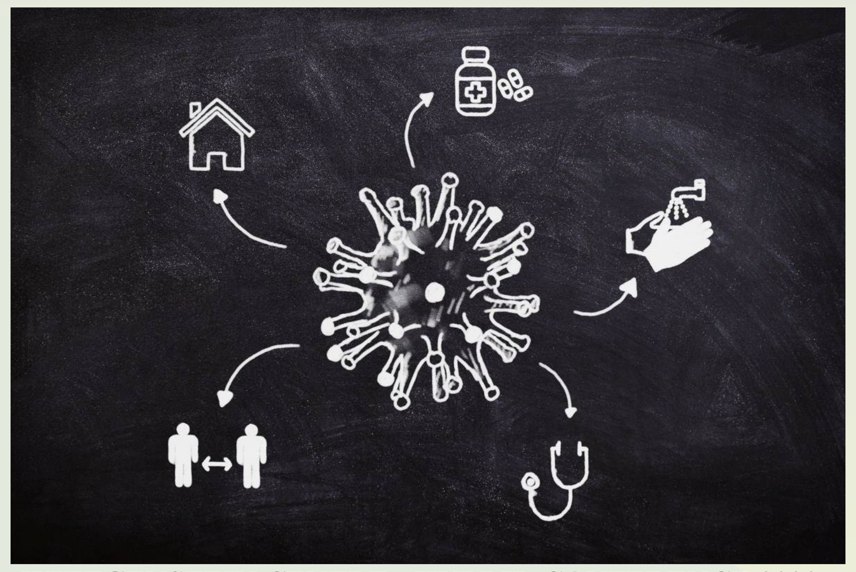

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Modelling COVID-19 Age-Sex Mortality Metrics

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ABSTRACT

This research builds upon the previous publications claiming that the male sex and advanced age populations are being more susceptible to COVID-19 death. Relations between sex and age gradients are explored analytically based upon the proposed log-polynomial regression model of COVID-19 mortality. This model enables mortality risk prediction at any arbitrary age, as well as derivation of several useful metrics:

- *Sex differential* is a ratio of male-to-female death risks for a given age group (known from the literature, see e.g. [4], developed furthermore)
- *Age parity* at which both sexes have equal vulnerability.
- *Age lag* is a number of years to subtract from male's age to match female's death risk (new concept, formally introduced in this work).

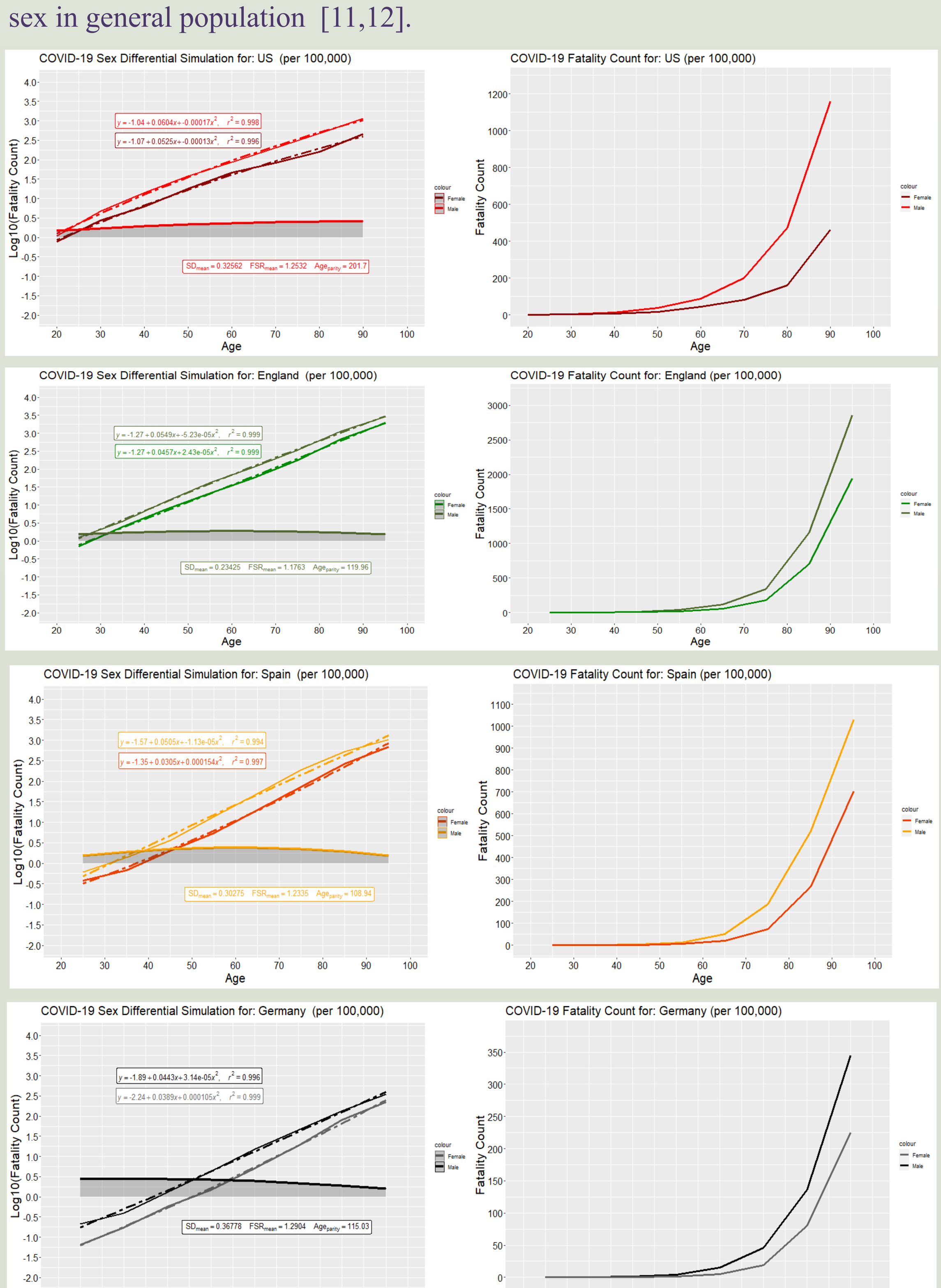
Modelling and simulations are conducted using the Fall 2020 COVID-19 data from six major countries, selected among the most affected from COVID-19 mortality perspective with over 360,000 deaths combined as of October 2020. Patterns and trends revealed are concisely described with just a few numbers. Both metrics show female's "advantage" is tempering at very old age.

MODELLING

The polynomial regression in the logarithmic space, i.e. log-polynomial, see eq. (1), would be more accurate and thus suitable fit than the customary simple regression log-linear model e.g. [1,4]. To avoid the model overfitting the data we limited the polynomial to the 2nd degree:

$$\log(y) = b_0 + b_1 x + b_2 x^2, \qquad (1)$$

where FC^M_{age}, FC^F_{age} and x represents an age group. FC represents an age group. FC here stands for Fatality Count, standardized per 100,000 of a given sex in general population [11,12].



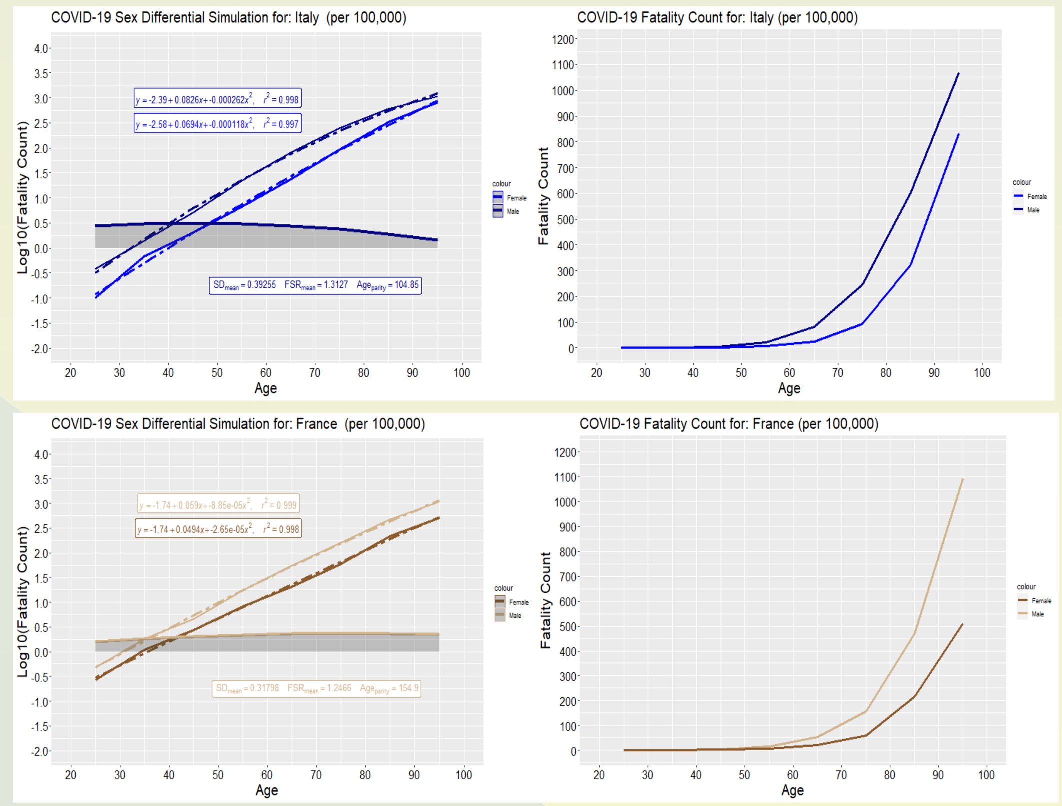


Figure 1. (right) Six country standardized mortality plots; (left) mortality plot of the log-linear scale along with log-polynomial regression lines for each sex (fine dotted lines). SD_{age} simulated using a log-polynomial regression model is at the left shown as a shaded area at the bottom of each plot.

METHODS: SEX DIFFERENTIAL

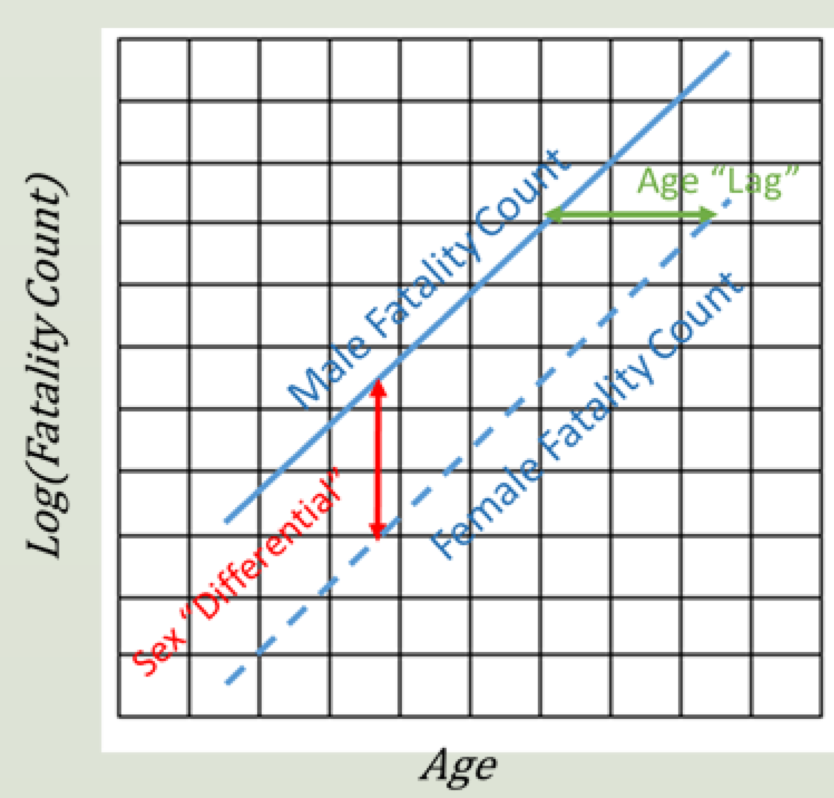


Figure 2. Concepts: COVID-19 mortality sex *differential* SG_{age} and age lag AL_{age}

The log-polynomial regression model from Eq. (1) allows expressing the "sex differential" (SD_{age}) as a y-distance between the male and the female $\log(FC^M_{age})$, $\log(FC^F_{age})$, see Figure 1. The idea is illustrated on Figure 1(a) where the sex differential is depicted as a gap, (b) SD_{age} is shown as a function of age. The formal equation for the COVID-19 SD_{age} is:

$$SD_{age} = \log(FC^M_{age}) - \log(FC^F_{age}) \quad \text{if measured on the log scale, or} \qquad (2)$$

$$SD_{linear\ (age)} = \frac{FC^M_{age}}{FC^F_{age}} \quad \text{if measured on the linear scale,}$$

Let us rename $SD_{linear\ (age)}$ as FSR_{age} (Fatality Sex Ratio), often referred to as the M/F ratio in e.g. [4]:

$$FSR_{age} = SD_{linear\ (age)} \qquad (3)$$

Having regression model fitted (Eq. (1)) to male's and female's fatality count data, SD_{age} can be rewritten to express the sex differential (gap) analytically, namely:

$$SD_{age} = \log(FC^M_x) - \log(FC^F_x) = y^M - y^F = (b^M_0 - b^F_0) + (b^M_1 - b^F_1)x + (b^M_2 - b^F_2)x^2 \qquad (4)$$

Using equation (4) we can predict the age "parity" with respect to the sex differential, i.e. the age at which the male's odds of dying will be on par with female's. For this we need to solve the $(b^M_0 - b^F_0) + (b^M_1 - b^F_1)x + (b^M_2 - b^F_2)x^2 = 0$ equation for x, i.e. age in years. The results for individual countries are shown on Figure 1(left) and Table 1.

METHODS: AGE LAG

Male fatality rates (risks) are generally higher than female's [1,2,4,5]. Given a male fatality risk y^M_{age} and same age female's y^F_{age}, the following holds true for most ages: $y^M_{age} - y^F_{age} = SD_{age} > 0$. That is the male's risk is usually higher than female's of the same age. How much younger a male should be (t in years) to "compensate" for the sex differential SD_{age}, i.e. to equalize the risks: $y^F_{age} = y^M_{age+t}$? This way a male younger by t will have the identical risk of dying from COVID-19. Therefore, we are referring to this t as the "age lag" AL_{age}, which is depicted on Figure 2(a) in green. Age lag shows by how many years (t) we need to shift the x ("age") of a male to achieve the risk parity with a female of age x. AL_{age} can be derived analytically as:

$$y^F_{age} = y^M_{age+t}, \text{ or} \qquad (5)$$

$$b^F_0 + b^F_1 x + b^F_2 x^2 = b^M_0 + b^M_1(x+t) + b^M_2(x+t)^2,$$

Finally, AL_{age}, i.e. t as a solution to the quadratic equation with respect to t:

$$b^M_2 t^2 + [2b^M_2 x + b^M_1]t + [(b^M_2 - b^F_2)x^2 + (b^M_1 - b^F_1)x + (b^M_0 - b^F_0)] = 0 \qquad (6)$$

We can see from Figure 3 that starting from the nearly zero AL_{20-29}, the lag widens up to negative -10 years later in life, to change the direction again and finally shrink back to zero towards 100 and on. Interpretation of $AL_{70} = t = -10$ is that the odds for the lethal outcome of a 70 years-old female are equal to those of a 60 years-old male. Interpretation of $AL_{age} = t = 0$ is that males and females of the same age have equal risks of dying from COVID-19

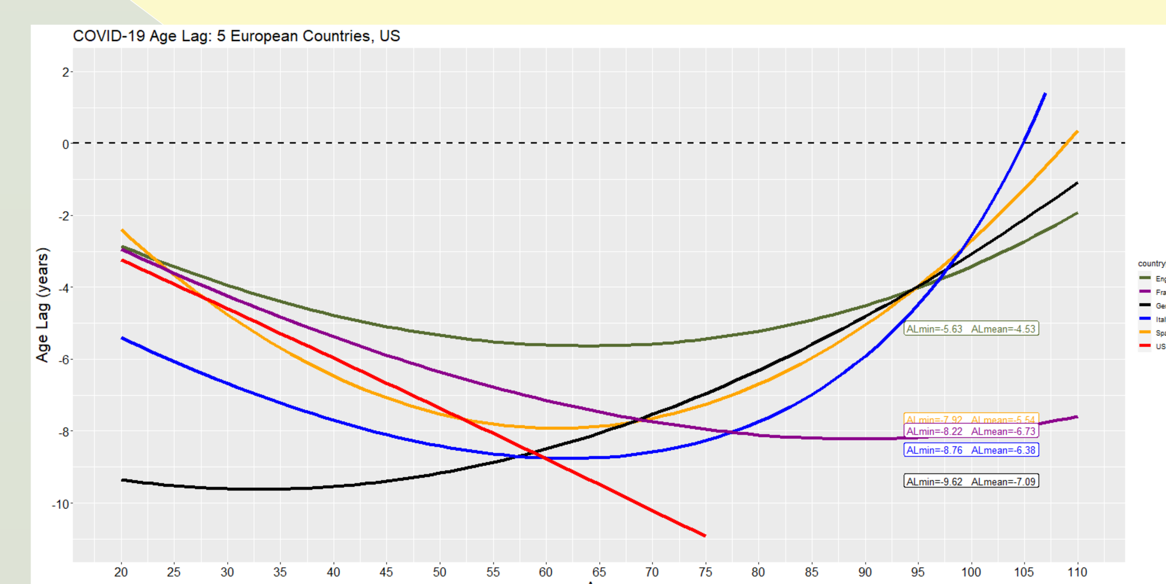


Figure 3. Simulated age lag AL_{age} for five European countries and the US.

RESULTS

COVID-19 mortality modelling results are concentrated in Table 1 below. FSR_{max} (not reported here) would exceed 3:1 male-to-female ratio for the most vulnerable age groups, typically 50-70, in consistency with sex differentials reported in [6].

Table 1. COVID-19 Sex-Age Modelling Results (Ages 20+).

Country	Sex Differential (SD)		Age Lag (AL)		Age_{parity}
	FSR_{mean} (times)	SD_{mean}	AL_{min} (years)	AL_{mean} (years)	(years)
Italy	1.31	0.39	-8.8	-6.4	104.8
Spain	1.23	0.3	-7.9	-5.5	108.9
England and Wales	1.18	0.23	-5.6	-4.5	120.0
Germany	1.29	0.37	-9.6	-7.1	115.0
France	1.25	0.32	-8.2	-6.7	154.9
USA	1.25	0.33	-16.3	-9.6	-

Note: Age_{parity} for US cannot be calculating; male and female trend lines are diverging apparently due to the lack of data for 90+.

Age_{parity} predicted for various countries, for which the data for 90+ was available, has varied widely. Beyond these, often unrealistically high ages, the survived males will truly become less vulnerable.

DISCUSSION

COVID-19 mortality risks are strongly affected by sex and age proportions in a given population. To concisely describe them analytically and facilitate dissecting trends, the paper has applied a log-polynomial regression model fit to a large volume of COVID-19 fatality data. Such modelling enables prediction of such valuable analytics as:

- Mortality risk prediction at any arbitrary age.
- Sex differential for a given age.
- Age parity at which both sexes have equal vulnerability
- Age lag in years to establish parity between male's and female's risks.

The results based on analysis of 360,000 COVID-19 deaths from six major countries, heavily affected by the pandemic, show that the well established trend of male's higher vulnerability [1,2,4,5] persists for most ages. However, with help of modelling, we can see how the trend changes and female's vulnerability is getting higher at very old, often unrealistic, age; the explanation of which is yet to be proposed.

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