כללי ממושך) בוצעו ללא התחשבות מספקת במשמעויות הכלכליות שלהם. עקב כך נוצר נזק כלכלי עצום למשק שחלקו לפחות היה יכול להימנע, תוך פגיעה מינימלית בתוצאי הבריאות של האוכלוסייה.

כחודשיים לאחר פתיחת הסגר הכללי נצפתה עליה בקצב ההדבקה, התחלואה והתמותה, ובספטמבר 2020 נטען כי רק סגר כללי שני יכול למנוע ולהוריד את קצב התחלואה והתמותה. בוצעו מספר הערכות של העלות הכלכלית של הסגר אשר נעה בין חצי מיליארד למיליארד שקל ליום אך לא נבדקה עלות/מועילות של הסגר. לאור זאת ישם צורך דחוף ביותר להעריך את יחס העלות/מועילות של סגר כזה. תקציר זה מציג ממצאים כמותיים ראשוניים של עלות/מועילות סגר כללי למניעת תמותה מקורונה.

שיטות

<u>הערכת עלות</u>

הנחת המוצא היא כי הסגר השני ייארך 30 יום, משך המקובל בעולם כמינימום הנדרש לצורך השפעה על התחלואה והתמותה, ולצורך הקבלה לניתוח נתוני הסגר הראשון. הערכת עלות נאמדה במונחי אובדן התמ"ג, למשך רבעון קדימה, על-פי ערך אובדן התמ"ג בסגר הראשון, על-פי הערכות הכלכלנית הראשית של משרד האוצר ודיווחי הלשכה המרכזית לסטטיסטיקה. יש לציין שתקופת הסגר הראשון כללה גם היא תקופת חגים, כמו הסגר השני. הערכת עלות זו הינה הערכת חסר, מכיוון היא אינה מביאה בחשבון נזקים כלכליים מעבר לטווח של רבעון אחד', ולא מקים כלכליים וחברתיים שאינם נמדדים ישירות בהשפעה על התמ"ג., כגון עליה באלימות בתוך המשפחה.

<u>הערכת מועילות</u>

הערכת המועילות של הסגר השני מבוססת על המועילות בהפחתת תמותה של הסגר הראשון. הסגר הראשון השפיע על הירידה בתמותה החל מחודש ועד כשלושה חודשים מהפעלתו (גרף 1), ולכן היכולת לחזות את השפעת הסגר השני מעבר לטווח זה מאד נמוכה, ותלויה במגוון רחב של גורמים שלא נותחו בשלב זה של המחקר. נתוני התמותה ברמה היומית נאספו מדיווחי משרד הבריאות. הערכת המועילות של הסגר לגבי התמותה הינה הערכת יתר, מכיוון שאינה מתחשבת

בהשפעת הסגר על התמותה בתחומים שאינם קשורים לקורונה, כגון עליה בהתאבדויות, והימנעות מטיפולים מצילי חיים, בשל היעדר נתונים בנושאים אלו, בנקודת זמן זו.

תוצאות

<u>עלות</u>

העלות הצפויה של הסגר מוערכת באובדן תמ"ג של 7% ברבעון (28% שנתי), וסה"כ כ25 מיליארד ₪, בדומה לאובדן התמ"ג שנוצר עקב הסגר הראשון.

<u>מועילות רפואית</u>

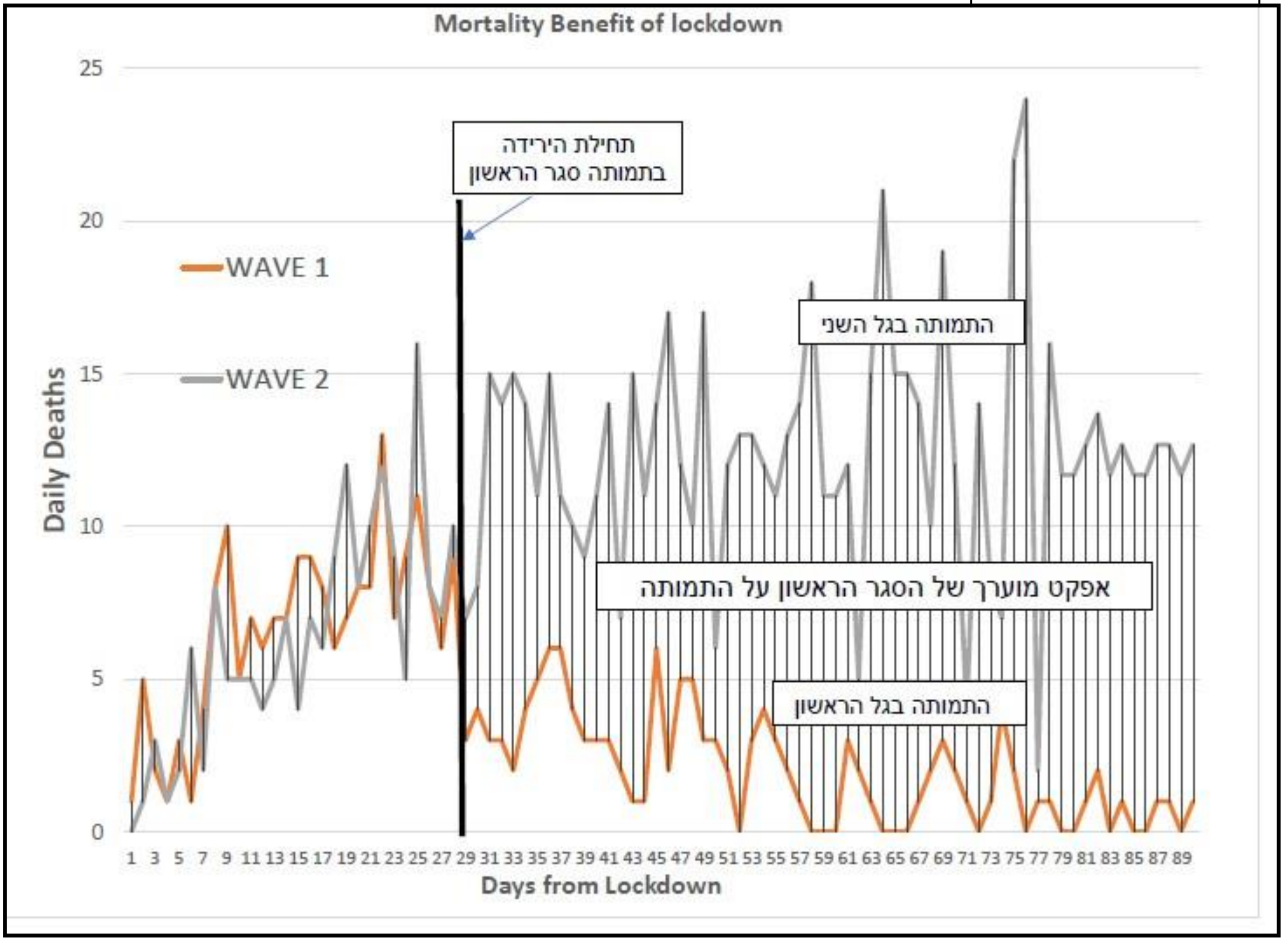
על-פי נתוני התמותה בסגר הראשון, בחודש הראשון של הפעלת הסגר השני לא צפוי שיפור בנתוני התמותה. החל מהחודש השני צפויה מניעה של 291 מקרי מוות (ממוצע של 9.7 ליום). בחודש השלישי צפויה מניעה של 350 מקרי מוות נוספים (11.7 מקרים בממוצע ליום), ובסה"כ 641 מקרי תמותה. תרשים 1 מציג את התחזית הצפויה של מקרי התמותה עם וללא סגר, על בסיס ההפרשים בפועל בשיעור התמותה היומי בין הגל הראשון והגל השני.

<u>יחס עלות/תועלת</u>

העלות למניעת מקרה תמותה יחיד מקורונה ע"י הפעלת סגר כללי במדינת ישראל הינה לפחות 39 מיליון ₪.

מסקנות

למרות הערכת החסר של העלות, והערכת היתר של המועילות, ממצאים ראשוניים של מחקר זה מדגימים יחס עלות/המועילות של הטלת סגר כללי חורג בסדרי גודל מכל נורמה מקובלת בעולם ליחס עלות/מועילות של השקעה בבריאות. מומלץ למקד את ההשקעות באמצעים שיועילו להפחתת התמותה בעלויות פחותות בהרבה: מיקוד הסגר למוקדי הדבקה כגון מקומות סגורים, ושיפור יכולת מערכת הבריאות להתמודד עם תחלואה רבה: הגדלת קיבולת טיפול נמרץ בבתי החולים, והגדלת היכולת לטפל בקהילה בחולים קלים.


Mortality Benefit of lockdown
25
20
15
10
5
0
Daily Deaths
WAVE 1
WAVE 2
תחילת הירידה
בתמותה סגר הראשון
התמותה בגל השני
אפקט מוערך של הסגר הראשון על התמותה
התמותה בגל הראשון
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89
Days from Lockdown