Adjusting COVID-19 Reports for Countries' Age Disparities: A Comparative Framework for Reporting Performances

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Abstract

Objectives: The COVID-19 outbreak has impacted distinct health care systems differently. While the rate of disease for COVID-19 is highly age-variant, there is no unified and age/gender-inclusive reporting taking place. This renders the comparison of individual countries based on their corresponding metrics, such as CFR difficult. In this paper, we examine cross-country differences, in terms of the age distribution of symptomatic cases, hospitalizations, intensive care unit (ICU) cases, and fatalities. In addition, we propose a new quality measure (called dissonance ratio) to facilitate comparison of countries' performance in testing and reporting COVID-19 cases (i.e., their reporting quality).

Methods: By combining population pyramids with estimated COVID-19 age-dependent conditional probabilities, we bridge country-level incidence data gathered from different countries and attribute the variability in data to country demographics.

Results: We show that age-adjustment can account for as much as *a 22-fold difference* in the expected number of fatalities across different countries. We provide case, hospitalization, ICU, and fatality breakdown estimates for a comprehensive list of countries. Also, a comparison is conducted between countries in terms of their performance in reporting COVID-19 cases and fatalities.

Conclusions: Our research sheds light on the importance of and propose a methodology to use countries' population pyramids for obtaining accurate estimates of the healthcare system requirements based on the experience of other, already affected, countries at the time of pandemics.

Keywords: COVID-19; population pyramids; infectious disease; conditional probability; reporting performance; pandemic.

Introduction

The first COVID-19 outbreak took place in the city of Wuhan in the Hubei province of China. Despite strict and robust prevention measures taken in the city, the virus has spread the rest of the world in a matter of a few weeks. Within three months, the World Health Organization (WHO) declared the outbreak a pandemic. While some more significantly than others, the virus has taken its toll on all countries with no exception. The global impact of COVID-19 has been very profound and probably unprecedented since the Spanish flu (H1N1 influenza circa 1918). Due to the novelty of the virus, and the nonexistence of vaccination, health professionals have been trying to cope with the pandemic using symptomatic treatment regimes.

Many governments are seeking out forming different strategies that involve mitigating the spread until a method of prevention or a well-defined, and a successful treatment regime is found (1). The main focus of such mitigation effects is to alleviate the burden on healthcare systems by spreading out the diffusion of cases over a more extended period of time. While trying to achieve this, governments also face many uncertainties. One such uncertainty involves the absence of proven methods to accurately estimate the potential demand for healthcare services (2,3).

At the time of this paper's writing, several governments, such as Italy and Spain, already had over 100% health services capacity utilization, while others were about to experience a similar influx of critical patients. It is clear that governments are in need of better understanding the dynamics of the spread for optimal or near-optimal resource allocation decisions. Unfortunately, due to the emergency and the gravity of the pandemic, and the lack of scantily found hard evidence causes, such decisions have been made through the seat-of-the-pants approaches.

Perhaps one of the reasons behind the lack of evidence is that there is no obvious way to map reports and studies pertaining to one country into another. Many regional differences make this mapping and transfer of the learnings and knowledge over to another domain particularly difficult. For the case of COVID-19, gender and age of the patient populations seem to be among the key drivers of such differences. Academics are acting swiftly to enrich the medical literature by reporting their findings on the virus-related population characteristics, diffusion patterns, treatment regimes, case dynamics, hospitalizations, ICU usages, and fatalities(4–7).

In this paper, as the first objective, we build on the studies and reports that involve age-based clinical fatality risks (CFR), infection fatality risks (IFR), hospitalizations, ICU usages, and fatal outcomes. Using the latest literature as well as expert opinions, we attempt to combine data from different regions in order to estimate and highlight: (i) country-level differences, and (ii) healthcare system demands for individual age groups. Specifically, using the data from six different countries, we study the spread of the virus for different age groups.

It is obvious that different countries, either due to their different policies or because of different healthcare infrastructures, do not perform equally well in conducting diagnostic tests and reporting a number of cases. Due to this fact, even countries with similar demographics and social distancing policies may report highly inconsistent numbers. Such inconsistencies will then make studying the disease's epidemiological characteristics challenging.

As the second objective, this paper seeks to propose an approach to compare the reporting performance of countries during the COVID-19 pandemic. For this purpose, we rely on the countries' similarities in terms of their age pyramids as well as the stage of the disease and assume that similar countries should experience similar population- and age-standardized numbers for their infections and death tolls. Considering US as the baseline, we then calculate a dissonance ratio for each country as a standardized measure of their performance in reporting cases and mortalities (i.e., a measure of the quality of their reports).

The rest of this paper is organized as follows: in the next section, a review of relevant studies from literature is provided. Following that, we describe our method and elaborate on the data used. The final section is dedicated to the findings and related discussions.

Background

The rapid spread of the novel coronavirus has even made the calculation of the rate of spread difficult. One frequently used way of measuring the spread is by computing the average number of secondary cases, or infections, that each case generates. This is known as the R-naught (R_0) (a.k.a., reproduction number) of the virus. The R_0's time- and place-dependent nature (typically smaller in the South Asian countries, depending on social distancing interventions such as case isolation, partial or complete lockdowns, school closure, and distance working by the local authorities) is making modeling the spread of the virus a moving target (8).

Even though the literature on COVID-19 is rapidly expanding, there is still a lack of consensus among academics and other scientists on the dynamics of the spread. Different estimates, for instance, are reported for the disease's R_0 ranging from 1.94 through 6.7 (6,9,10). This can perhaps be attributed to many reasons, such as the unpreparedness to a pandemic at this level, the lack of unified reporting systems due to diversity of health systems across the world, and the novelty of the pandemic itself.

Studies also report varying figures for other epidemiological measures such as CFR or IFR. Several underlying reasons may explain these variabilities. Perhaps one of the most plausible reasons is the abundance of undocumented cases. In their study, Li et al. (10) highlight that one of the reasons for the rapid spread of the virus is lack of documentation. They estimate that around 86% of all infections were undocumented. Another study from South Korea suggests similar undocumented case percentages at around 55-86% (11). News also suggests that even mortality cases often go unreported. A recent article in The Economist (12) highlighted stark differences between the number of expected death cases (including those attributed to COVID-19) and the actual death cases. Their estimation, based on regions' normal death rates, suggests the actual death-toll of the novel COVID-19 being more than double of what is being reported in different regions in Italy, Spain, and France. Perhaps this may be one of the reasons for conflicting CFR and IFR figures reported in the literature. While some studies suggested an estimated case fatality risk of as high as 7.2% (13) in Italy, other studies reported a CFR of 3.4% in China (14), and 2.3% using the age-adjusted Diamond Princess cruise ship data (15). More recent works report somewhat lower case fatality rates circa 1.4-1.5%% (16,17), both using data from Wuhan.

Similar variations also hold for IFR. Studies report IFRs as low as 0.5% using the Diamond Princess cruise ship data (15), 0.94%, and 0.657% using Wuhan data (18) and (19), respectively. Even though these numbers significantly differ from each other, there seems to be (i) convergence to a CFR of 1.5% over time, (ii) CFR/IFR ratio appears to hover around 2-3, indicating as much as 40-70% asymptomatic cases of the virus.

One of the apparent reasons behind the differences in reported CFRs and IFRs is the different demographics in different countries. As the virus affects the elderly more than the young, the virus takes a different toll on each country, depending on its age demographics (15,20). There may be several other reasons, including the fact that the age distribution of the infected population may differ from the overall age distribution. Hence, R_0 may significantly differ across age groups. However, there is a lack of by-age (and gender)-group reporting. For instance, Raj Bhopal (21), in his article expresses the importance and urgency of adjusting/reporting age and gender breakdowns of COVID-19 related data.

In this paper we pursue two objectives; First, we take into account the cross-country age disparities to handle such inconsistencies by providing country-independent conditional probabilities for each age group and then estimating the number of infections, hospitalizations, ICU visits, and mortality for each country given its age distribution. To this end, we assume that deaths, hospitalizations, and ICU usages are proxy measures for COVID-19 spread, also that similar spread patterns apply to each age group across countries—the virus is identical across all countries. We also demonstrate some evidence for the acceptability of these assumptions.

Second, relying on our findings from the first part, we propose a measure to assess the quality of testing and reporting COVID-19 cases across countries and comparing countries' performance in those manners. We believe that lack of such a measure in the literature has led to many studies relying on poor quality COVID-19 data in their analyses, which may lead to misleading conclusions.

Method and Dataset

Many of the existing studies that are focused on modeling the spread of the COVID-19 have been using a few different models such as susceptible-infected-recovered (SIR) and its covariates (mainly SEIR: susceptible-exposed-infected-recovered, or Sidarthe model) (22–26). These studies often ignore age-dependent variations from one country to another, or are limited to one country, or sometimes two (1).

In this study, instead of computing the spread of the virus, we look at the results of different scenarios. Specifically, we design three different spread scenarios (mild, moderate, and severe) by transferring knowledge learned from the seasonal flu pandemic as well as existing estimates for COVID-19 spread measures (R_0, proportion of symptomatic infections (C), and proportion of reported cases) from the literature. Then taking into account expert opinions, we choose the best scenario (closest one to their opinions).

The best scenario is then used, along with the US (our baseline country) population age distribution, to calculate a set of conditional probabilities to estimate probability of infection, hospitalization, ICU admission, and death for a given person from each age group. At the end, the calculated probabilities are applied to the countries' age pyramids to estimate cases, hospitalizations, ICU usage, and fatalities in each country (adjusted for their population age distribution).

Scenarios and Expert opinions

While aggressive quarantines and enforcing/recommending social distancing can change the outcome of the burden on healthcare systems, the primary health care capacities are the bottleneck for almost all countries. The size of the susceptible population typically depends on different R_0 values. By enforcing/recommending social distancing, governments attempt to mitigate the situation and reduce this number (*Figure 1*).

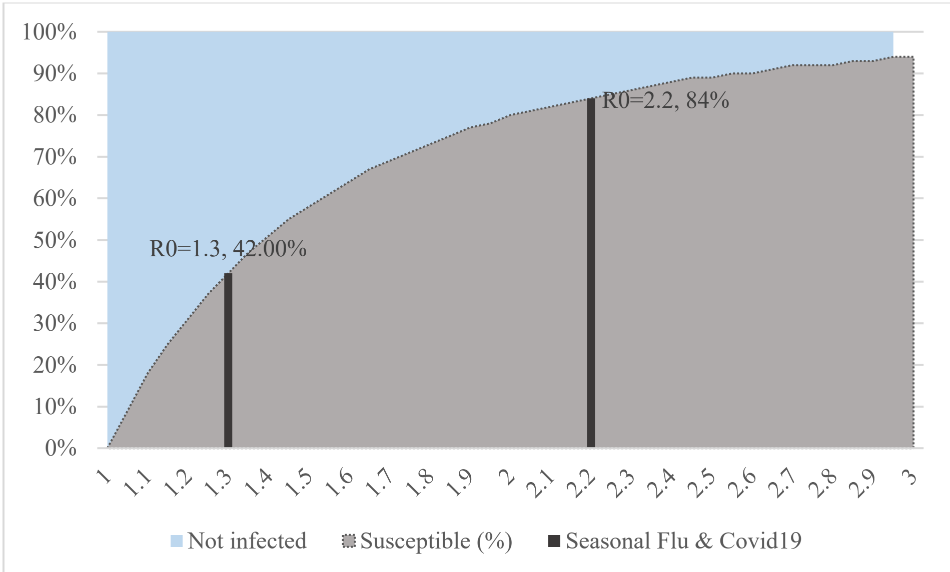

Figure 1. Different R_0 values and corresponding estimated percent of susceptible populations.

The novel coronavirus is often compared and contrasted against seasonal flu. Using CDC numbers over the last two flu seasons (2017-2019), we estimate the following table for the seasonal flu for comparison purposes.

Table 1. The seasonal flu numbers from the CDC.

Seasonal flu (based on CDC data)	US Cases	As % of Susceptible Population	Per 1M
Susceptible population (R0=1.3)	134.4M	100.00%	420,000
Population with symptoms	40M	29.80%	121K
Medical Visits	15M	11.10%	45.5K
Hospitalization	0.6M	0.44%	1,823
Fatality	40K	0.03%	121
CFR	0.03%		

We construct an analogous table to seasonal flu using expert opinions (27,28) (See Table 2). To this end, we constructed different scenarios severe (Scenario 1) to mild (Scenario 3) based on the estimates provided by the existing literature. We construct this table for the United States. By making use of suggested estimates based on (27,29), we create a range of possible R_0 values (i.e., 1.5-2.2) to estimate the percentage of susceptible population. Using the literature, we then estimate upper and lower limits for symptomatic cases, reported cases (not all of the symptomatic cases are reported), hospitalizations (as a percentage of reported cases), as well as ICU cases (in terms of cases), and fatalities in an age-adjusted manner.

Estimating fatalities is challenging since case fatality rates depend on a number of factors, including:

(i) The number of tests (and therefore, the number of positive cases) conducted each individual country. Many countries—excluding countries such as Iceland, where a significant portion of the population was tested—conduct selective testing. This may involve a selection bias where only the people with severe enough symptoms may be tested.

(ii) The delay between the symptom onsets and the time of deaths.

(iii) The varying levels of adequacy/inadequacy of the healthcare systems.

(iv) The rates of smoking or the prevalence of chronical illnesses. We chose to use CFR of 1.5% for the United States for our analysis.

Table 2. Different COVID-19 spread estimates for the United States (numbers are in millions)

COVID-19	Scen. 1	Scen. 2	Scen. 3	Expert Opinion 1	Expert Opinion 2
Susceptible population (overall R0={2.2[1], 1.8, 1.5[2]})	276.4	240.2	190.8	160-210M	-
The population with symptoms {.50[3], .35, .20[4]}(C)	138	84	38	-	-
Reported cases (as the ratio of symptomatic cases) {.11[5], .15, .20[6]}	27.6	13	4.2	-	-
Hospitalizations (36%[7,8] of reported cases)(H)	10	4.5	1.5	2.4-21M	-
ICU patients (% of Hospitalizations–7.4%[9,10])(I)	0.7	0.34	0.11	-	~0.08[11]
Fatalities (D)	0.41	0.19	0.063	0.2-1.7M	0.03-0.12
CFR {1.5[12,13]}	1.50%	1.50%	1.50%		

[1] (10)**Error! Bookmark not defined.** : estimates R_0 value as 2.2 for Wuhan data.
[2] (30) estimates R_0 value as 1.5 for South Korea where the virus is relatively better contained
[3] (17) finds a 50% chance of developing symptoms using Wuhan data.
[4] (31) suggests that the ratio of asymptomatic cases could be as high as 80%.
[5] (32) uses South Korean data and similar age corrections and estimate that only around 11% of cases are reported in the US.
[6] (33) uses an estimation interval of 40-60% in their analysis. However, we construct our scenarios using similar to the US-based study.
[7] (34) CDC estimates also yield a similar number in the US. However, the data has no age breakdown and includes some unknown cases.
[8] The rate is estimated as 0.36 using conditional probabilities and age distributions based on Spanish Data (35)
[9] (29) estimates that around a fifth of hospitalization days will require ICU stays for the US. However, they do not provide projections based on the number of hospitalization and ICU cases. Their numbers are in seem consistent with Spanish data (35).
[10] The crude rate is estimated as 7.4% of total hospitalizations using Spanish Data (35)**Error! Bookmark not defined.** . However, each case stays in ICU for an average of 15 days (36). (0.074 x 15 = 1.11)
[11] Assuming a 10-day average duration of stay.
[12](16,17) indicated a CFR of 1.5%.
[13] (37) indicates 0.7% CFR in Germany; such numbers usually come from countries where the spread is better contained.

Based on the characteristics of the COVID-19, the Center for Disease Control (CDC) estimated that 2.4 to 21 million Americans would require hospitalization, and a death-toll of as much as 480,000 may be expected (27). According to the same projection, the death toll could be any figure from 200,000 to as high as 1.7 million. Another more recent estimate assuming full social distancing through May (as of April 8, 2020), the White House estimated this figure to fall between 30,000 and 126,000 (28). These numbers are shown in the last two columns of Table 2. Given the closeness of estimates made by Scenario 3 (the mildest scenario) and the expert opinions, we rely on that scenario for establishing the conditional probabilities discussed in the following section.

Conditional Probabilities

In this study, we use countries' age distributions (population pyramids) and data involving different countries to create country-independent conditional probabilities for each age group. The severity of COVID-19 is also gender-dependent. However, due to the unavailability of data, we did not take gender into account.

As discussed earlier, we report our findings using the mildest of the three scenarios since its estimates turned out to be more consistent with the expert opinions (see Table 2). We use the following notation to formulate the conditional probabilities for each age group:

E: Events, E = {C: Case, A: Age, H: Hospitalization, I: Intensive Unit Care, D: Death)
$P(C)$: The probability of being infected with symptoms. Using the scenario-2 with R_0=1.8, we estimate the proportion of the susceptible population as 0.73, with a 35% probability of developing symptoms: $P(C) = 0.35 \times 0.73$
$P(R)$: The probability of being a reported case: $P(R) = P(C) \times .15$
$P(H)$: The probability of hospitalization. This number depends on the percentage of reported cases, as well as the size of the population with symptoms. Using 0.15 and 36% of the rate of hospitalization we use ($P(H) = P(C) \times .11 \times .36$)
$P(I)$: The probability of needing ICU ($P(I) = P(H) \times 0.074$)
$P(D)$: The probability of death for the cases (CFR) ($P(D) = P(R) \times .015$)
$P(A_i)$: The probability of each age group *i* for a given country (using the country population pyramid)
$P(C|A_i)$: The probability of being infected with symptoms given age group *i*

$$P(C|A_i) = \frac{P(A_i|C)}{P(A_i)} P(C)$$

where $P(A_i|C)$: The probability of the age group *i*, given case.
We compute other conditional probabilities similarly for events {H, I, D} and then use them to simulate the mild scenario breakdowns for the United States. By using population pyramids and

the US data, we replicate the same scenario for each individual country and report the results (per 1 million residents).

Assessment of Quality of COVID-19 Case Reporting

The second question this study seeks to address is that during the COVID-19 pandemic, how well different affected countries performed in conducting tests and reporting the cases. In order to answer this question, it is critical to have a base for comparing the countries' performance with one another (i.e., to assess their relative quality of reporting). For this purpose, through a series of calculations described below, we estimate an age-standardized expected number of cases and fatalities for each country, such that countries can be compared regardless of their age distributions. The procedure is explained below.

Using conditional probabilities, we calculate a set of successive measure for each country described below:

a. Age-Adjustment Fatality Coefficient (AAFC): We calculate the age-adjusted expected number of deaths by setting the global fatality baseline coefficient at "1" for the world. The coefficient value higher than “1” typically corresponds to an aging population. For instance, we estimate AAFC for Japan (one of the oldest nations in the world) as 3.41 (1037/204 from Table 1) and AAFC for Niger (the youngest nation) as 0.15. A 22-fold difference.
b. Age-Adjusted ICU Coefficient (AAICUC): The number of expected ICU cases corresponding to corresponding to AAFC of one. Calculated using the formula:

$$AAICUC = \frac{Expected\ ICU\ cases}{Expected\ Fatalities} \times AAFC$$

Countries with AAICUC of greater than the global average, 2.26, typically are expected to have heavier demand per capita for their intensive care units.

c. Age-Adjusted Hospitalization Coefficient (AAHC): The number of expected hospitalization cases corresponding to AAFC of one. Calculated using the formula:

$$\text{AAHC}=\frac{Expected\ Number\ of\ Hospitalizations}{Expected\ Fatalities}\times AAFC$$

d. Cumulative Fatalities (CF): Number of cumulative fatalities for each country as of May 13.
e. Day-Adjusted Cumulative Cases (DACC): Using a sliding lag window, we estimated the average number of days from the case reported to recovery (or fatality) as 8 days (38). Therefore, DACC corresponds to the reported cumulative number of cases 8 days prior to CF numbers.
f. Actual Case Fatality Risk (ACFR): Calculated as CF/DACC
g. Expected Infections per Fatality (EIPF): A recent study estimated the IFR of COVID-19 to be 1.3 for the US (39). Using this value for the US by adjusting AAFC of the US yields:

$$EIPF_{US}=\frac{1.89}{0.013}=145$$

The figure represents the number of infections in the US, corresponding to one fatality at the baseline. Values for other countries are calculated using

$$EIPF_i=\frac{RIPF_i}{RIPF_{US}}\times EIPF_{US}$$

Countries with higher numbers are expected to report more cases than that of the US.
h. Reported Infections per Fatality (RIPF): Calculated as 1/ACFR for each country.
i. Age-adjusted Reported Fatalities per 1M (AARFPM): Some countries, given their population pyramids, are expected to report more cases. This column age and population (per 1M) adjusts the CF values for each country. Note that AARFPM values depend on the stage of the spread.
j. Dissonance Ratio (DR): Calculated as RIPF/ACFR. A value (typically less than 1) that indicates how well two or more countries with roughly the same AARFPM values

performed in testing and reporting COVID-19 cases. Smaller DR values indicate possible under-reporting by the corresponding country.

Results

Age-adjusted Estimates of COVID-19

Unfortunately, the only source of data that explicitly provided the age breakdowns of hospitalization and ICU cases (P(A|H), and P(A|I)) we could found was Spain (35). After comparing the estimated P(H) and P(I)s from Spain data and the data from the Institute for Health Metrics and Evaluation (28), we concluded the numbers are consistent and decided to use age breakdowns from the Spanish dataset as the baseline for calculating conditional probabilities. A sample table, including some of the probabilities using the reports by the Spanish Ministry of Health, is given in Table 3.

Table 3. *Probabilities and conditional probabilities for Spain*

Age Group	P(A)	#Inf. Cases	P(A|C)	#Hosp.	P(A|H)	#ICU cases	P(A|I)	#Deaths	P(A|D)
0-9	9.3%	130	0.6%	35	0.45%	1	0%	0	0.0%
10-19	10.0%	226	1.1%	20	0.26%	1	0%	1	0.1%
20-29	10.0%	1,352	6.6%	200	2.6%	10	2%	4	0.5%
30-39	13.2%	2,386	11.7%	431	5.6%	18	3%	3	0.4%
40-49	17.0%	3,190	15.6%	778	10.1%	45	8%	9	1.1%
50-59	14.9%	3,433	16.8%	1,074	13.9%	106	18%	20	2.5%
60-69	11.1%	3,179	15.6%	1,432	18.6%	162	28%	63	7.8%
70-79	8.4%	3,304	16.1%	1,858	24.1%	192	34%	164	20.4%
80+	6.2%	3,271	16.0%	1,871	24.3%	38	7%	541	67.2%

Using age-corrections via conditional probabilities also shows that reported numbers are quite consistent across-countries (Table 4). As shown in this table, there is a 0.97 correlation between the estimated and the reported age group probabilities for the United States, suggesting the acceptable performance of the proposed approach for age adjustments.

Table 4- *Computing age group probabilities for given cases in (i) Spain, (ii) in the US calculated using Spain data, and (iii) reported by CDC. While the correlation between (i) and (iii) is .88, the correlation between (i) and (ii) is as high as .97.*

Age Group	$P(A)_{US}$	$P(A)_{Sp}$	$P(A\|C)_{Sp}$	$P(A\|C)_{US}$ from Spain data	$P(A\|C)_{US}$ reported
0-9	12.1%	9.3%	0.6%	0.9%	2.5%
10-19	12.9%	10.0%	1.1%	1.6%	2.5%
20-29	14.0%	10.0%	6.6%	10.5%	11.5%
30-39	13.4%	13.2%	11.7%	13.3%	11.5%
40-49	12.2%	17.0%	15.6%	12.7%	14.5%
50-59	12.9%	14.9%	16.8%	16.4%	17.5%
60-69	11.5%	11.1%	15.5%	18.1%	17.1%
70-79	7.0%	8.4%	16.1%	15.1%	12.6%
80+	3.9%	6.2%	16.0%	11.4%	10.2%

We then use country demographics, CDC estimations for the US, and data sets available (shown in Table 5) to compute age-adjusted probabilities and number of cases for each of the events (Susceptible, Case with symptoms, Hospitalization, IUC case, and Deaths). For all countries, we report all numbers per 1 million for easy comparison in Appendix Table 1Appendix Table 2.

Table 5- *Datasets used in this study*

Country	South Korea(30)	Spain(35)	US(30)	China(19)	Italy(13)
Number of cases	6,284	20,471	2,449	44,669	~34,000
Number of hospitalizations	-	7,699	-	-	-
Number of ICU cases	-	573	-	-	-
Number of fatalities in the study	42	805	44	805	1,625

Studies report different case- and death-related age-breakdowns for a variety of countries. We observed that taking conditional probabilities—based on population age distributions in individual countries—into account, we can help mitigate the variability in the reported results. Figure 2 visually confirms the reduction in inconsistencies by taking age adjustments into account.

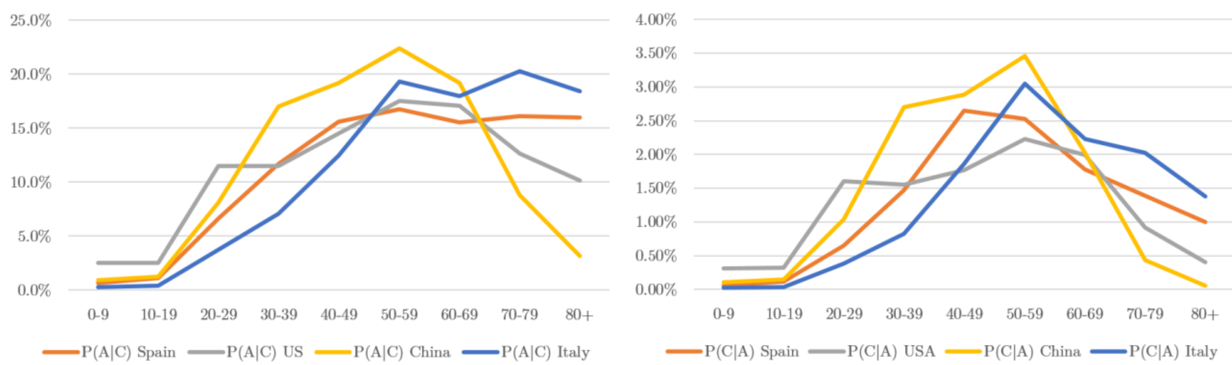

Figure 2. Age breakdown patterns of cases with (left) and without (right) taking country population pyramids (in terms of conditional probabilities) into account.

Figure 3 also highlights the age distribution differences for different events. ICU beds and invasive ventilators are in short supply, and some health systems prioritize younger patients over the older ones in order to increase the chances of survival. While debated from ethical viewpoints, the figure also demonstrates such preferences.

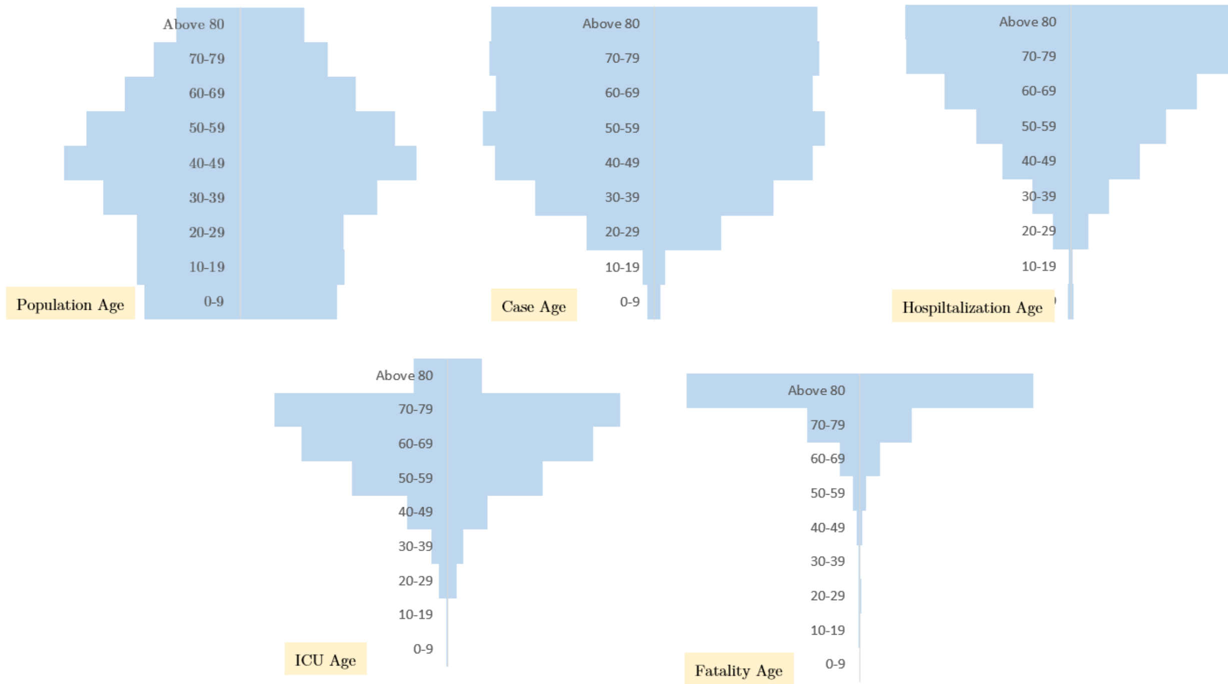

Figure 3. Age pyramids for cases, hospitalization, ICU uses, and fatalities for Spain.

Assessing Countries' Reporting Quality

As explained earlier, for each country, we calculated a dissonance ratio (DR) number indicating how well the governments have done in conducting tests and reporting cases, given some age-standardized expected number of cases. The DR estimates (along with other related measures) are reported in detail in Appendix Table 2.

At the time of writing this manuscript, some of the countries were still experiencing the early stages of the breakout. At the end of the COVID-19 spread, the Appendix Table 2 would include similar values in column AARFPM across all countries. As AARFPM values indicate the progress for the breakout, we filtered out the countries with less than 10 AARFPM for better interpretability. This column, therefore, may be interpreted as a crude measure of reliability (hence progress of the spread) for dissonance ratios (i.e., the higher this value, the more evidence we have for the magnitude of the dissonance). Therefore, the table is ordered by AARFPM values rather than dissonance ratios. The correct way of interpreting the results is by comparing the DR values of row-wise nearby countries (with similar AARFPM values). For instance, Finland, Hungary, and Israel have similar AARFPM values (20.1, 20.2, and 20.6, respectively) indicating them being at the same stage of the epidemic. However, their Dissonance Ratios are 0.04, 0.23, and 0.55, respectively. This indicates comparatively better case reporting (including testing) by Israel. At the end of the pandemic, all countries in the table are expected to have roughly the same AARFPM values, making reporting quality of them all comparable to one another through the proposed standardized DR measure.

Discussion

In this paper, we focus on age-dependent breakdowns of cases, hospitalizations, ICU usages, and fatalities (events) using a range of scenarios. We construct these scenarios by using expert views and existing reports in the literature and based on the US data. We then use conditional probabilities to compute age-standardized breakdowns for the events for all individual countries.

Our results propose a few important implications. First, the results highlight the effect of demographical differences across countries on COVID-19 spread. Figure 4 indicates a comparison between Niger and Japan (as the youngest and oldest populations in the world, respectively). It suggests, provided that everything else remains the same, the death toll difference due to age demographics could be as much as 20 times (47 vs. 1,037 deaths per 1M population according to Appendix Table 1).

Second, our results have the potential to help decision-makers to accommodate age-specific aspects of the spread. Creating different age-based isolation strategies, depending on the age-demographics of individual countries, may be considered. This is essentially important given the limited capacity of health care systems in the affected countries. At this time, one of the major concerns of the governments in the countries affected by COVID-19 is to have reliable estimates of medical requirements to plan ahead proper measures. We argue that providing such estimates based on age groups can give the authorities a clearer picture of what they should expect in different regions of their countries based on the demographic profile of the population in each region. The proposed approach is not exclusively for COVID-19 and may be employed by the decision-makers for estimating capacity requirements in the future epidemic situations.

Also, our study attempts to combine several parameters calculated or taken from different academic papers, reports, or data sources together in creating a range of scenarios. While this approach provides a somewhat holistic view of the phenomenon, it also omits other country-level differences such as social isolation policies, prevention strategies, and the effectiveness of the individual healthcare systems (i.e., our research limitations). Future research may extend the proposed approach by involving such factors (upon the availability of data for them) in the calculation of conditional probabilities. Appendix Table 1 must be interpreted as a comparison tool for different countries' exposure to the virus.

Additionally, we propose an approach to compare countries' performance in reporting COVID-19 cases. Clearly, not all countries have the same healthcare infrastructure to conduct enough number of tests to identify infected people. Despite these differences, official reports published by the governments of different countries are being used in a similar manner to study the characteristics of the novel coronavirus, which may cause significant bias to their findings. It is crucial then to provide a means to recognize those countries that perform better in running tests and reporting cases, thereby providing more reliable numbers for studying the pandemic. Appendix Table 2 lays out a base for comparing the reporting performance of the countries by taking into account their age disparities as well as the progress stage of the disease. Using that tool, researchers could have a better understanding of the accuracy of reported numbers by each country by looking into their dissonance ratio number.

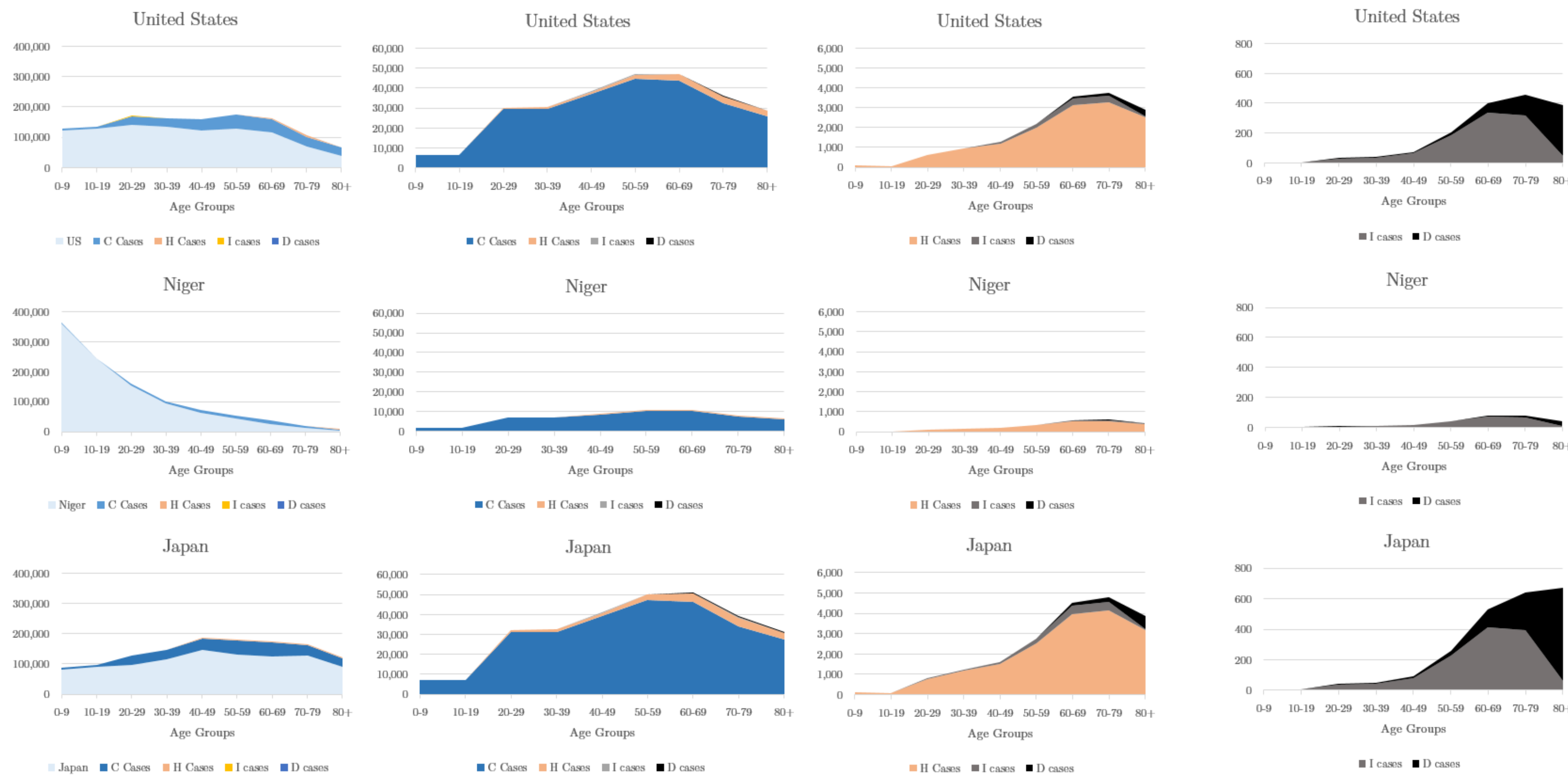

Figure 4. Age-dependent event estimations for the US, the country with the youngest population in the world (Niger), and with the oldest (Japan). y-axis is for scaling purposes based on one of the scenarios per 1M.

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Appendix

Appendix Table 1- Scenario-2 based event breakdowns for individual countries

Country	Population (K)	Cases per 1M	Hosp. per 1M	ICU per 1M	Deaths per 1M
Portugal	10,196	275,770	16,717	1,218	854
Germany	83,783	275,671	16,521	1,194	852
Italy	60,461	275,463	16,903	1,223	902
Greece	10,423	273,517	16,472	1,173	879
Switzerland	8,655	272,148	15,554	1,130	720
Bulgaria	6,949	271,055	16,053	1,216	706
Japan	126,475	271,042	17,430	1,256	1,037
Hungary	9,660	270,439	15,464	1,160	665
Finland	5,542	270,389	16,135	1,195	784
Netherlands	17,136	269,922	15,626	1,169	705
Spain	46,733	269,495	15,673	1,117	772
Republic of Korea	51,270	269,133	14,500	1,102	556
Romania	19,236	268,786	15,330	1,133	677
Poland	37,847	267,820	15,109	1,113	656
Belgium	11,589	267,496	15,314	1,104	736
Denmark	5,792	266,784	15,340	1,144	694
Czech	10,708	265,466	15,251	1,153	642
Sweden	10,099	264,504	15,248	1,108	729
United Kingdom	67,886	264,035	14,909	1,078	694
Ukraine	43,734	263,634	14,445	1,065	598
Norway	5,421	261,559	14,405	1,060	619
Cuba	11,326	260,576	13,965	1,038	562
Belarus	9,449	256,685	13,641	1,004	548
US	329,064	255,500	13,797	1,021	575
New Zealand	4,822	254,069	13,778	1,022	576
Australia	25,498	253,440	13,696	993	590

Country	Population (K)	Cases per 1M	Hosp. per 1M	ICU per 1M	Deaths per 1M
Russian Federation	145,935	253,217	13,567	997	551
Uruguay	3,474	244,333	12,945	912	586
Ireland	4,938	242,002	12,670	941	493
Chile	19,116	234,534	11,579	853	429
China	1,439,324	227,809	10,805	875	326
Argentina	45,197	213,004	10,468	759	400
Israel	8,655	211,875	10,745	771	438
Sri Lanka	21,413	211,258	10,060	822	304
Brazil	212,560	207,735	9,592	722	318
Colombia	50,883	198,163	9,060	679	301
World	**7,794,799**	**197,313**	**9,131**	**688**	**304**
Tunisia	11,819	196,661	8,884	680	281
Turkey	84,339	195,387	8,928	677	290
Peru	32,972	191,468	8,717	649	290
Viet Nam	97,338	190,509	8,391	608	284
Kazakhstan	18,776	181,352	8,042	604	258
Venezuela (Bolivarian Republic of)	28,437	180,853	8,072	628	247
Mexico	128,933	177,978	7,887	589	256
Dominica	10,847	174,998	7,815	574	263
Azerbaijan	10,139	173,391	7,261	557	214
Ecuador	17,643	173,165	7,726	571	257
Morocco	36,910	172,690	7,503	604	214
Malaysia	32,365	168,392	7,211	575	205
Bolivia	11,674	163,184	7,436	533	267
Iran (Islamic Republic of)	83,993	161,603	6,787	541	189
Algeria	43,852	159,997	6,934	521	217
Paraguay	7,132	155,116	6,797	516	213
India	1,380,004	154,638	6,475	529	176
Indonesia	273,523	154,124	6,343	531	165
Bangladesh	164,690	142,614	5,915	448	177
Philippines	109,581	136,985	5,625	457	152
Nepal	29,138	133,698	5,539	465	145
South Africa	59,308	132,704	5,360	455	135

Country	Population (K)	Cases per 1M	Hosp. per 1M	ICU per 1M	Deaths per 1M
Turkmenistan	6,031	129,106	5,120	398	143
Egypt	102,335	129,065	5,306	440	140
Uzbekistan	33,470	128,528	5,038	401	135
Syrian Arab Republic	17,500	125,473	5,083	400	141
Pakistan	220,892	112,174	4,521	370	119
Jordan	10,205	108,890	4,301	345	114
Saudi Arabia	34,815	102,129	3,777	317	91
Sudan	43,849	93,224	3,681	308	93
Ethiopia	114,964	88,752	3,545	291	93
Iraq	40,223	88,523	3,410	280	87
Iraq	40,223	88,523	3,410	280	87
South Sudan	11,195	85,682	3,366	285	84
State of Palestine	5,101	85,658	3,307	278	82
Madagascar	27,692	82,226	3,138	265	77
Ghana	31,073	79,587	2,934	280	63
Senegal	16,745	77,735	2,989	261	71
Democratic Republic of the Congo	89,561	76,412	2,970	255	72
Yemen	29,825	74,766	2,840	250	67
Mozambique	31,255	71,548	2,752	239	66
Somalia	15,893	70,564	2,714	242	63
Côte d'Ivoire	26,378	68,960	2,558	243	55
Cameroon	26,545	68,088	2,540	232	57
United Republic of Tanzania	59,734	66,731	2,484	229	55
Afghanistan	38,928	66,159	2,469	227	55
Kenya	53,771	66,064	2,407	219	53
Nigeria	206,139	60,712	2,193	228	43
Burkina Faso	20,903	60,006	2,200	209	47
Mali	20,249	59,879	2,230	207	49
Niger	24,207	59,262	2,215	215	47

Appendix Table 2- Measuring the gap between expected case reporting vs. actual case reporting

Country	Popul. (K)	ACFR	RIPF	EIPF	DR	AARFPM	CF	DACC	AAHC	AAICUC	AAFC
Belgium	11,589	17.4%	5.73	161	0.04	310.3	8,707	49,906	50.4	3.63	2.42
United Kingdom	67,886	17.2%	5.82	157	0.04	206.9	32,065	186,599	49.0	3.55	2.28
Italy	60,461	14.6%	6.86	178	0.04	171.3	30,739	210,717	55.6	4.02	2.97
Sweden	10,099	14.6%	6.85	161	0.04	134.4	3,256	22,317	50.2	3.64	2.40
Hungary	9,660	14.0%	7.14	163	0.04	20.1	425	3,035	50.9	3.82	2.19
Netherlands	17,136	13.4%	7.44	165	0.05	137.2	5,456	40,571	51.4	3.85	2.32
Spain	46,733	12.3%	8.13	165	0.05	225.3	26,744	217,466	51.6	3.67	2.54
Mexico	128,933	15.2%	6.57	85	0.08	32.9	3,573	23,471	25.9	1.94	0.84
Romania	19,236	7.4%	13.54	162	0.08	22.6	972	13,163	50.4	3.73	2.23
Brazil	212,560	11.4%	8.78	101	0.09	51.8	11,519	101,147	31.6	2.38	1.05
US	329,064	7.0%	14.35	145	0.10	129.6	80,684	1,158,041	45.4	3.36	1.89
Ireland	4,938	6.8%	14.66	134	0.11	183.1	1,467	21,506	41.7	3.10	1.62
Denmark	5,792	5.6%	17.87	162	0.11	40.3	533	9,523	50.5	3.76	2.28
Finland	5,542	5.2%	19.39	170	0.11	18.9	271	5,254	53.1	3.93	2.58
Switzerland	8,655	5.2%	19.34	164	0.12	75.2	1,542	29,822	51.2	3.72	2.37
Algeria	43,852	11.3%	8.82	72	0.12	16.2	507	4,474	22.8	1.71	0.71
Germany	83,783	4.6%	21.66	174	0.12	32.0	7,533	163,175	54.3	3.93	2.80
World	**7,794,799**	**8.2%**	**12.13**	**96**	**0.13**	**36.6**	**285,760**	**3,465,608**	**30.0**	**2.26**	**1.00**
Portugal	10,196	4.5%	22.31	176	0.13	39.9	1,144	25,524	55.0	4.01	2.81
Czech	10,708	3.6%	27.59	161	0.17	12.4	282	7,781	50.2	3.79	2.11

Country	Popul. (K)	ACFR	RIPF	EIPF	DR	AARFPM	CF	DACC	AAHC	AAICUC	AAFC
Bolivia	11,674	7.7%	13.07	76	0.17	11.9	122	1,594	24.5	1.75	0.88
Ecuador	17,643	7.3%	13.77	77	0.18	143.8	2,145	29,538	25.4	1.88	0.85
Iran	83,993	6.9%	14.57	78	0.19	128.0	6,685	97,424	22.3	1.78	0.62
Philippines	109,581	7.9%	12.70	62	0.20	13.2	726	9,223	18.5	1.50	0.50
Egypt	102,335	8.2%	12.13	54	0.22	11.3	533	6,465	17.5	1.45	0.46
Norway	5,421	2.9%	34.86	152	0.23	20.2	224	7,809	47.4	3.49	2.04
Dominican Republic	10,847	4.9%	20.24	83	0.24	41.8	393	7,954	25.7	1.89	0.87
Peru	32,972	4.3%	23.42	94	0.25	62.3	1,961	45,928	28.7	2.13	0.95
Turkey	84,339	3.0%	32.82	94	0.35	47.7	3,841	126,045	29.4	2.23	0.95
Somalia	15,893	7.2%	13.88	29	0.48	15.7	52	722	8.9	0.80	0.21
Chile	19,116	1.6%	60.88	122	0.50	11.9	323	19,663	38.1	2.81	1.41
Israel	8,655	1.6%	62.82	113	0.55	20.6	258	16,208	35.3	2.54	1.44
Burkina Faso	20,903	7.6%	13.24	23	0.57	15.4	50	662	7.2	0.69	0.15
Cameroon	26,545	6.0%	16.62	27	0.62	25.1	125	2,077	8.4	0.76	0.19
Mali	20,249	6.9%	14.44	23	0.62	11.9	39	563	7.3	0.68	0.16
Niger	24,207	6.1%	16.30	24	0.69	12.2	46	750	7.3	0.71	0.15
Afghanistan	38,928	4.5%	22.16	26	0.85	17.3	122	2,704	8.1	0.75	0.18
Saudi Arabia	34,815	0.9%	105.93	45	2.34	24.4	255	27,011	12.4	1.04	0.30