

Appendix
Modeling COVID-19 Mortality Across 44 Countries: Face Covering May Reduce Deaths
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Appendix 1. Extended Timeline of Non-Pharmaceutical Interventions (NPI) in Mask and No-Mask Countries During the Time of the Study¹⁻⁷⁰

Country	Face coverage			Restriction of movement				Social distancing						
	Mask	Quarantine		Home stay		Travel restriction		Schools' closure		Business closure		Restriction of gathering		
	Applied	Applied	Lifted	Applied	Lifted	Applied	Lifted	Applied	Lifted	Applied	Lifted	Applied	Lifted	
a. Countries with national mask policy														
Austria	14-Apr	13-Mar		16-Mar		16-Mar					14-Apr		14-Apr	
Bahrain	9-Apr	22-Mar		22-Mar		22-Mar		22-Mar		22-Mar		22-Mar		22-Mar
Cyprus	1-May	30-Apr	21-May	30-Apr	21-May	30-Apr	9-Jun	30-Apr	21-May	30-Apr	21-May			
Czech	12-Mar	16-Mar	24-Apr	16-Mar	11-May	12-Mar	11-May	14-Mar	11-May	14-Mar	11-May	14-Mar	11-May	
Estonia	1-May	13-Mar	17-May	13-Mar	17-May	13-Mar	17-May	13-Mar	17-May	13-Mar	17-May	13-Mar	17-May	
Germany	27-Apr	22-Mar		22-Mar		15-Mar		13-Mar		22-Mar		22-Mar		
Greece	4-May	22-Mar	4-May	22-Mar	4-May	22-Mar	4-May	13-Mar	4-May	16-Mar	4-May	27-Feb	4-May	
Hong Kong	16-Mar	5-Feb				19-Mar		31-Jan	27-May			29-Mar		
Iceland	24-Mar	1-Mar		1-Mar		1-Mar		13-Mar		24-Mar		16-Mar		
Ireland	5-May	12-Mar	30-May	12-Mar	30-May	12-Mar	30-May	12-Mar	30-May	24-Mar	29-Jun			
Hungary	27-Apr	16-Mar		13-Mar		13-Mar						16-Mar		
Israel	12-Apr	14-Apr	4-Apr	16-Apr		26-Feb		12-Mar	19-May	16-Mar	27-May	15-Mar		
Japan	1-Mar	7-Apr	25-May	30-Mar	25-May	7-Feb	25-May	2-Mar	25-May	10-Apr	25-May	30-Mar	25-May	
South Korea	15-Feb	20-Feb	22-Apr	20-Feb	22-Apr	24-Feb	22-Apr			20-Feb	22-Apr			
Latvia	2-Mar	13-Mar		13-Mar	15-Jul	13-Mar	15-Jul	13-Mar	15-Jul	13-Mar	15-Jul	13-Mar	13-Jul	
Lithuania	13-Apr	16-Mar	11-May	16-Mar	1-Jul	16-Mar	1-Jul	16-Mar	1-Jul	25-Mar	1-Jul	16-Mar	1-Jul	
Luxembourg	20-Apr	15-Mar		15-Mar		15-Mar		15-Mar		15-Mar		15-Mar		
Malta	1-May	25-Feb		7-Apr		12-Mar		12-Mar		22-Mar		12-Mar		
Oman	29-Apr	10-Apr	3-Jul	10-Apr	3-Jul	10-Apr	3-Jul	10-Apr	3-Jul	10-Apr	3-Jul	10-Apr	3-Jul	
Poland	15-Apr	12-Mar	3-May	12-Mar	3-May	12-Mar	3-May	12-Mar	3-May	12-Mar	3-May	10-Mar	20-Apr	
Portugal	18-Apr	18-Mar	18-May	25-Mar	18-May	25-Mar	18-May	25-Mar	18-May	25-Mar	18-May	25-Mar	18-May	
Qatar	26-Apr	9-Mar	15-Jun	9-Mar	15-Jul	9-Mar	15-Jul	9-Mar	1-Sep	9-Mar	1-Aug	9-Mar	1-Aug	
Russia	7-Feb	2-Mar		30-Mar	22-Jun	15-Feb	22-Jun	2-Mar	22-Jun	2-Mar	22-Jun	2-Mar	22-Jun	
Singapore	14-Apr	7-Apr	2-Jun	7-Apr	2-Jun	7-Apr	2-Jun	7-Apr	31-Dec-21	7-Apr	2-Jun	7-Apr	2-Jun	
Slovakia	25-Mar	13-Mar		13-Mar	22-Apr	13-Mar	22-May	8-Mar	1-Sep	16-Mar	6-May	10-Mar	22-May	

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Slovenia	29-Mar	10-Mar	15-May	10-Mar	15-May	10-Mar	15-May	10-Mar		10-Mar	15-May	10-Mar	15-May
United Arab Emirates	27-Mar	26-Mar	15-Apr	26-Mar	26-Apr	26-Mar	30-Dec	3-Mar	30-Jun	23-Mar	1-Sep	18-Mar	1-Sep

Country	Face coverage		Restriction of movement				Social distancing						
	Mask	Quarantine	Home stay	Travel restriction	Schools' closure	Business closure	Restriction of gathering						
	Applied	Applied	Lifted	Applied	Lifted	Applied	Lifted	Applied	Lifted	Applied	Lifted		
Countries with no national mask policy													
Andorra		16-Mar		16-Mar		16-Mar		16-Mar		16-Mar		16-Mar	
Belarus		30-Mar	17-Apr	30-Mar	17-Apr	30-Mar	17-Apr	4-Apr	17-Apr	30-Mar	17-Apr	30-Mar	17-Apr
Belgium		12-Mar	4-May	12-Mar	4-May	12-Mar	4-May	12-Mar	4-May	12-Mar		12-Mar	
Brunei		15-Mar	23-May	15-Mar	23-May	15-Mar	23-May	15-Mar	2-Jun	16-Mar	23-May	16-Mar	23-May
Croatia		22-Mar	22-May	22-Mar	22-May	22-Mar	22-May	22-Mar	1-Sep	22-Mar	22-May	22-Mar	5-Jul
Denmark		13-Mar	15-Apr	13-Mar	15-Apr	13-Mar	15-Apr	13-Mar	15-Aug	13-Mar	15-Aug	13-Mar	15-Aug
Finland		16-Mar	15-Apr	16-Mar	15-Apr	16-Mar	15-Apr	16-Mar	13-May	16-Mar	1-Jun	16-Mar	1-Jun
France		16-Mar	11-May	16-Mar	11-May	16-Mar	11-May	16-Mar	11-May	16-Mar	11-May	16-Mar	11-May
Italy		24-Feb	3-Jun	8-Mar	3-Jun	31-Jan	3-Jun	4-Mar	1-Sep	21-Mar	18-May	23-Feb	15-Jun
Liechtenstein		16-Mar		16-Mar		16-Mar		16-Mar		16-Mar		16-Mar	
Netherlands		12-Mar	20-May	12-Mar	20-May	13-Mar	20-May	12-Mar	1-Sep	12-Mar	20-May	12-Mar	15-Jun
Norway		12-Mar		12-Mar		13-Mar		12-Mar		12-Mar		12-Mar	
Saudi Arabia		15-Mar		15-Mar		21-Mar	21-May	15-Mar		15-Mar		15-Mar	26-Jul
Spain		22-Mar	21-Jun	22-Mar	21-Jun	22-Mar	21-Jun	22-Mar	21-Jun	28-Mar	12-Apr	28-Mar	12-Apr
Sweden				16-Mar	15-Jun	18-Mar	15-Jun	16-Mar	15-Jun			11-Mar	15-Jun
Switzerland		16-Mar	27-Apr	16-Mar	27-Apr	16-Mar	27-Apr	16-Mar		16-Mar	27-Apr	28-Feb	
United Kingdom		22-Mar	30-May	22-Mar	30-May	22-Mar	15-Jun	22-Mar	1-Sep	22-Mar	1-Sep	22-Mar	1-Sep

Appendix 2. Glossary of the United Nations Development Program (UNDP) - Human Development Index (HDI) and World Health Organization (WHO) - Health System Performance index

United Nations Development Program (UNDP) - Human Development Index (HDI)⁷¹

The human development index (HDI) developed by the United Nations Development Program (UNDP), is a composite summary measure of country development status. In its calculation, each country's score is the average achievement of the country in 3 key dimensions of human development. These include (1) a long and healthy life; (2) being knowledgeable; (3) have a decent standard of living. The health dimension is assessed by life expectancy at birth, the education dimension is measured by mean of years of schooling for adults aged 25 years and more and expected years of schooling for children of school entering age. The standard of living dimension is measured by gross national income (GNI) per capita. The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI. The scores for the 3 HDI dimension indices are then aggregated into a composite index using geometric mean with equal weights to the three dimensions.

World Health Organization (WHO) - Health System Performance index⁷²

The Health System Performance index developed by the World Health Organization (WHO) is a composite summary measure of country health system performance. In its calculation, each country's score is the average achievement of the country in 5 key goals (dimensions) of health system performance. These include (1) health (outcomes) quality, (2) health (outcomes) equity, (3) (health systems) responsiveness quality, (4) (health systems) responsiveness equity, and (5) (health systems) fairness in financing. The Health System Performance index is a weighted average of the 5 component goals, where the first, second, and fifth goal are weighted at 0.25, and the third and fourth goals are weighted at 0.125. These weights are based on a survey carried out by WHO to elicit stated preferences of individuals in their relative valuations of the goals of the health system.

Appendix 3. Fixed effect modeling

While a linear mixed effect model is a suitable modeling technique for longitudinal data, one can also apply an one-way fixed effect model to assess similar behavior. The model we use here is as follows:

$$\ln(\text{Mortality Per Million})_{ij} = (\text{Country})_i + (\text{National Facemask Policy})_{ij} B_1 + (\text{Days})_{ij} B_2 + (\text{Days}^2)_{ij} B_3 + (\text{Monday})_{ij} B_4 + (\text{Quarantine Policy})_{ij} B_5 + [(\text{Group})_i \times (\text{Days})_{ij}] B_6 + [(\text{Group})_{ij} \times (\text{Days}^2)_{ij}] B_7 + [(\text{National Facemask Policy})_{ij} \times (\text{Days})_{ij}] B_8 + [(\text{National Facemask Policy})_{ij} \times (\text{Days}^2)_{ij}] B_9 + \epsilon_{ij}$$

where $Country_i$ is the country level fixed effect. Note that this model is much simpler than the full model presented in the main manuscript. This is because an one-way fixed effect model is not able to estimate country level predictors (such as the social trust score), hence all country level predictors are omitted in this model. Ideally the country level fixed effect should adjust for these confounders. The estimated coefficients are presented in the following table.

Appendix Table 3. Estimated Coefficients for Fixed Effect Modeling

Parameter	Coefficient	SE	p-value
National mask policy (yes vs no)	0.14	0.12	0.27
Number of days since the first COVID-19 case	0.16	<0.01	<0.01
Number of days since the first COVID-19 case (squared)	>-0.01	<0.01	<0.01
Monday (yes vs no)	>-0.01	<0.01	0.33
National movement restriction (yes vs no)	0.29	0.02	<0.01
Group x days since the first COVID-19 case	-0.06	<0.01	<0.01
Group x days since the first COVID-19 case (squared)	<0.01	<0.01	<0.01
National mask policy x number of days since the first COVID-19 case	<0.01	<0.01	0.31
National mask policy x number of days since the first COVID-19 case (squared)	>-0.01	<0.01	<0.01

Comparing this table with Table 3, we can see that most of the coefficient estimates remain similar, indicating that the linear mixed model and fixed effect model coincide with each other. Performing a similar analysis as in the main manuscript, we can show that the countries without facemask policy have a daily average increase of 0.1576 – 0.0022(days since first case) log death per million, while countries with facemask policy have a daily average increase of 0.1056 – 0.0007(days since first case) log death per million. These results also confirm those shown in the main manuscript.

Appendix 4. Parallel trend assumption modeling

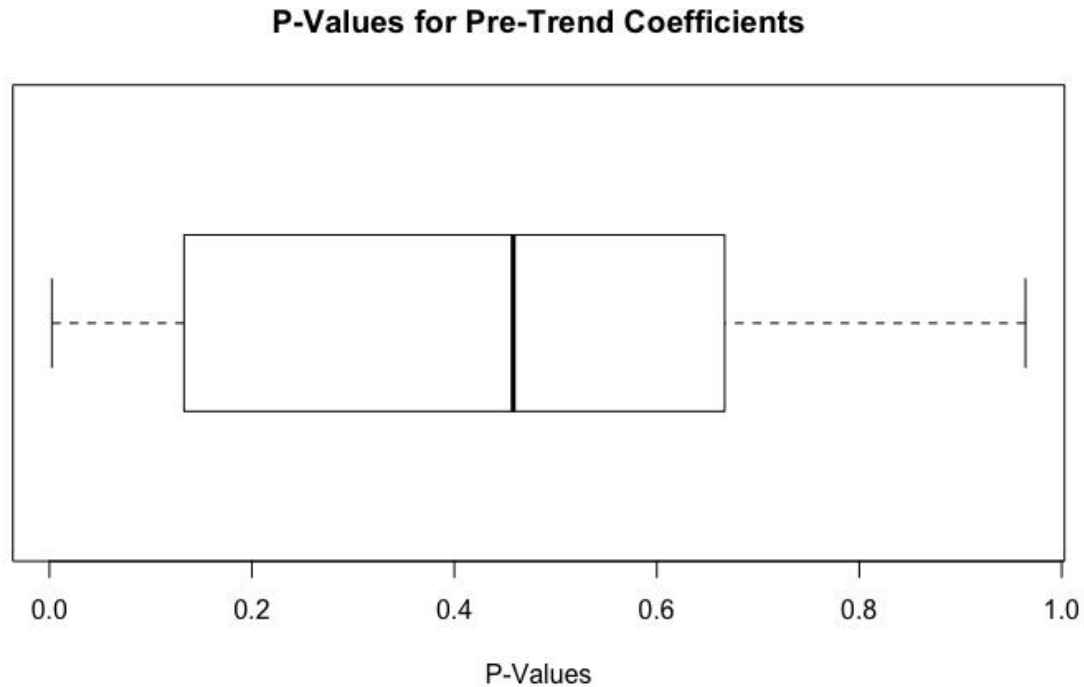
As discussed in the main manuscript, it is important to show that no pre-trend exists for such data set, which in-turn reveals the significance of the effect of intervention. One approach to verify this assumption involves fitting a dynamic event model,⁷³ and to show certain estimated coefficients are statistically insignificant. In particular, we define the variable K_{it} , called “relative time”, as the number of time points relative to the mask policy implementation for masked country i , i.e. $K_{it} = t - E_i$, where E_i is the time of mask implementation for masked country i . Note, this value will be negative for time points t prior to mask implementation, and positive otherwise. The dynamic event model takes the following form:

$$\begin{aligned} \ln(\text{Mortality Per Million})_{ij} = & B_0 + (\text{Days})_{ij} B_1 + (\text{Days}^2)_{ij} B_2 + (\text{Monday})_{ij} B_3 + (\text{Population} \\ & \text{Density})_i B_4 + (\text{Population over 65})_i B_5 + (\text{Urban Ratio})_i B_6 + (\text{Sex})_i B_7 + (\text{Quarantine Policy})_{ij} B_8 \\ & + (\text{Migrant Index})_i B_9 + (\text{Health Expenditure})_i B_{10} + (\text{ICU Beds})_i B_{11} + (\text{Hospital Beds})_i B_{12} + \\ & (\text{Social Trust})_i B_{13} + \sum_{k=-\infty}^{\infty} \gamma_k \mathbf{1}\{K_{it}=k\} + \mu_i + (\text{Days})_{ij} v_i + \epsilon_{ij} \end{aligned}$$

In the model above, $\mathbf{1}\{.\}$ denotes the indicator function, where $\mathbf{1}\{.\} = 1$ if the expression within is satisfied, and 0 otherwise. Pre-trend data will have $k < 0$, while data after mask policy implementation will have $k \geq 0$. Note this mixed effect model is similar to the main model presented in the manuscript.

We chose to model the dynamic effects using a similar structure since a mixed effect model fits the data better, and adjusting for different variables can help eliminate potential confounders, so the γ coefficients can estimate any existing pre-trend and post-trend. In order to show that pre-trend doesn't exist in the data, one needs to show all γ_k are statistically insignificant for $k < 0$, which indicates that countries with mask implementation do not have additional confounding factors unexplained by the model prior to mask implementation. One approach is verify this is to observe the p -values of γ_k for when $k < 0$. Below shows the boxplot for such p -values.

Appendix Figure 4. Boxplot of p -values γ_k for when $k < 0$.



Notes: Observing the boxplot in Appendix Figure 4, one can see that a majority of the coefficients are statistically insignificant (with p -value greater than 0.05). Out of 55 pre-trend coefficients, only 9 showed statistical significance. Deeper examination at these 9 coefficients reveals that all are at time periods -34 and earlier, indicating these coefficients capture the relative times at least 34 days prior to mask implementation. Provided only a few countries have relative times of -34 days and earlier, these estimated coefficients are less stable and hence can potentially be affected by random noise. Based on this analysis, we can confirm that no pre-trend exists in this data set, hence showing the significance of mask policy implementation.

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Appendix 5. Investigation of non-pharmaceutical interventions

While we have demonstrated the association between facemask policy and mortality, it can be argued that other non-pharmaceutical interventions have also played a role in controlling the mortality rate. According to Appendix Table 1 above, there are potentially 6 other interventions in placed during our period of study, such as quarantine, home stay, schools' closure, etc. To demonstrate the association of facemask policy remains in the presences of other interventions, individual models were fitted that include an additional time variable to control for the duration of each restriction policy. Below shows the modeling results for each of the 6 policies. Given our main focus concerns the variables that involve mask policy, groupings, and days into the pandemic, only a subset of estimated coefficients are presented.

Appendix Table 5. Estimated Coefficients (and *p*-values) for Models With Duration of Individual Intervention Policies

Parameter	Quarantine	Home stay	Travel restriction	Schools' closure	Business closure	Restriction of gathering
Group (mask vs no mask)	1.08 (0.02)	1.09 (0.01)	1.00 (0.02)	1.00 (0.03)	1.23 (0.01)	1.02 (0.03)
National mask policy (yes vs no)	0.39 (0.02)	0.40 (0.01)	0.40 (0.01)	0.43 (0.01)	0.38 (0.01)	0.38 (0.01)
Number of days since the first COVID-19 case	0.13 (<0.01)	0.13 (<0.01)	0.13 (<0.01)	0.13 (<0.01)	0.15 (<0.01)	0.14 (<0.01)
Number of days since the first COVID-19 case (squared)	>-0.01 (<0.01)	>-0.01 (<0.01)	>-0.01 (<0.01)	>-0.01 (<0.01)	>-0.01 (<0.01)	>-0.01 (<0.01)
Duration of policy	0.04 (<0.01)	0.04 (<0.01)	0.04 (<0.01)	0.04 (<0.01)	0.02 (<0.01)	0.03 (<0.01)
Group x days since the first COVID-19 case	-0.05 (<0.01)	-0.05 (<0.01)	-0.05 (<0.01)	-0.06 (<0.01)	-0.05 (<0.01)	-0.05 (<0.01)
Group x days since the first COVID-19 case (squared)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)
National mask policy x number of days since the first COVID-19 case	-0.01 (<0.01)	-0.01 (<0.01)	-0.01 (<0.01)	-0.01 (<0.01)	-0.01 (<0.01)	-0.01 (<0.01)
National mask policy x number of days since the first COVID-19 case (squared)	<0.01 (0.04)	<0.01 (0.03)	<0.01 (0.03)	<0.01 (0.01)	<0.01 (0.05)	<0.01 (0.05)

The above Appendix Table 5, reveals the estimated coefficients are similar to those presented in Table 3 from the manuscript. This indicates that the association between facial mask policy and COVID-19 mortality is not changed by the presences of other non-pharmaceutical interventions. Moreover, when including all 6 policies into the model, the results remain similar.

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