

Report 26 Reduction in mobility and COVID-19 transmission

Pierre Nouvellet¹, Sangeeta Bhatia, Anne Cori, Kylie E C Ainslie, Marc Baguelin, Samir Bhatt, Adhiratha Boonyasiri, Nicholas F Brazeau, Lorenzo Cattarino, Laura V Cooper, Helen Coupland, Zulma M Cucunuba, Gina Cuomo-Dannenburg, Amy Dighe, Bimandra A Djaafara, Ilaria Dorigatti, Oliver D Eales, Sabine L van Elsland, Fabricia F Nascimento, Richard G FitzJohn, Katy A M Gaythorpe, Lily Geidelberg, Nicholas C Grassly, William D Green, Arran Hamlet, Katharina Hauck, Wes Hinsley, Natsuko Imai, Benjamin Jeffrey, Edward Knock, Daniel J Laydon, John A Lees, Tara Mangal, Thomas A Mellan, Gemma Nedjati-Gilani, Kris V Parag, Margarita Pons-Salort, Manon Ragonnet-Cronin, Steven Riley, H Juliette T Unwin, Robert Verity, Michaela A C Vollmer, Erik Volz, Patrick G T Walker, Caroline E Walters, Haowei Wang, Oliver J Watson, Charles Whittaker, Lilith K Whittles, Xiaoyue Xi, Neil M. Ferguson, Christl A. Donnelly

WHO Collaborating Centre for Infectious Disease Modelling
MRC Centre for Global Infectious Disease Analysis
Abdul Latif Jameel Institute for Disease and Emergency Analytics (J-IDEA)
Imperial College London
School of Life Sciences, University of Sussex
Department of Statistics, University of Oxford

¹Corresponding author: p.nouvellet@imperial.ac.uk, pierre.nouvellet@sussex.ac.uk

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Summary

In response to the COVID-19 pandemic, countries have sought to control transmission of SARS-CoV-2 by restricting population movement through social distancing interventions, reducing the number of contacts.

Mobility data represent an important proxy measure of social distancing. Here, we develop a framework to infer the relationship between mobility and the key measure of population-level disease transmission, the reproduction number (R). The framework is applied to 53 countries with sustained SARS-CoV-2 transmission based on two distinct country-specific automated measures of human mobility, Apple and Google mobility data.

For both datasets, the relationship between mobility and transmission was consistent within and across countries and explained more than 85% of the variance in the observed variation in transmissibility. We quantified country-specific mobility thresholds defined as the reduction in mobility necessary to expect a decline in new infections ($R < 1$).

While social contacts were sufficiently reduced in France, Spain and the United Kingdom to control COVID-19 as of the 10th of May, we find that enhanced control measures are still warranted for the majority of countries. We found encouraging early evidence of some decoupling of transmission and mobility in 10 countries, a key indicator of successful easing of social-distancing restrictions.

Easing social-distancing restrictions should be considered very carefully, as small increases in contact rates are likely to risk resurgence even where COVID-19 is apparently under control. Overall, strong population-wide social-distancing measures are effective to control COVID-19; however gradual easing of restrictions must be accompanied by alternative interventions, such as efficient contact-tracing, to ensure control.

1. Introduction

Since the declaration of COVID-19 as a Public Health Emergency of International Concern in late January 2020¹, many countries have struggled to prevent the importation^{2,3} and subsequent local transmission of SARS-CoV-2⁴, the virus that causes COVID-19⁵.

Social-distancing, case isolation, and shielding have been widely used to limit community-level transmission of SARS-CoV-2 and protect vulnerable groups^{6,7}. These interventions aim to reduce mobility and contact within the population and thus to reduce the transmissibility of SARS-CoV-2, as measured by the reproduction number (R, the average number of secondary cases caused by a primary case). Early in the epidemic, reductions in a variety of digital sources of mobility data were shown to correlate well with decreases in incidence^{8,9} and contact patterns¹⁰.

In the face of the threat posed by COVID-19, most countries rapidly implemented intensive social distancing policies to suppress transmission (bringing R to below 1) and thus avoid overwhelming healthcare capacity¹¹. While such a reduction in new cases has now been convincingly observed in mainland China¹², Italy, France, Spain the UK¹³⁻¹⁵, and Hong Kong¹⁶, where in some cases a reduction in transmission has been explicitly linked to the reduction in mobility^{17,18}, many countries are still experiencing widespread transmission of SARS-CoV-2^{19,20}.

Understanding how well mobility data reflects population contact rates and whether that relationship is changing in countries transitioning from lockdown measures is important for tracking the trajectory of country epidemics, improving forecasting and assessing the effectiveness of ongoing control measures. Here, we characterise the relationship between transmission and different mobility data streams for 53 countries around the world.

2. Methods

Data

Data on deaths due to COVID-19 by country were sourced from the European Centres for Disease Control (ECDC)⁴, including daily death counts reported by each country's official surveillance system up to the 26th of April 2020. Our analysis is based on countries which fulfil the following three criteria: 1) at least 10 deaths reported in the last week of data, 2) at least 10 deaths in the preceding week, and 3) at least 100 deaths reported in total. These criteria were chosen to ensure that the countries included showed evidence of active transmission.

Mobility data were sourced from Apple²² and Google²³. These data reflect the movement of people with an Apple or Android device using mapping apps. For the Apple data, the measure of mobility is reported for three data streams: 'driving', 'walking' and 'transit' mobility. For the Google data, the measure of mobility is reported for six data streams: 'residential', 'grocery and pharmacy', 'parks', 'transit stations', 'workplaces' and 'retail and recreation', and our analysis focused on the last three data streams. Both measures estimate relative daily mobility for each country and are quantified relative to the maximum mobility measured across the time series (prior to the pandemic WHO declaration). Apple and Google mobility data were available from the 13th of January and 15th of February 2020, respectively, up to the last day that deaths were analysed (10th of May).

Our analysis is based on 53 countries for which we had epidemiological data (meeting our active transmission thresholds) and mobility data. This include 37 countries for which we had both Google and Apple mobility data; 3 countries for which we only Apple mobility data; and 13 countries for which we had only Google mobility data (see Table S1).

Processing mobility data

The various mobility data streams (i.e. driving, walking and transit movement for Apple and the six streams for Google) showed both short- and long-term variability in movement levels. For each country and data source, we: 1) combined the mobility data streams (aggregating 'walking', 'driving' and 'transit' for Apple and 'retail and recreation', 'transit stations' and 'workplaces' for Google) into a single measure; 2) calculated a weekly average (Thursday-to-Thursday); 3) assigned this average to the Thursday of each week, and 4) interpolated mobility on other days linearly from these. This smoothed measure of mobility was then rescaled (between 0 and 1) relative to the maximum Monday-to-Thursday observed average to obtain a single daily measure of relative mobility by country $m_{t,i}$ (Fig. 1.a).

Estimating transmissibility, R, using mobility data

We define the instantaneous reproduction number on day t , $R_{t,i}$, which reflects the level of transmissibility in country i on that day. We assume $R_{t,i}$ is linked to relative mobility on that day via the following:

$$\log(R_{t,i}) = \log(R_{0,i}) - \beta_i (1 - m_{t,i})$$

where $R_{0,i}$ is the basic reproduction number in country i and $m_{t,i}$ is the relative mobility in country i on day t . When mobility is at its peak (1 or 100%), transmissibility is characterised by the basic reproduction number. Reduced mobility leads to reductions in the effective reproduction number (when β_i is positive). As the maximum smoothed mobility in the observed range is scaled to 1, the estimates of the basic reproduction numbers can be thought as upper bound, similarly to defining the reproduction number of a vector borne disease as transmissibility during the period with highest vectorial transmission.

In this framework, due to the delay between infection and deaths, the instantaneous reproduction number experienced by those dying on day t in country i , $R_{t,i}^D$, is a weighted average of the instantaneous reproduction number on day t , $R_{t,i}$:

$$R_{t,i}^D = \sum_{s=0}^t R_{s,i} h(t-s)$$

assuming that the infection-to-death interval follows a gamma distribution, h , with mean 18.8 days and standard deviation of 8.46 days¹⁹ (see SI.7 for details).

We relate the observed reported deaths on day t in country i to the basic reproduction number ($R_{0,i}$) and the parameter (β_i) linking transmissibility to mobility ($m_{t,i}$) using the renewal equation^{24,25}:

$$D_{t,i} \sim NB \left(R_{t,i}^D \sum_{s=0}^t [D_{s,i} w_{t-s}], \delta \right)$$

where $D_{t,i}$ is the reported deaths on day t in country i , and w is the serial interval (i.e. a serial interval for deaths defined as the time between deaths of the infector and infectee) assumed to be gamma distributed with mean of 6.48 days and standard deviation 3.83 days¹¹. Here we assume that the number of reported deaths follow a negative binomial distribution (such that the variance in the observed numbers of deaths is greater than or equal to the expected number of deaths) with over-dispersion δ .

The framework outlined above and estimates of transmissibility obtained are robust to under-reporting of deaths but are affected by variation in levels of reporting.

Once the relationship between mobility and $R_{t,i}$ is estimated, we can evaluate the distribution for $R_{t,i}$ for any level of mobility. Using a fine grid of mobility, we obtained estimates of corresponding $R_{t,i}$, and this allowed us to estimate the distribution of the reduction of mobility when $R_{t,i} = 1$. This *mobility threshold* can be interpreted as the reduction in measured mobility that would be necessary in order to achieve control, given the other behaviours of the population over the period under study (e.g. country-specific ways that people are interacting with each other and country-specific additional control measures such as testing and contact tracing).

Implementation and caveats

We estimated the joint posterior distribution of $R_{0,i}$'s and β_i 's using a Markov Chain Monte Carlo procedure with a Metropolis-Hasting algorithm²⁶. Posterior distributions for $R_{t,i}$ and $R_{t,i}^D$ can be directly obtained from the above. To ensure our parameter estimates were data-driven, we used uninformative prior distributions for $R_{0,i}$'s (uniform in the range [2; 5]) and β_i 's (uniform in the range [-100; 100]).

As there are likely to be large heterogeneities in first the transmissibility between individuals and second the reporting of deaths, we assume a negative binomial likelihood by default, which allows us to estimate an over-dispersion parameter, δ . We used an exponential prior for δ with a mean of 1 (equivalent to a geometric likelihood). As a sensitivity analysis, we also fit the model using a Poisson likelihood (see SI for results). The model was also fitted using an alternative lower shorter serial interval of deaths with mean 4.8 and standard deviation 2.7 days²⁷. We evaluated the correlation between estimated mobility thresholds and basic reproduction number across countries to ensure the variation in the estimated thresholds was not driven by the variation in estimated basic reproduction number (SI). Finally, as the reporting of deaths might have changed during the country-specific early phase of the epidemic, we re-estimated the mobility-transmission relationship discarding from the likelihood all days previous to the two consecutive weeks reporting each at least 10 deaths (the criteria for sustained epidemic, see SI).

Fitting the data with the model outlined above imposes a functional relationship between mobility and transmissibility. Therefore, as well as the model above, we fitted a ‘null’ model, where transmissibility was not linked to mobility (i.e. $\beta_i = 0$). This ‘null’ model assumes a single growth rate and that the epidemic was growing unchanged and dynamics can be characterised by a single parameter, $R_{0,i}$. For each country, the best model was chosen using the Deviance Information Criterion (DIC)²⁸.

The best-fitting model was fitted at multiple time-points, allowing us to evaluate its predictive ability in real-time. The nine time points fitted were the week ending the 15th of March until the week ending 10th of May 2020. For countries that met our active transmission criteria and for which we had mobility data, we fitted the full and the null models (using the whole time series of deaths up to the last date), assuming either a Poisson or negative binomial distribution for reported deaths.

Evaluating model fit

We assessed whether the simple model outlined above (two parameters per country, $R_{0,i}$ and β_i) captured the trends in the instantaneous reproduction number. Independent of the mobility data, we estimated the instantaneous reproduction number based on well-established methodology²⁴ and the associated R package ‘*EpiEstim*’²⁵. Using a Bayesian framework, the method estimates the instantaneous reproduction number based on daily death counts:

$$D_{t,i} \sim P \left(R_{t,i}^{D,obs} \sum_{s=0}^t [D_{s,i} w_{t-s}] \right)$$

with $R_{t,i}^{D,obs}$ the ‘observed’ instantaneous reproduction number. Weekly estimates of $R_{t,i}^{D,obs}$ were obtained assuming constant transmissibility for 7 days. The estimated $R_{t,i}^{D,obs}$ ’s from *EpiEstim*²⁵ assume a Poisson distribution of reported deaths. We also implemented a negative binomial model, which is equivalent to *EpiEstim* in the limit when there is no over-dispersion. This is critical as allowing over-dispersion is likely to change the $R_{t,i}^{D,obs}$ estimate, especially when reported deaths are low.

For each country, we could then compare $R_{t,i}^D$ and $R_{t,i}^{D,obs}$. While $R_{t,i}^D$ relies on estimating 1 or 2 parameters ($R_{0,i}$, and β_i if the null model is rejected), $R_{t,i}^{D,obs}$ relies on estimating as many parameters as there are number of weeks in the time-series of deaths.

As well as comparing the estimated instantaneous reproduction numbers over time, we compared the relationship between $R_{t,i}^D$ and $R_{t,i}^{D,obs}$ and mobility.

To do so, we linked death-related reproduction numbers to the earlier mobility patterns, $m_{t,i}$, when those dying were infected. We defined an effective mobility, $m_{t,t}^{eff}$, at time t that characterises the mobility at the time of infection of those who died at time t :

$$R_{t,i}^D = R_{0,i} e^{-\beta_i(1-m_{t,t}^{eff})}$$

Thus,

$$R_{t,i}^D = \sum_{s=0}^t R_{s,i} h_{t-s} = \sum_{s=0}^t R_{0,i} e^{-\beta_i(1-m_{i,s})} h(t-s)$$

(where $h(t-s)$ is the infection-to-death interval distribution). Therefore, the effective mobility is:

$$m_{t,t}^{eff} = 1 + \frac{1}{\beta_i} \log \left(\sum_{s=0}^t e^{-\beta_i(1-m_{i,s})} h(t-s) \right)$$

We can now plot $R_{t,i}^D$ and $R_{t,i}^{D,obs}$ against the effective mobility at the time of infection.

Interestingly, estimating the effective mobility experienced by those dying on day t relies on assumptions about the functional relationship between mobility and R_t . Intuitively, assuming that the effective mobility is equal to the past mobility weighted by the infection-to-death interval is equivalent to assuming a linear relationship between mobility and the reproduction number. Assuming $R_{t,i} = R_{0,i} - \beta_i(1 - m_{t,i})$, then, following the same logic as above, we have: $m_{t,t}^{eff} = 1 - (\sum_{s=0}^t (1 - m_{i,s})h(t-s))$.

Once the relationship between mobility and $R_{t,i}$ is characterised, we can evaluate the posterior distribution for $R_{t,i}$ for any mobility including when $R_{t,i} = 1$.

Dampening of the transmission-mobility relationship

As countries seek a way to ease social distancing measures, alternative public health control strategies are being considered, such as increased testing and contact tracing. Furthermore, while restrictions on travel are being relaxed, often recommendations for social distancing remain in force. We would therefore expect some decoupling of transmission and mobility, leading to a weakening of the correlation between mobility and underlying contact rates (and therefore transmission). The effect on ongoing effective controls which are decoupled from mobility would translate into a reduction of $R_{0,i}$ (and possibly a change in β_i), i.e. if the virus had been originally introduced while those measures were in place, baseline transmission would have been lower.

As $R_{t,i}^D$ is entirely and solely determined by estimated $R_{0,i}$ and β_i , we argue that a median $R_{t,i}^{D,obs}$ lower than the estimated 2.5th percentile of $R_{t,i}^D$ provide evidence of such a dampening of the transmissibility-mobility relationship. We do not attempt to infer the new mobility-transmissibility relationship, as it is too early to be robustly evaluated.

Producing short-term forecasts and longer-term scenario modelling

Short-term forecasts

Given the inferred relationship between mobility and transmission, and the delay between infection and deaths, recent mobility patterns can be used to inform future incidence of deaths.

We can use the same equation used for inference to project deaths forward. Past and recent mobility pattern inform $R_{t,i}^D$, and a branching process simulation was used to forecast future deaths.

As forecasts are produced for a 7-day horizon, we must make assumptions about mobility patterns during those 7 days. However, forecasts are robust to future mobility assumptions as they are weighted by the distribution of the infection-to-death interval. Given the assumed infection-to-death interval distribution, on the last final day of forecast (day 7), the last 7 days of projected mobility will be weighted by $\sum_{s=0}^7 h_s = 2.9\%$.

For our short-term forecasts, we assume future mobility is equal to the last observed measure of mobility.

Longer-term scenario modelling

For longer-term simulations, we explore two scenarios, assuming future mobility will be:

- maintained at its current level
- gradually increased from its current level to its maximum over a period of 60 days (linear increase in mobility).

Those scenarios were evaluated for a 60-day horizon.

3. Results

The negative binomial model outperformed the Poisson model for the distribution of the daily number of deaths in every week of inference. Unless otherwise specified, results presented below assume a negative binomial distribution of reported deaths (default likelihood).

Temporal variation in mobility

We found a consistent pattern of reduction in mobility across countries and across different mobility data sources (Figure 1a, for the UK and SI for other countries). Over the 53 countries considered, the median mobility estimated on the 10th of May was reduced by 56% according to Apple, and 51% according to Google from their maximum levels.

The 10% of countries with the smallest changes in mobility according to Apple data (including Denmark, Finland, Sweden and Ukraine) showed a less than 39% drop. The lowest change 10% of countries from Google data showed a less than 36% drop, with countries including Belarus, Cameroon, Denmark, Germany and Sweden. Using Apple data, the 10% of countries with the highest drops in mobility (including included Ireland, Morocco, Philippines and Spain) saw over a 76% drop. The same figure from Google data was 68% and the 10% of countries included Bolivia, Honduras, Panama, Peru and the Philippines.

Correlation between mobility and transmissibility

We found a consistent correlation between reductions in mobility and reductions in transmission intensity.

The null model (where mobility does not affect transmissibility) was accepted in only 6% (16 times) of the (263) country/inference periods. This tended to happen early in an epidemic, perhaps reflecting that the mobility had not changed sufficiently by then for the analysis to be well powered. For the most recent two weeks of inference in every country, the null model was never accepted.

For the UK (as well as other countries, see SI), a sharp decline in mobility (Figure 1a) was correlated with a sharp decline in the estimated reproduction number for cases $R_{t,i}$ (Figure 1b, red), which, after accounting for the infection-to-death interval, is later reflected in a sharp decline in the estimated reproduction number for deaths $R_{t,i}^D$ (Fig.1b, blue). The temporal trends in $R_{t,i}^D$ are well correlated to those in the 'observed' instantaneous reproduction number for deaths, $R_{t,i}^{D,obs}$, as estimated by the 'EpiEstim'-like method (Fig.1b, grey).

By linking mobility to transmissibility, we were able to capture both temporal trends in transmissibility and its relationship with mobility across multiple countries (Figure 1b,c and SI). Specifically, the relationship between mobility and transmissibility (Figure 1c) is well captured by our simple model, and, across countries, 87% of the variation in $R_{t,i}^{D,obs}$ are explained by the simple (R-squared of $R_{t,i}^{D,obs}$ against $R_{t,i}^D$).

Mobility thresholds

We estimated mobility thresholds for every country defined as the reduction in mobility necessary to bring transmissibility below the threshold of 1 (Figure 3 for Apple thresholds, see Figure SI.1 for Google thresholds).

We estimated that in the UK a reduction of 66% (95% CrI: 62-69%) of Apple mobility and 57% (95% CrI: 54.-61%) of Google mobility would be sufficient to reduce the reproduction number below 1.

Given the mobility reduction in the UK (on the 10th of May reached) – 70% (Apple), 66% (Google) – were above the estimated thresholds, we predict that the epidemic in the UK is under control (Figure 1-2).

On the 10th of May in the UK, we estimate that the reproduction numbers for new infections, $R_{t,i}$, were 0.91 (95% CrI: 0.84-0.99) and 0.82 (95% CrI: 0.74-0.90) according to Apple and Google data, respectively. Further, the reproduction numbers estimated from deaths, $R_{t,i}^D$, were estimated at 0.83 (95% CrI: 0.76-0.91) and 0.77 (95% CrI: 0.69-0.85), respectively. The lower reproduction number associated with deaths ($R_{t,i}^D$) than infection ($R_{t,i}$) suggests that on the 10th of May recent increases in mobility (Figure 2b) led to recent increases in transmissibility.

We found substantial heterogeneity between countries in estimating this mobility threshold (Figure 3, SI.1-2). The median mobility reduction threshold across the countries considered (estimated as the median of country-specific medians) was estimated to be a 68% (Apple) or 59% (Google) reduction. Countries such as Sweden and Switzerland appeared to require a smaller reduction in mobility to bring R below one. While Apple and Google mobility estimates and their respective mobility thresholds differed from each other, for most countries, both thresholds estimated were consistent relative to the observed mobility (Figure SI.2).

As of the 10th of May, in only 3 countries (France, Spain and the UK) the observed reduction in mobility was higher than the estimated upper 95% CrI thresholds, suggesting an epidemic under control (Figure 3 and SI.1-2, and Table SI.2). In 30 out of the 53 countries considered, the reduction in mobility was lower than the estimated lower 95% CrI thresholds (based on combined information), suggesting ongoing epidemics. For the remaining 20 countries, the latest mobility estimates overlapped with one or both of the mobility thresholds estimated, suggesting weak evidence of control.

The mobility threshold estimates were robust to assumptions about the serial interval distribution, and the parametric distribution of the number of reported deaths assumed (Poisson or negative binomial) (Figure 3-SI.1 and Table SI.3). In addition, across countries, the estimated mobility thresholds were not correlated with the estimated Basic reproduction numbers (Figure SI.3) and estimated parameters were robust to discarding the very early dynamic from the likelihood (i.e. before our sustained epidemic criteria is met, Figure SI.4).

Dampening of the transmission-mobility relationship

As of the 10th of May 2020, the median $R_{t,i}^{D,obs}$ was lower than the estimated 2.5th percentile of $R_{t,i}^D$, for 10 countries suggesting a decoupling of the transmission-mobility relationship: Austria, Canada, Denmark, Germany, Ireland, Poland, Sweden, Switzerland, Turkey and the UK.

Future scenarios

Short-term forecasting performed well (see Figure 3a,c for UK Apple-based and SI for UK Google-based and for other countries), especially once the null-model was rejected (blue forecasts in Figure 3a).

In the UK, the latest estimated reproduction numbers are significantly below the threshold of 1 (Figure 3b) but are sufficiently high that, even if social behaviour and control interventions remain unchanged, the epidemic in the UK would likely continue for months (Figure 3c). If social behaviour and control interventions remain unchanged, we expect daily deaths predicted to drop below 100 around the end of June (Apple: median after 9th of July, 95% CrI [13th of June; after 9th of July], Google: median 28th of June, 95% CrI [30th of June; after 9th of July]). Without other changes (e.g. no increased in contact tracing), an increase in mobility unsurprisingly show a rapid reversion to exponential growth (Figure 3d).

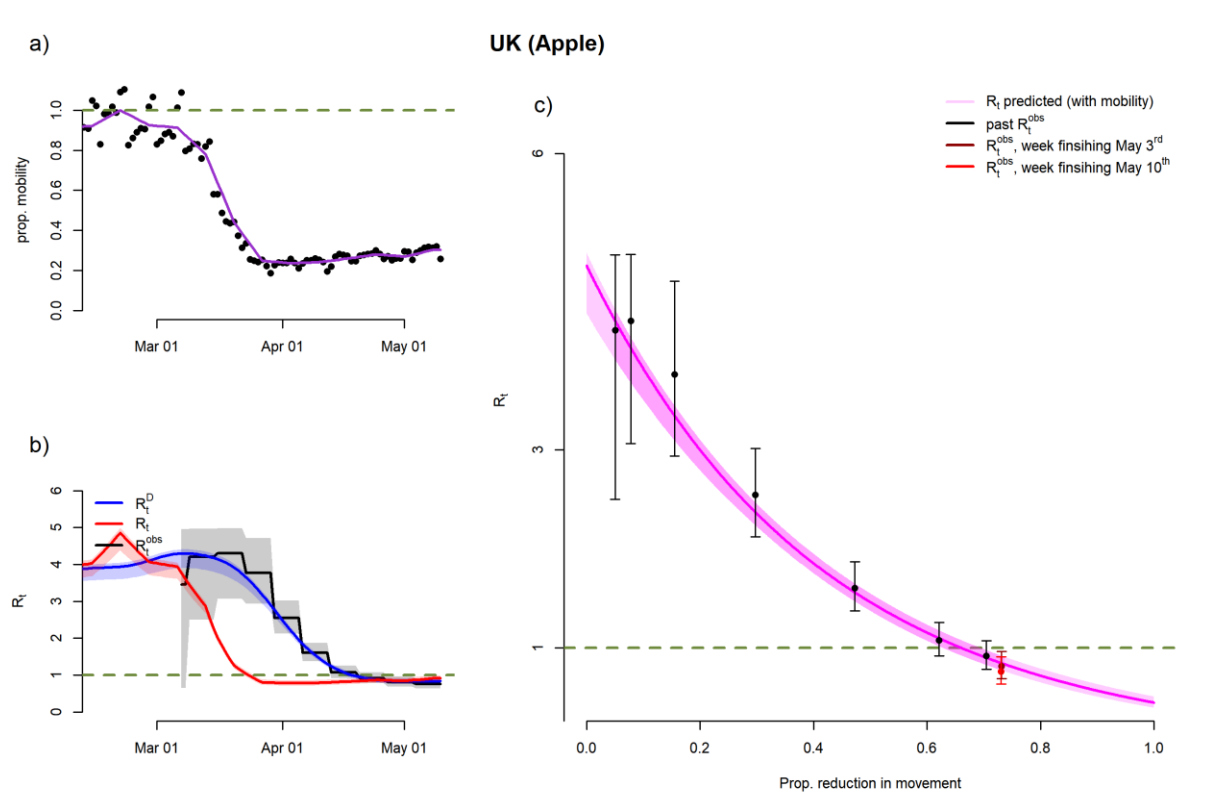


Figure 1: Relationship between mobility and transmission. **a)** Smoothed Apple mobility (purple line) and daily mobility (aggregated and scaled over the data streams). **b)** Estimated daily reproduction number for new infections (red) and deaths by date of reported death (blue) estimated using the best-fitting model and mobility data. Instantaneous reproduction number estimated from deaths data alone using a daily 7-day sliding window (grey); only estimates for which the coefficient of variation was lower than 0.2 are shown. In each case shading represents the 95% credible interval. **c)** Estimates of the reproduction number against changes in mobility using our best model (2 estimated parameters) (pink line showing the median predictions, with shading indicating the 95% posterior interval) and 'observed' instantaneous reproduction number using 'EpiEstim'-like method (black with 95% credible interval, estimates for the last 2 weeks are shown in dark and bright red respectively).

Results based on Apple mobility data - equivalent figure using Google mobility can be found in the SI (Figure SI.54); the Apple-related figure is shown as it provides a marginally better fit (DIC using Google Apple: 740; DIC using Google mobility: 744, see Table SI.2).

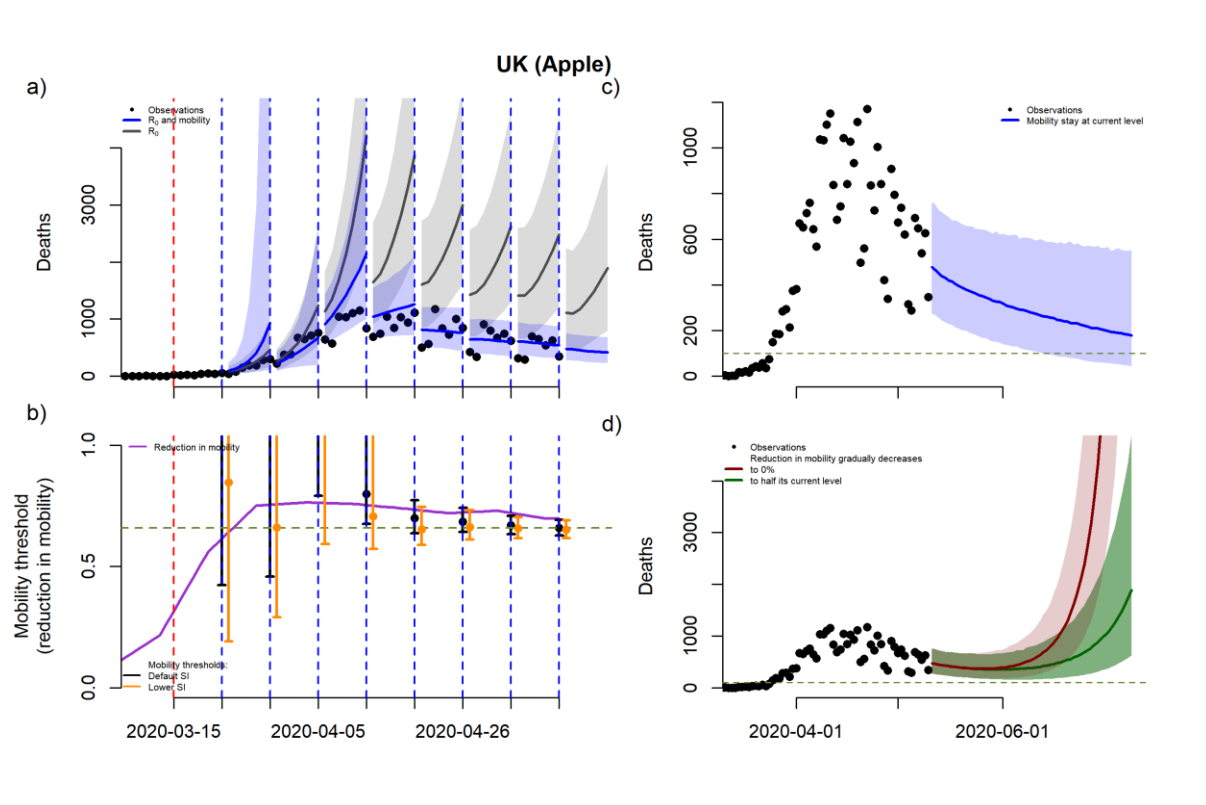


Figure 2: Using mobility to predict future incidence of deaths. **a)** Observed daily incidence of reported deaths in the United Kingdom (black circles) and past and most recent short-term forecasts. Forecasts are ‘out-of-sample’ predictions relying on model fit given the data available before the start of the forecast. Blue forecasts show results for the model with a link to mobility, while grey forecast is the null model (no effect of mobility). **b)** Median and 95% CrI estimated mobility thresholds to interrupt transmission in the UK for each week of inference (black and orange for default and alternative lower serial interval). The purple solid line shows the smoothed reduction in daily mobility. Red/blue vertical lines indicate weeks where no threshold/a threshold could be estimated. The green horizontal dashed line shows the most recently estimated median threshold. **c-d)** Long-term forecasts of incidence of reported deaths for the United Kingdom assuming mobility stays at the level observed on the 10th of May (**c**) or gradually increases back to 100% within 2 months (red), or to a level intermediate between its current and maximum level (green) (**d**) without other changes. The forecasts assume the default serial interval and a negative binomial likelihood. The green horizontal dashed dotted lines show the threshold of 100 reported deaths per day.

Results based on Apple mobility data - equivalent figure using Google mobility can be found in the SI (Figure SI.54); the Apple related figure is shown as it provides a marginally better fit (DIC using Google Apple: 740; DIC using Google mobility: 744, see Table SI.2).

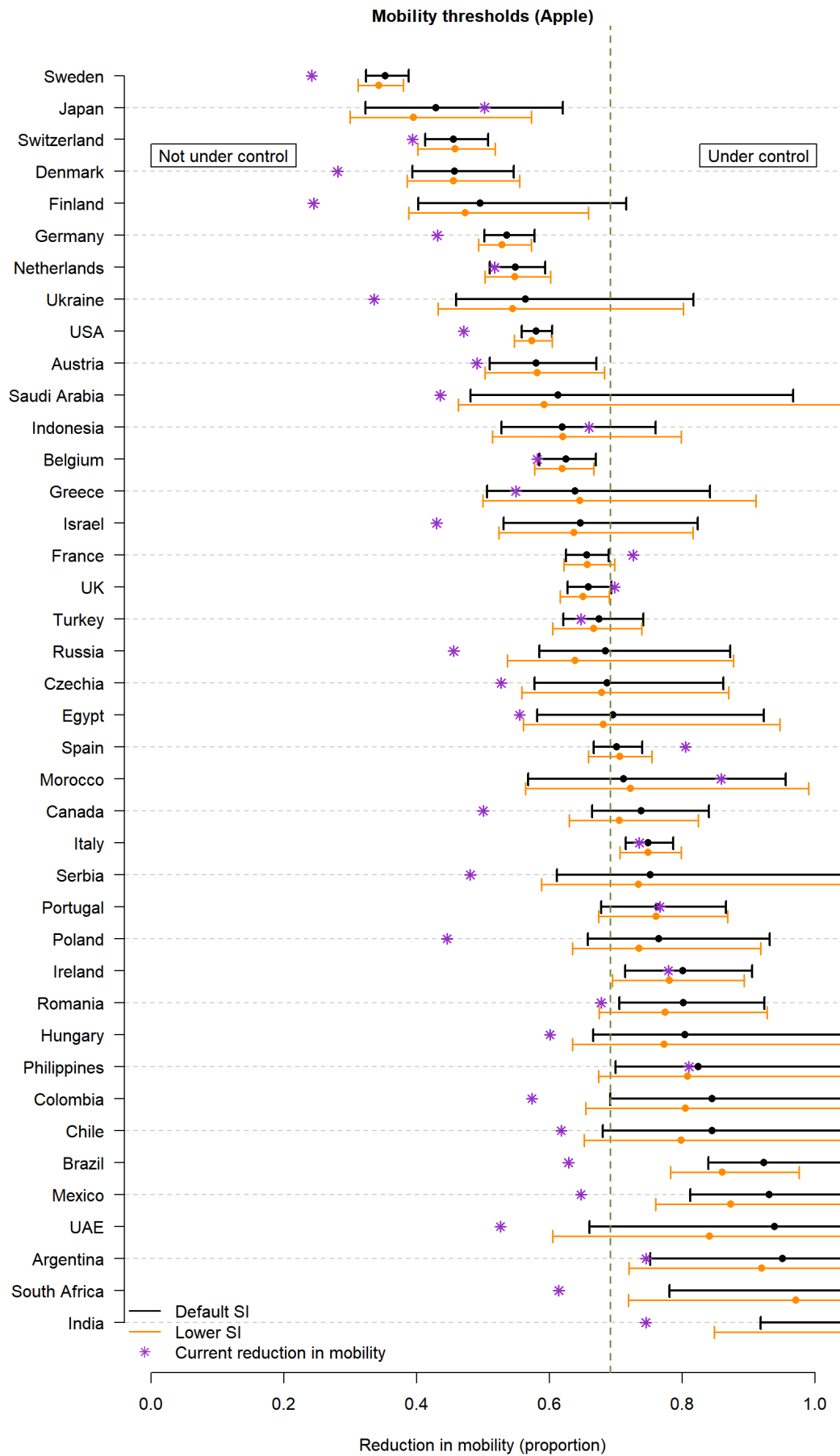


Figure 3: Results based on Apple mobility data. Median and 95% CrI country-specific Apple mobility thresholds to interrupt transmission (to achieve $R < 1$). The main (black) thresholds assume the default serial interval and a negative binomial likelihood (estimated thresholds for the alternative lower serial interval in orange, see SI for Poisson likelihood). The dashed vertical green line represents the median threshold estimated from the countries' medians. The purple stars represent where the latest mobility has been estimated (on 10th of May). A purple star on the right of the credible interval indicates that the reduction in mobility appears to be sufficient to contain COVID-19 transmission. Equivalent figure for the Google mobility thresholds can be found in the SI (Figure SI.1). For some countries, we only have Google or Apple mobility; The Google mobility thresholds figure includes 13 additional countries: Afghanistan, Bangladesh, Belarus, Bolivia, Cameroon, Dominican Republic, Ecuador, Honduras, Moldova, Nigeria, Pakistan, Panama and Peru.

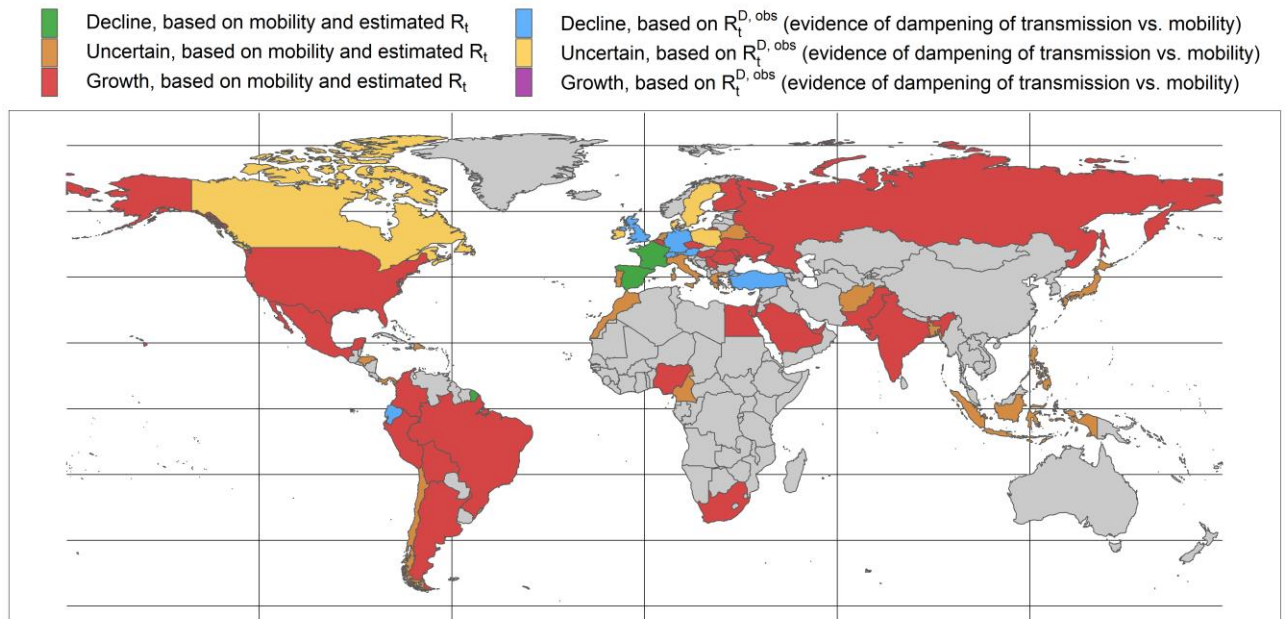


Figure 4: Map showing epidemics trend in selected countries on the 10th of May 2020. Where we found evidence of recent dampening of the mobility/transmissibility relationship, we present results based on $R_{t,i}^{D,obs}$. Where we found no such evidence, we present results based on $R_{t,i}$, which rely on mobility estimates. When this interpretation of the $R_{t,i}$ estimates based on Apple/Google differed, we present the most uncertain one (Chile and Italy: growth or uncertain, Japan, decline or uncertain). Countries in grey indicate countries where we could not estimate the mobility threshold.

4. Discussion

We found consistent evidence that automated measures of mobility correlate well with transmission intensity over time in several countries. The relationship holds for both Apple and Google mobility data and was robust to assumptions about the likelihood and serial interval distribution. Given the precisely estimated relationship between mobility and transmissibility, short-term forecasting of future transmission based on assumptions of future mobility was possible and performed well. As mobility data increasingly become available in real-time (currently updated across countries with 2-to-4, 7-to-10 - days delay for Apple, Google mobility), future epidemiological forecasts may increasingly rely on this type of data.

Our framework allows us to estimate country-specific mobility thresholds: if the reduction in mobility reaches a certain level, we predict that SARS-CoV-2 infection incidence will decline, if all other factors that impact on transmissibility stay unchanged. Although Apple and Google mobility measures differ, and therefore so do the mobility thresholds, the link between transmissibility and each mobility measure was clear and consistent at any given time.

For the majority of countries included in our analyses, current levels of mobility are significantly higher, or at least not significantly lower, than the mobility threshold required for infection incidence to decline. However, the success of a few countries in controlling COVID-19 through population-wide social distancing and case isolation is encouraging and highlights the potential of such public health interventions.

The heterogeneity in estimated mobility thresholds between countries likely reflects socio-cultural differences and/or the differences in the interventions each country has implemented. While we were able to characterise between countries heterogeneity, within country heterogeneity is likely to also exist but were not considered here, for country-specific analyses of transmission see: for Brazil¹⁹, Italy¹⁸, and the US¹⁷.

Previous studies, prior to the pandemic, have shown how the proximity and interpersonal distances maintained between people while interacting vary substantially between countries, likely due to cultural differences²⁹, and this could influence baseline national levels of SARS-CoV-2 transmission. Similarly, it is likely that awareness of SARS-CoV-2 transmission will affect those interpersonal distances differently between countries, leading to heterogeneities in the relative reductions in mobility required to achieve COVID-19 control.

In addition, the COVID-19 public health responses are highly variable between countries. In particular, the levels of contact-tracing and testing vary considerably. South Korea, having previously experienced a large MERS coronavirus outbreak³⁰, implemented an aggressive strategy of tracing (and testing) early on³¹, allowing rapid control of the epidemic. South Korea was not included in this analysis as reported deaths are currently very low, falling short of our threshold for inclusion.

It follows that country-specific mobility thresholds are likely not constant but will vary over space and time. As a country intensifies its contact-tracing efforts, the mobility threshold would likely decrease (i.e. a smaller reduction would be required). Also, many countries are attempting to re-open (thus increasing mobility) while maintaining physical distancing. Our analysis also indicates that in the few countries where population-wide social distancing and case isolation have been successfully implemented, the margin to lift mobility restrictions is very small if everything else remains the same.

However, as alternative strategies such as more complete contact-tracing are implemented, the lifting of mobility restrictions could be more substantial without risking the success achieved³².

We conclude that for 53 countries currently experiencing active SARS-CoV-2 transmission, there is a strong link between mobility measures and transmissibility, supporting the implementation of population-wide social distancing interventions to control the epidemic. Of those 53 countries, mobility measured until 10th of May was sufficiently reduced to ensure a decline in the epidemic in only three countries (France, Spain and the UK). However, even for Spain, which shows the strongest reduction in mobility relative to its mobility threshold, control efforts are fragile. If everything else remained as before, a 20% increase in Spain's current mobility could lead to rapid epidemic growth.

As many countries are easing social-distancing policies, our analysis illustrates that sustainable lifting of population-wide social-distancing measures should be undertaken very carefully and replaced with equally effective control measures, such as thorough contact-tracing^{32,33}. Encouragingly, in ten countries, we found some early evidence of a recent dampening of the relationship between transmission and mobility, suggesting alternative control strategies have been implemented and significantly decrease transmission. This raises the hope that easing of social-distancing measures without a second wave of deaths is possible but requires careful monitoring of the level of transmission.

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6. Supplementary data

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Mobility data

Table SI.1: Table summarising the total number of deaths reported, minimum-recorded relative mobility, as well as the number of data streams used to estimate mobility. (For example, the minimum mobility observed in Afghanistan was 53.7% of the baseline, representing a 46.3% reduction.)

Country	Cumulative deaths	Minimum mobility recorded		STREAMS of mobility data	
		Apple	Google	Apple	Google
Afghanistan	115	NA	54	NA	3
Argentina	300	10	21	2	3
Austria	615	24	29	2	3
Bangladesh	214	NA	30	NA	3
Belarus	126	NA	62	NA	3
Belgium	8581	26	30	3	3
Bolivia	114	NA	15	NA	3
Brazil	10627	24	39	3	3
Cameroon	108	NA	73	NA	3
Canada	4693	33	38	3	3
Chile	304	22	36	2	3
Colombia	445	27	20	2	3
Czechia	276	21	44	3	3
Denmark	526	41	50	3	3
Dominican Rep.	385	NA	24	NA	3
Ecuador	1717	NA	18	NA	3
Egypt	514	29	45	2	3
Finland	265	51	49	3	3
France	26310	15	22	3	3
Germany	7377	33	46	3	3
Greece	151	17	27	2	3
Honduras	108	NA	24	NA	3
Hungary	413	24	46	2	3
India	2109	17	28	2	3
Indonesia	959	31	51	2	3
Ireland	1467	15	28	3	3
Israel	247	26	28	2	3
Italy	30395	10	21	3	3
Japan	613	48	56	3	3
Mexico	3353	27	41	3	3
Moldova	161	NA	38	NA	3
Morocco	186	10	NA	2	NA
Netherlands	5422	31	47	3	3
Nigeria	128	NA	48	NA	3

Pakistan	639	NA	37	NA	3
Panama	237	NA	18	NA	3
Peru	1814	NA	16	NA	3
Philippines	704	17	20	3	3
Poland	785	24	39	2	3
Portugal	1126	12	26	2	3
Romania	926	21	36	2	3
Russia	1827	38	NA	2	NA
Saudi Arabia	239	46	29	2	3
Serbia	213	22	29	2	3
South Africa	186	14	24	0	0
Spain	26621	7	15	3	3
Sweden	3220	60	66	3	3
Switzerland	1531	35	40	3	3
Turkey	3739	23	29	2	3
UK	31587	24	28	3	3
Ukraine	376	46	NA	2	NA
United Arab Emirates	185	38	34	0	0
USA	78794	36	49	3	3

Mobility thresholds by countries

Table S12: Basic reproduction number and mobility thresholds with default serial interval and negative binomial likelihood for Apple and Google mobility.

country	Apple Mobility				Google mobility			
	R0	Latest mobility	Estimated threshold (median ; 95% CrI)	DIC	R0	Latest mobility	Estimated threshold (median; 95% CrI)	DIC
Afghanistan	-	-	-	-	3.1 ; 95%CrI [2.1 ; 4.8]	41	58 ; 95%CrI [38 ; -]	180
Argentina	3.5 ; 95%CrI [2.2 ; 4.9]	75	95 ; 95%CrI [75 ; -]	277	3.4 ; 95%CrI [2.2 ; 4.9]	59	78 ; 95%CrI [61 ; -]	279
Austria	4.6 ; 95%CrI [3.4 ; 5]	49	58 ; 95%CrI [51 ; 67]	347	4.3 ; 95%CrI [3 ; 4.9]	39	50 ; 95%CrI [43 ; 59]	344
Bangladesh	-	-	-	-	3.8 ; 95%CrI [2.2 ; 4.9]	59	69 ; 95%CrI [53 ; -]	225
Belarus	-	-	-	-	3.4 ; 95%CrI [2.1 ; 4.9]	27	33 ; 95%CrI [23 ; 73]	165
Belgium	4.9 ; 95%CrI [4.5 ; 5]	58	63 ; 95%CrI [59 ; 67]	601	4.8 ; 95%CrI [4.3 ; 5]	53	58 ; 95%CrI [54 ; 62]	581
Bolivia	-	-	-	-	3.3 ; 95%CrI [2.1 ; 4.8]	78	- ; 95%CrI [84 ; -]	175
Brazil	4.6 ; 95%CrI [3.4 ; 5]	63	92 ; 95%CrI [84 ; -]	542	4.1 ; 95%CrI [3.2 ; 4.9]	44	70 ; 95%CrI [63 ; 82]	543
Cameroon	-	-	-	-	3.5 ; 95%CrI [2.1 ; 4.9]	18	25 ; 95%CrI [18 ; 41]	196
Canada	4.4 ; 95%CrI [3.3 ; 5]	50	74 ; 95%CrI [66 ; 84]	478	4.3 ; 95%CrI [3.1 ; 4.9]	51	66 ; 95%CrI [60 ; 76]	476
Chile	4.3 ; 95%CrI [2.6 ; 5]	62	85 ; 95%CrI [68 ; -]	251	4.2 ; 95%CrI [2.5 ; 5]	53	64 ; 95%CrI [52 ; 92]	251
Colombia	4.2 ; 95%CrI [2.6 ; 5]	57	85 ; 95%CrI [69 ; -]	278	4 ; 95%CrI [2.4 ; 4.9]	65	89 ; 95%CrI [71 ; -]	279
Czechia	4.5 ; 95%CrI [3 ; 5]	53	69 ; 95%CrI [58 ; 86]	257	4.5 ; 95%CrI [3.2 ; 5]	37	48 ; 95%CrI [40 ; 60]	255
Denmark	4.4 ; 95%CrI [3.2 ; 5]	28	46 ; 95%CrI [39 ; 55]	323	4.2 ; 95%CrI [2.7 ; 5]	33	41 ; 95%CrI [35 ; 51]	324
Dominican Rep.	-	-	-	-	-	66	67 ; 95%CrI [55 ; 87]	297
Ecuador	-	-	-	-	3.6 ; 95%CrI [2.3 ; 4.8]	-	-	-
Egypt	-	-	-	-	3.6 ; 95%CrI [2.4 ; 4.8]	68	76 ; 95%CrI [67 ; 90]	595
Finland	3.8 ; 95%CrI [2.3 ; 4.9]	56	70 ; 95%CrI [58 ; 92]	335	3.4 ; 95%CrI [2.1 ; 4.8]	44	55 ; 95%CrI [45 ; 81]	337
France	3.9 ; 95%CrI [2.1 ; 5]	24	50 ; 95%CrI [40 ; 72]	259	4.1 ; 95%CrI [2.3 ; 4.9]	36	49 ; 95%CrI [39 ; 69]	256
Germany	4.8 ; 95%CrI [4.2 ; 5]	73	66 ; 95%CrI [63 ; 69]	819	3.8 ; 95%CrI [3.4 ; 4.4]	66	56 ; 95%CrI [53 ; 59]	803
Greece	4.8 ; 95%CrI [4.2 ; 5]	43	54 ; 95%CrI [50 ; 58]	596	4.4 ; 95%CrI [3.5 ; 4.9]	31	42 ; 95%CrI [39 ; 45]	582
Honduras	3.9 ; 95%CrI [2.3 ; 4.9]	55	64 ; 95%CrI [51 ; 84]	238	3.5 ; 95%CrI [2.1 ; 4.9]	43	53 ; 95%CrI [41 ; 72]	239
Hungary	-	-	-	-	3.7 ; 95%CrI [2.2 ; 4.9]	69	75 ; 95%CrI [56 ; -]	198

India	4.1 ; 95%CrI [2.3 ; 5]	60	80 ; 95%CrI [67 ; -]	289	3.9 ; 95%CrI [2.3 ; 4.9]	37	55 ; 95%CrI [45 ; 75]	288
Indonesia	3.9 ; 95%CrI [2.6 ; 4.9]	75	- ; 95%CrI [92 ; -]	393	3.5 ; 95%CrI [2.3 ; 4.8]	64	94 ; 95%CrI [77 ; -]	395
Ireland	3.3 ; 95%CrI [2.2 ; 4.7]	66	62 ; 95%CrI [53 ; 76]	416	2.6 ; 95%CrI [2 ; 3.6]	48	38 ; 95%CrI [31 ; 49]	416
Israel	4.6 ; 95%CrI [3.6 ; 5]	78	80 ; 95%CrI [71 ; 91]	414	4.6 ; 95%CrI [3.5 ; 5]	64	65 ; 95%CrI [58 ; 74]	409
Italy	4.4 ; 95%CrI [2.8 ; 5]	43	65 ; 95%CrI [53 ; 82]	248	4.4 ; 95%CrI [2.9 ; 5]	39	58 ; 95%CrI [48 ; 73]	248
Japan	4.3 ; 95%CrI [3.7 ; 4.9]	74	75 ; 95%CrI [72 ; 79]	836	3.3 ; 95%CrI [2.9 ; 3.7]	54	61 ; 95%CrI [58 ; 65]	852
Mexico	2.4 ; 95%CrI [2 ; 3.3]	50	43 ; 95%CrI [32 ; 62]	421	2.5 ; 95%CrI [2 ; 3.4]	44	29 ; 95%CrI [22 ; 43]	405
Moldova	4.4 ; 95%CrI [2.9 ; 5]	65	93 ; 95%CrI [81 ; -]	405	4 ; 95%CrI [2.6 ; 4.9]	55	70 ; 95%CrI [60 ; 94]	406
Morocco	-	-	-	-	3.9 ; 95%CrI [2.2 ; 5]	44	74 ; 95%CrI [56 ; -]	208
Netherlands	3.9 ; 95%CrI [2.2 ; 4.9]	86	71 ; 95%CrI [57 ; 96]	245	-	-	-	-
Nigeria	4.6 ; 95%CrI [3.9 ; 5]	52	55 ; 95%CrI [51 ; 59]	561	3.9 ; 95%CrI [3.1 ; 4.7]	39	40 ; 95%CrI [37 ; 44]	566
Pakistan	-	-	-	-	3.2 ; 95%CrI [2.1 ; 4.8]	38	84 ; 95%CrI [53 ; -]	166
Pa - ma	-	-	-	-	3 ; 95%CrI [2.1 ; 4.6]	47	75 ; 95%CrI [56 ; -]	312
Peru	-	-	-	-	3.3 ; 95%CrI [2.1 ; 4.8]	76	82 ; 95%CrI [63 ; -]	259
Philippines	-	-	-	-	4 ; 95%CrI [2.3 ; 4.9]	74	- ; 95%CrI [92 ; -]	373
Poland	3.5 ; 95%CrI [2.2 ; 4.9]	81	82 ; 95%CrI [70 ; -]	394	2.8 ; 95%CrI [2.1 ; 4.1]	73	73 ; 95%CrI [60 ; 100]	389
Portugal	4.3 ; 95%CrI [2.8 ; 5]	45	77 ; 95%CrI [66 ; 93]	354	4.3 ; 95%CrI [2.9 ; 5]	38	59 ; 95%CrI [51 ; 71]	353
Romania	4.7 ; 95%CrI [3.6 ; 5]	77	76 ; 95%CrI [68 ; 87]	392	4.6 ; 95%CrI [3.4 ; 5]	58	60 ; 95%CrI [53 ; 69]	392
Russia	4.5 ; 95%CrI [3.4 ; 5]	68	80 ; 95%CrI [71 ; 92]	352	4.3 ; 95%CrI [3 ; 5]	52	63 ; 95%CrI [54 ; 75]	353
Saudi Arabia	4.3 ; 95%CrI [2.9 ; 5]	46	68 ; 95%CrI [59 ; 87]	335	-	-	-	-
Serbia	-	44	61 ; 95%CrI [48 ; 97]	234	-	59	79 ; 95%CrI [61 ; -]	236
South Africa	4 ; 95%CrI [2.3 ; 4.9]	-	-	-	3.8 ; 95%CrI [2.2 ; 4.9]	-	-	-
Spain	4.1 ; 95%CrI [2.3 ; 5]	48	75 ; 95%CrI [61 ; -]	238	3.8 ; 95%CrI [2.3 ; 4.9]	42	66 ; 95%CrI [52 ; 91]	240
Sweden	-	61	- ; 95%CrI [78 ; -]	204	-	55	94 ; 95%CrI [66 ; -]	205
Switzerland	3.5 ; 95%CrI [2.1 ; 4.9]	-	-	-	3.1 ; 95%CrI [2.1 ; 4.8]	-	-	-
Turkey	4.1 ; 95%CrI [3.6 ; 4.6]	81	70 ; 95%CrI [67 ; 74]	755	3.5 ; 95%CrI [3.1 ; 4]	66	60 ; 95%CrI [57 ; 64]	766
UK	4.7 ; 95%CrI [3.8 ; 5]	24	35 ; 95%CrI [32 ; 39]	583	4.6 ; 95%CrI [3.4 ; 5]	20	27 ; 95%CrI [25 ; 30]	566
Ukraine	4.5 ; 95%CrI [3.4 ; 5]	39	46 ; 95%CrI [41 ; 51]	481	3.6 ; 95%CrI [2.7 ; 4.6]	42	43 ; 95%CrI [38 ; 49]	480
UAE	4.8 ; 95%CrI [4 ; 5]	65	68 ; 95%CrI [62 ; 74]	460	4.5 ; 95%CrI [3.5 ; 5]	59	57 ; 95%CrI [52 ; 63]	462
USA	-	53	94 ; 95%CrI [66 ; -]	198	-	53	- ; 95%CrI [67 ; -]	199

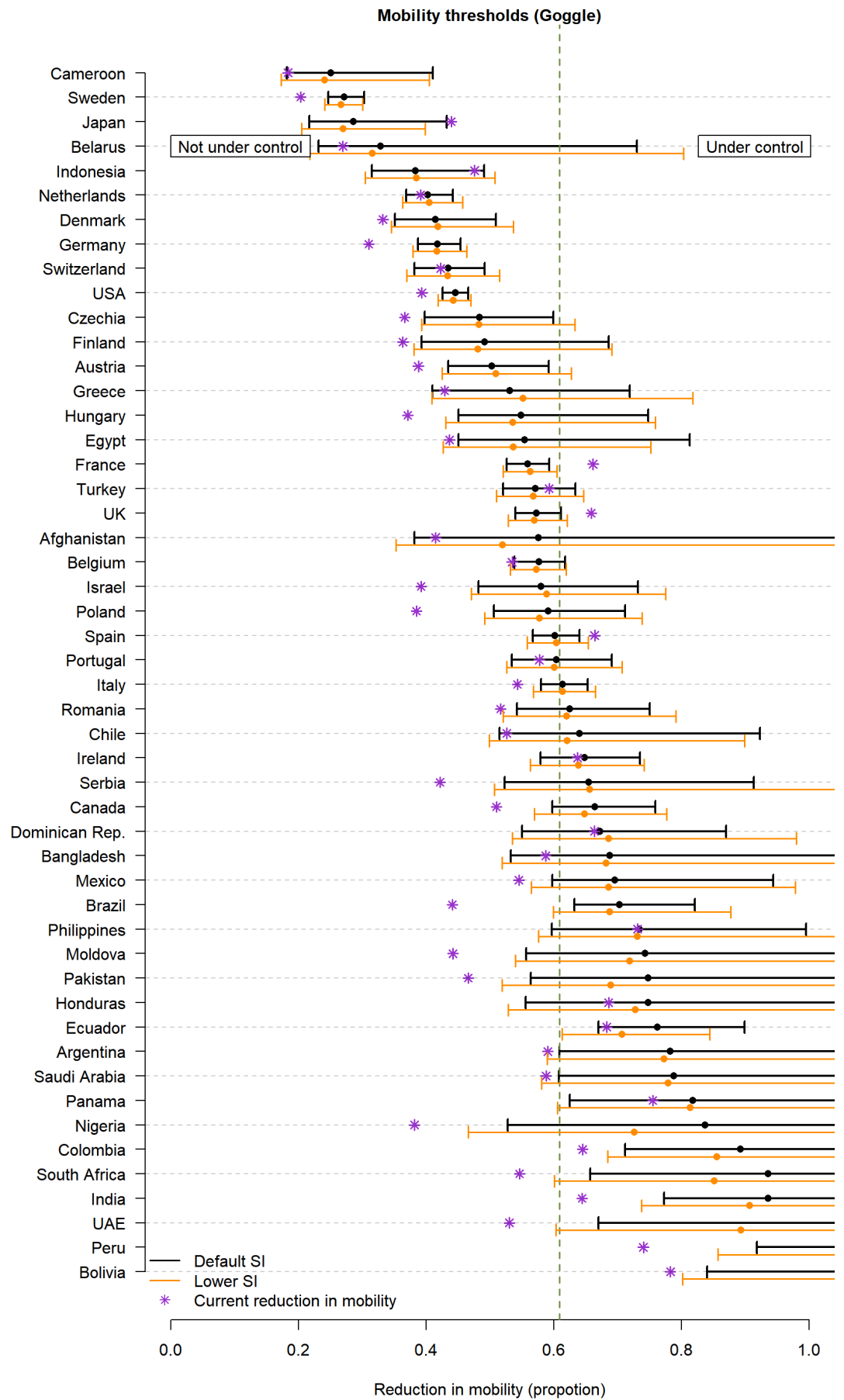


Figure SI.1: Results based on Google mobility data (equivalent to Figure 3 in main text). Median and 95% CrI country-specific Apple mobility thresholds to interrupt transmission (to achieve $R < 1$). The main (black) thresholds assume the default serial interval and a negative binomial likelihood (estimated thresholds for the alternative lower serial interval in orange, see SI for Poisson likelihood). The dashed vertical green line represents the median threshold estimated from the countries' medians. The purple stars represent where the latest mobility has been estimated (on 10th of May). A purple star on the right of the credible interval indicates that the reduction in mobility appears to be sufficient to contain COVID-19 transmission.

In a given country, both Apple and Google mobility estimates and the estimated mobility thresholds. However, the important aspect in term drawing a consistent understanding of the situation is: the level of mobility observed relative to the threshold. In the figure below, we plot for both Apple and Google the mobility thresholds scaled (divided) by the latest observed mobility. This allow visualising how consistent the pattern estimated are.

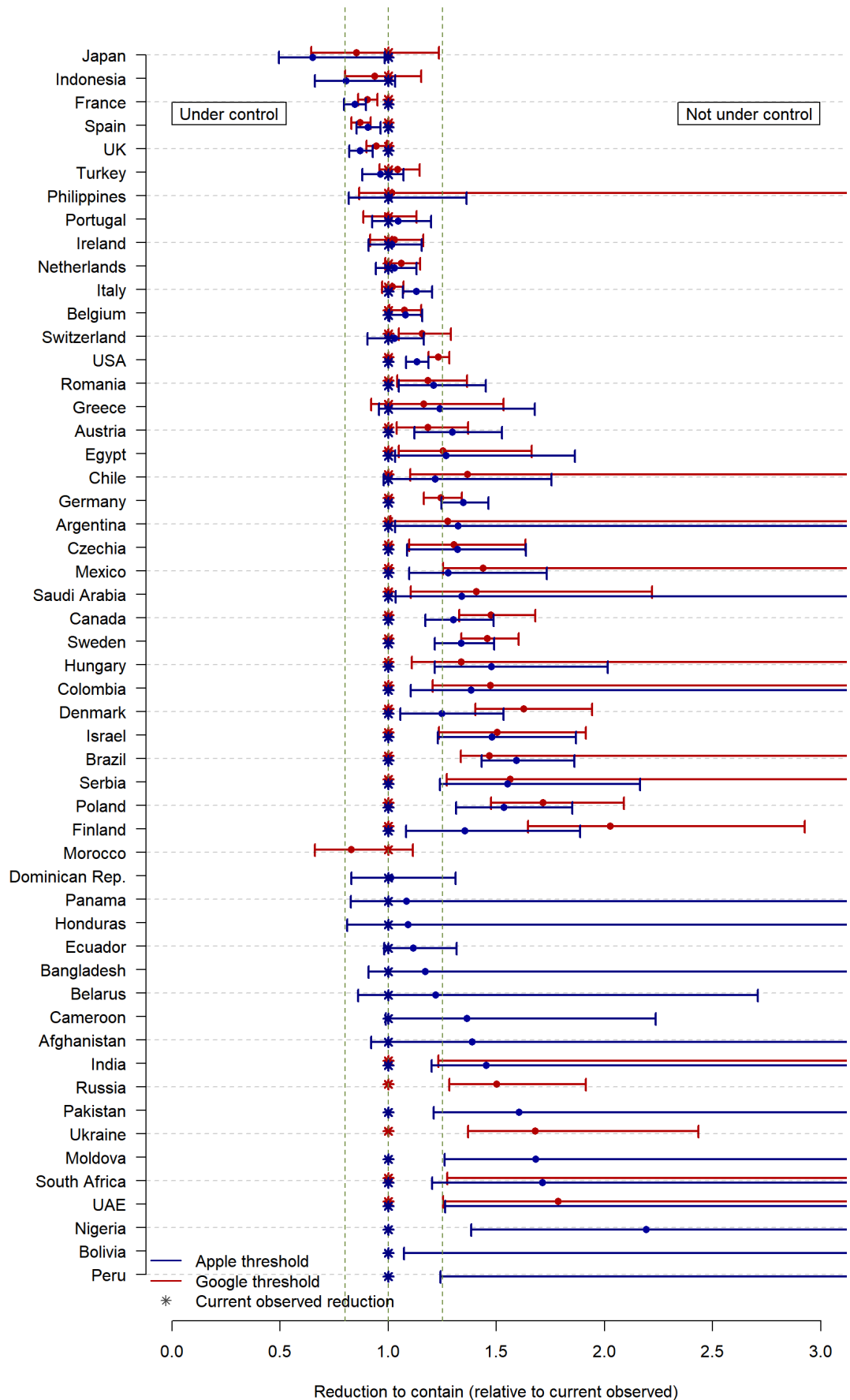


Figure SI.2: Apple (blue) and Google (red) mobility thresholds (median and 95% CrI) standardised by the latest reduction in mobility observed. Credible interval on the left of the star indicate that reduction in mobility appears to be sufficient to contain COVID-19 transmission.

Correlation between R0 and the mobility threshold

We evaluated the correlation between estimated mobility thresholds and basic reproduction number across countries to ensure the variation in the estimated thresholds was not driven by the variation in estimated basic reproduction number.

We found no evidence of a correlation between the estimated mobility threshold and the estimated Basic reproduction number.

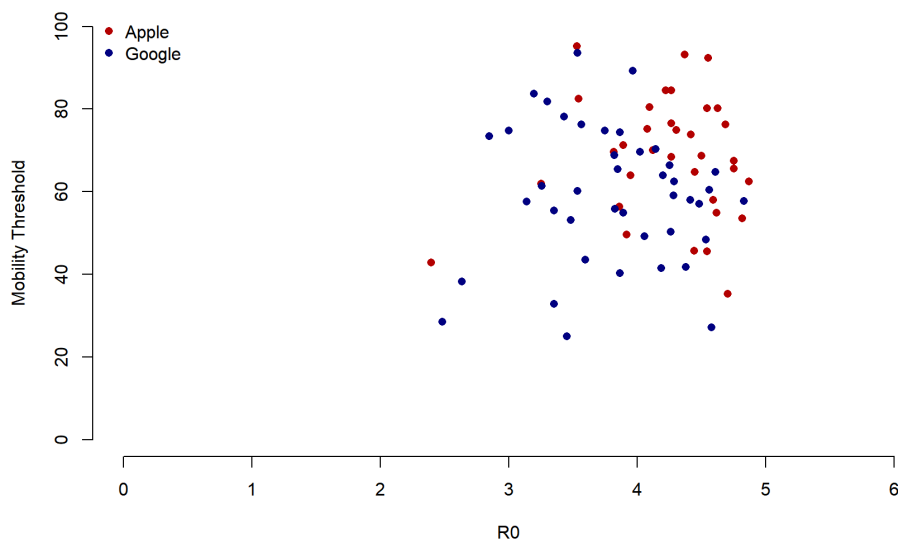


Figure SI.3: Relationship between the estimated (medians) Basic Reproduction number and the estimated (medians) mobility thresholds. For both Apple and Google mobility, we found no significant correlation between the estimated R0 and mobility thresholds.

Sensitivity of estimated parameters to early epidemic dynamics

As the reporting of deaths might have changed during the country-specific early phase of the epidemic, we re-estimated the mobility-transmission relationship discarding from the likelihood all days previous to the two consecutive weeks reporting each at least 10 deaths (the criteria for sustained epidemic). However, the estimated parameters were robust to discarding the very early dynamic from the likelihood (i.e. before our sustained epidemic criteria is met).

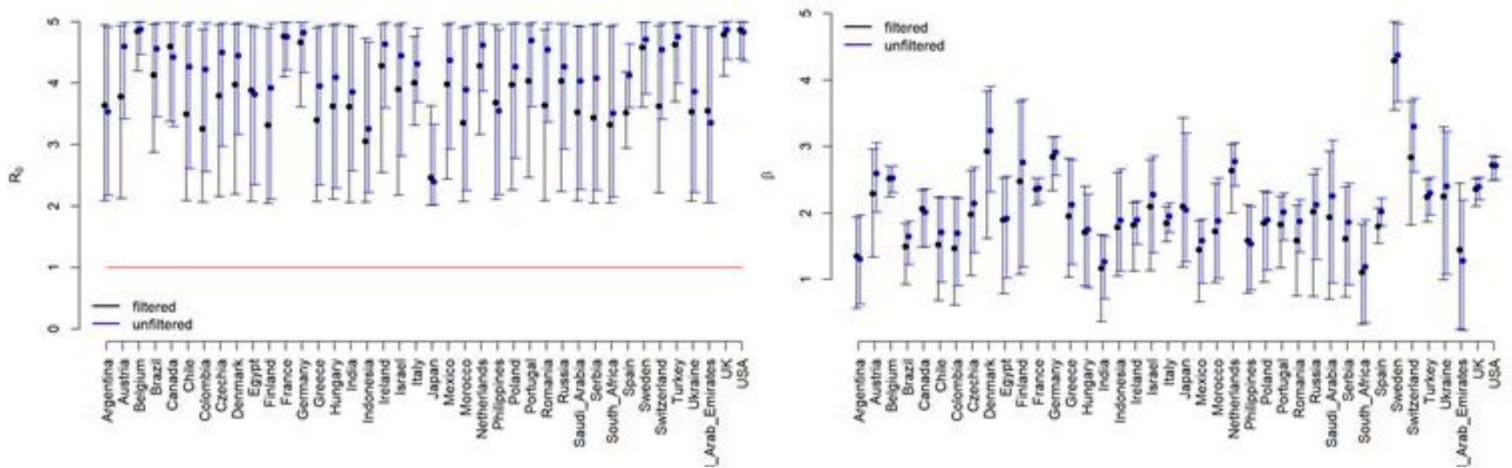


Figure SI.4: Estimated parameters when discarding the early epidemic phase (black), or including the early epidemic phase (blue) from the likelihood calculation.

Main analysis per country

Afghanistan

Current reduction in mobility observed is within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is also within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction is below the median threshold, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

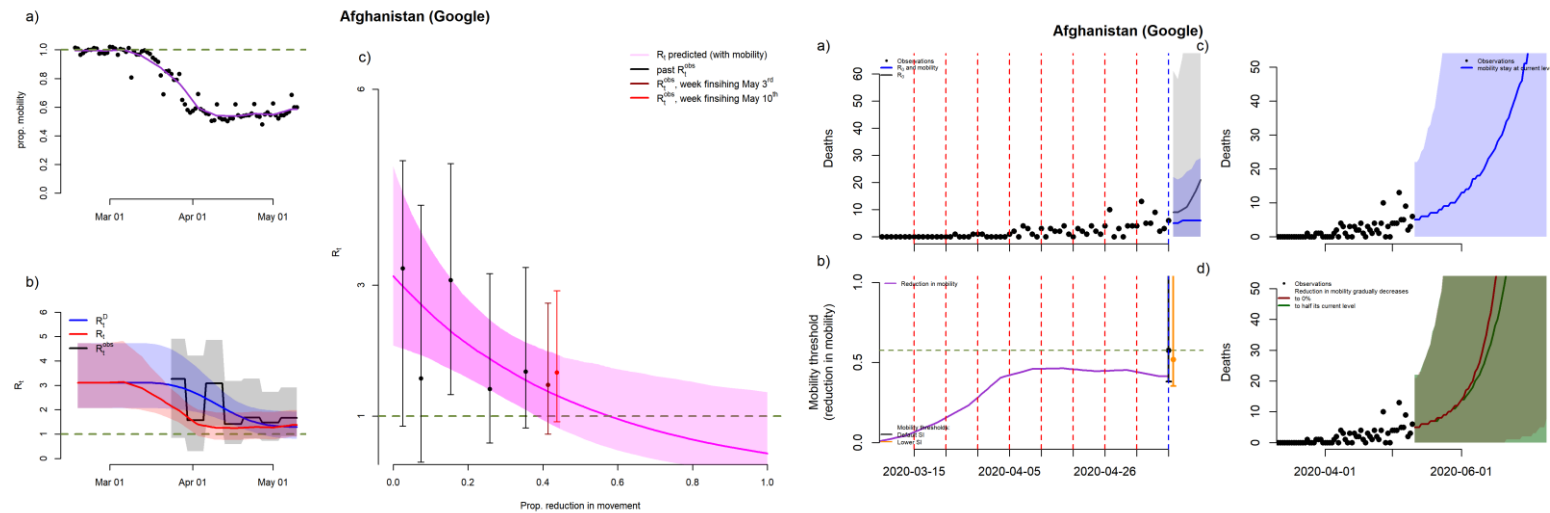


Figure SI.3: As in Figure 1-2 of main text.

Argentina

Current reductions in mobility observed are above/within the interquartile range of the current country-specific reductions in mobility for Apple/Google. The estimated median mobility thresholds are within/above the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google), suggesting relatively high reduction in mobility is necessary to ensure control. Mobility reductions have been within the range of the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows increasing mobility, which suggest increasing transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

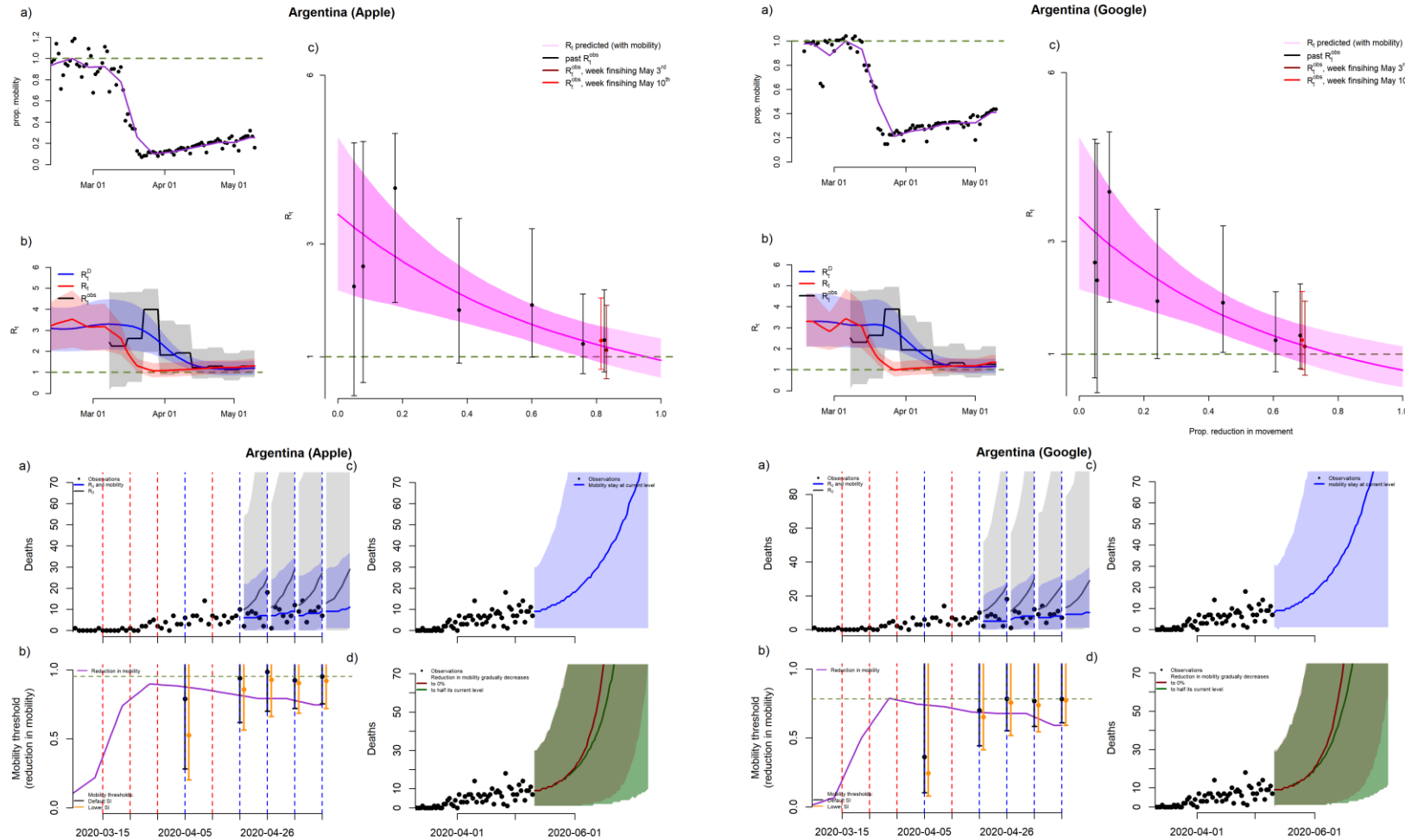


Figure SI.4: As in Figure 1-2 of main text.

Austria

Current reductions in mobility observed are within/below the interquartile range of the current country-specific reductions in mobility for Apple/Google. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility is necessary to ensure control. Mobility reductions have been in the range of the 95% CrI mobility threshold but no longer are, suggesting that, on its own, not enough reduction in mobility is in place to ensure control. We see good evidence for dampening of the relationship between transmission and mobility based on both Apple and Google mobility (i.e. in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) transmission is under control. Forecasts presented, particularly long-term ones, can therefore not be trusted.

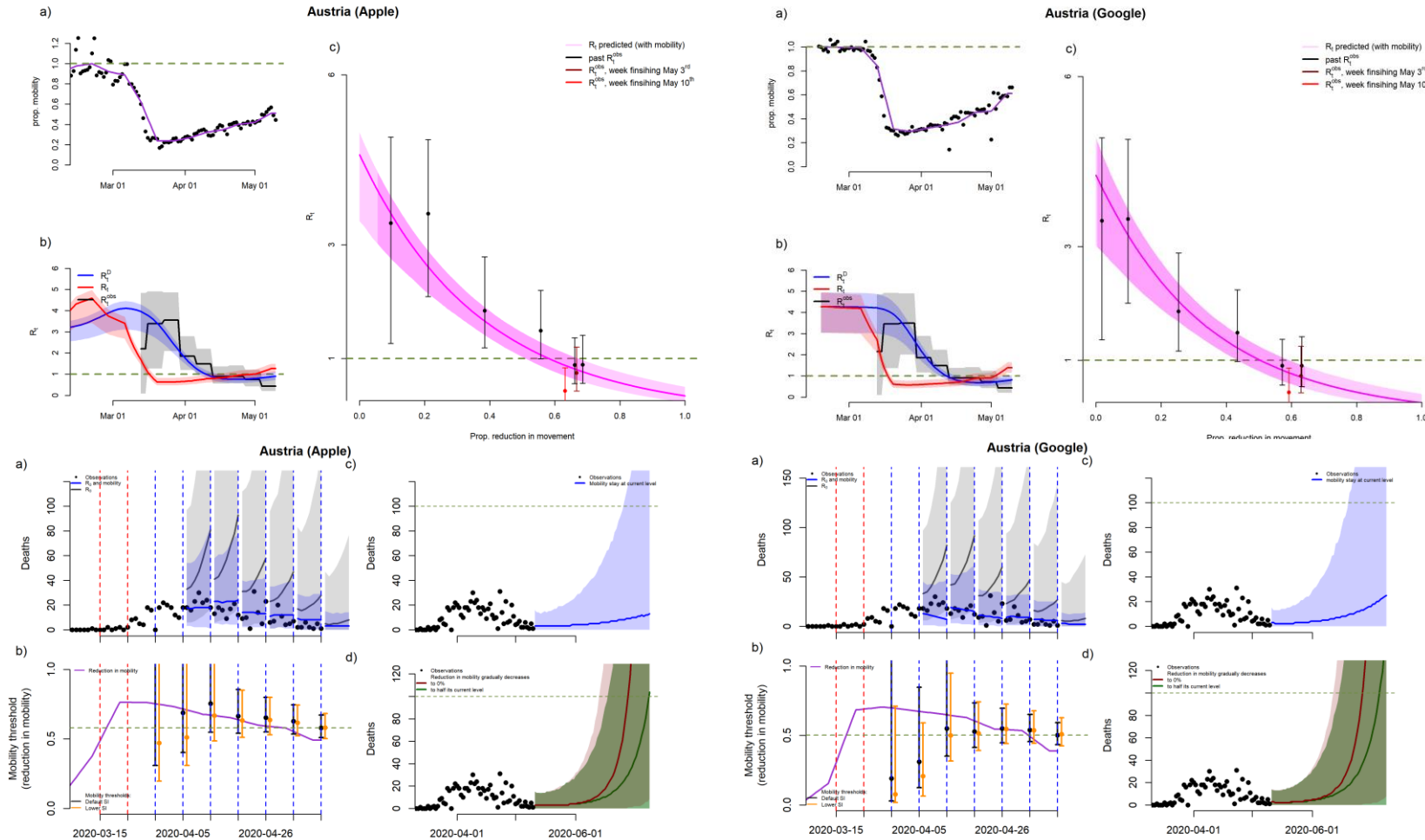


Figure SI.5: As in Figure 1-2 of main text.

Bangladesh

Current reduction in mobility observed is within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction is in the range of the 95% CrI mobility threshold but still lower than the median threshold, suggesting more reduction in mobility is needed to ensure control. Recent trend shows increasing mobility, which suggests increase in transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

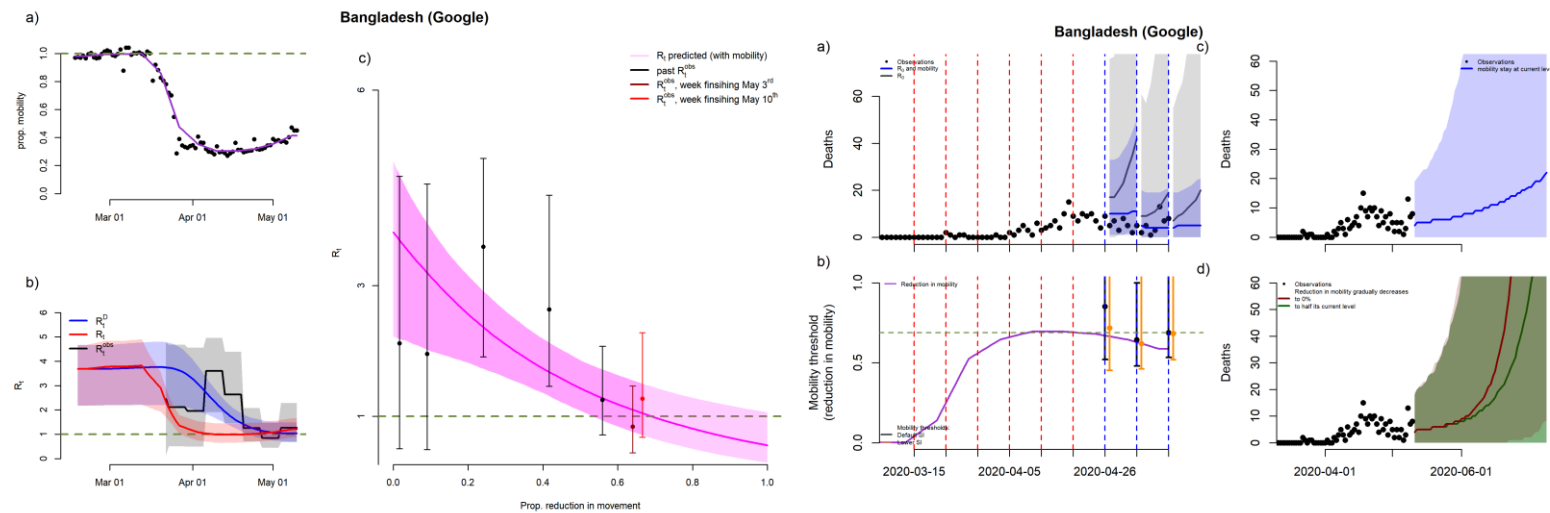


Figure SI.6: As in Figure 1-2 of main text.

Belarus

Current reduction in mobility observed is below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility is necessary to ensure control. Mobility reduction is in the range of the 95% CrI mobility threshold but still lower than the median threshold, suggesting more reduction in mobility is needed to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

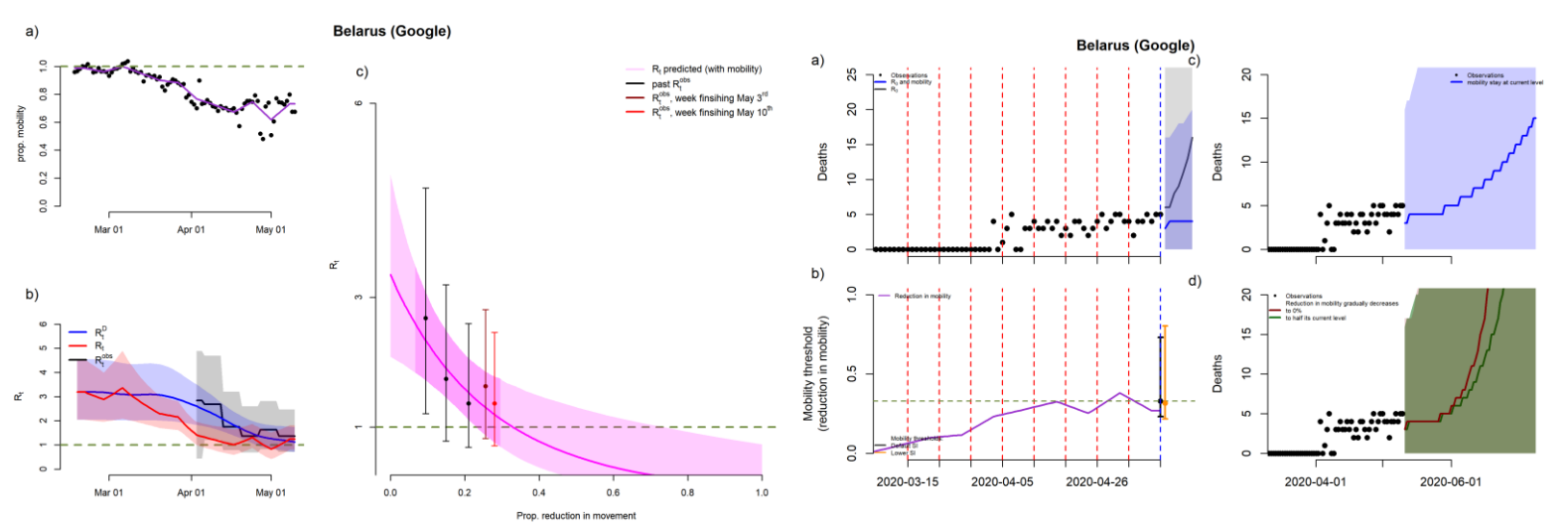


Figure SI.7: As in Figure 1-2 of main text.

Belgium

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been within the range of the 95% CrI mobility threshold but no longer are, suggesting that, on its own, not enough reduction in mobility is in place to ensure control. We see some evidence for dampening of the relationship between transmission and mobility based on both Apple and Google mobility, but only for two weeks ago (not in the last week considered), suggesting that alternative control strategies have been implemented and, but based on death (and so with a delay) current transmission may be under control, but uncertainty remain.

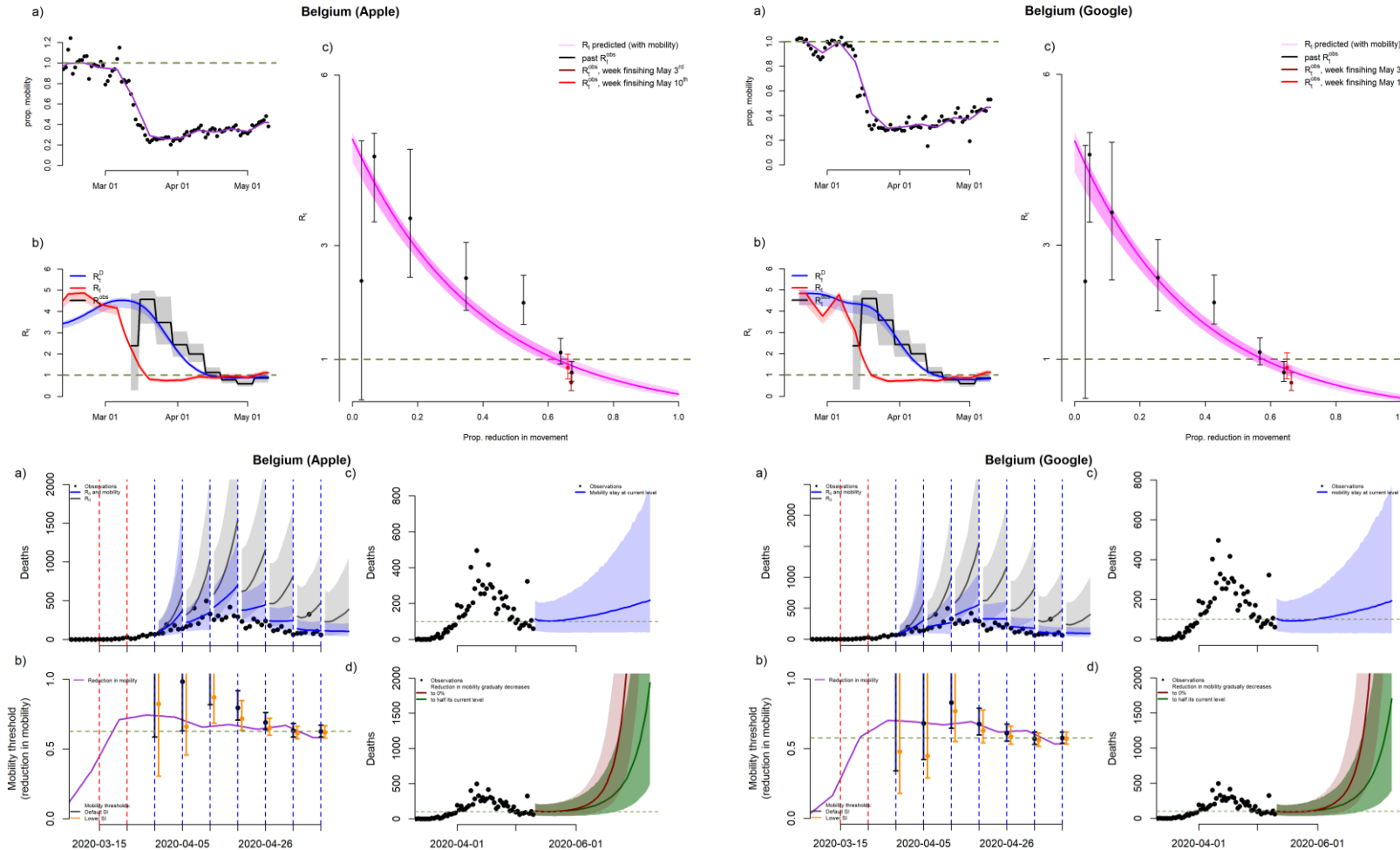


Figure SI.8: As in Figure 1-2 of main text.

Bolivia

Current reduction in mobility observed is above the interquartile range of the current country-specific reductions in mobility. The estimated mobility threshold is above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high reduction in mobility is necessary to ensure control. Mobility reduction is below the range of the 95% CrI mobility threshold, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

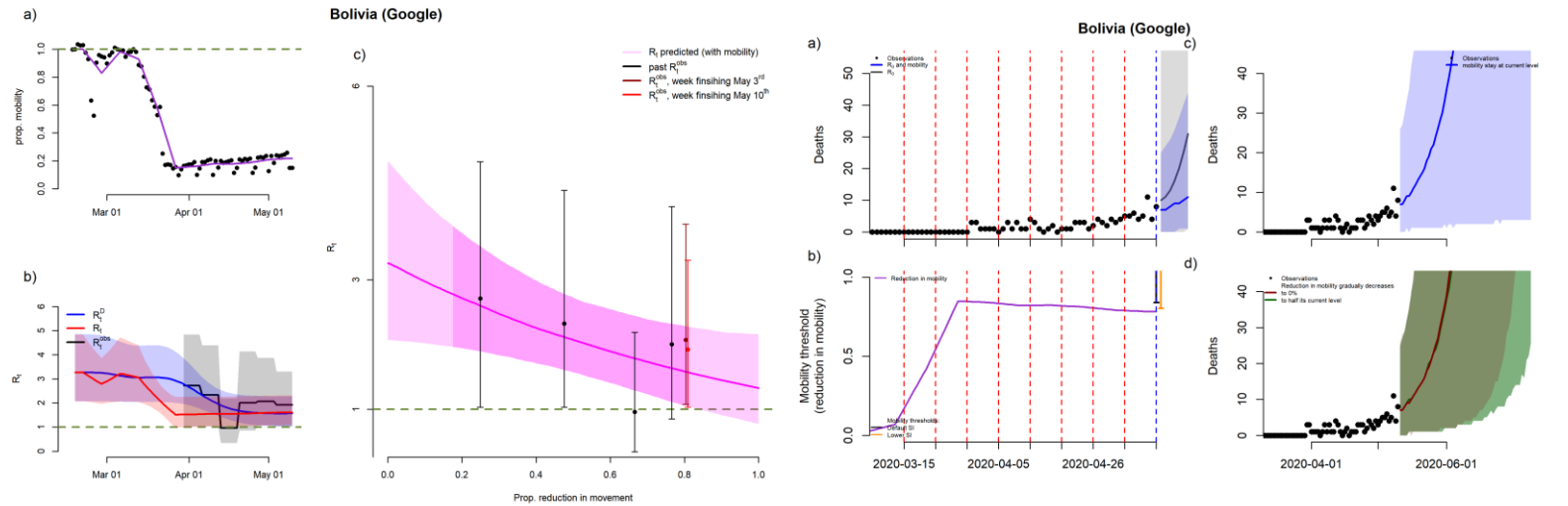


Figure SI.9: As in Figure 1-2 of main text.

Brazil

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within/above the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google), suggesting relatively high reduction in mobility is necessary to ensure control. Mobility reductions have been lower than the 95% CrI mobility threshold for the last 4 weeks considered, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows increasing mobility, which suggests increasing transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

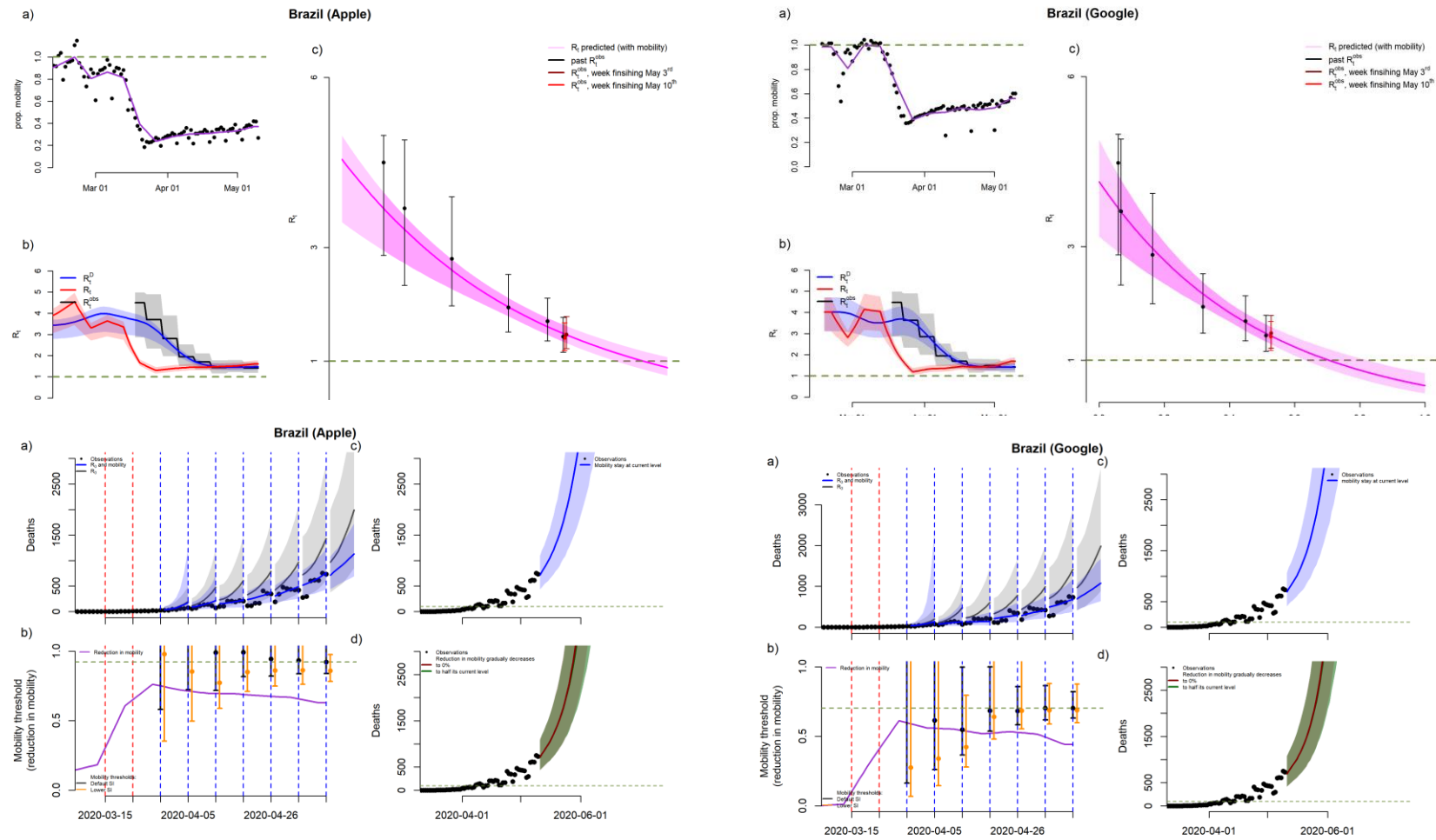


Figure SI.10: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Cameroon

Reporting of deaths seems highly variable in time, and results should be interpreted with caution. Current reduction in mobility observed is below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is below the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction is below the 95% CrI threshold, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

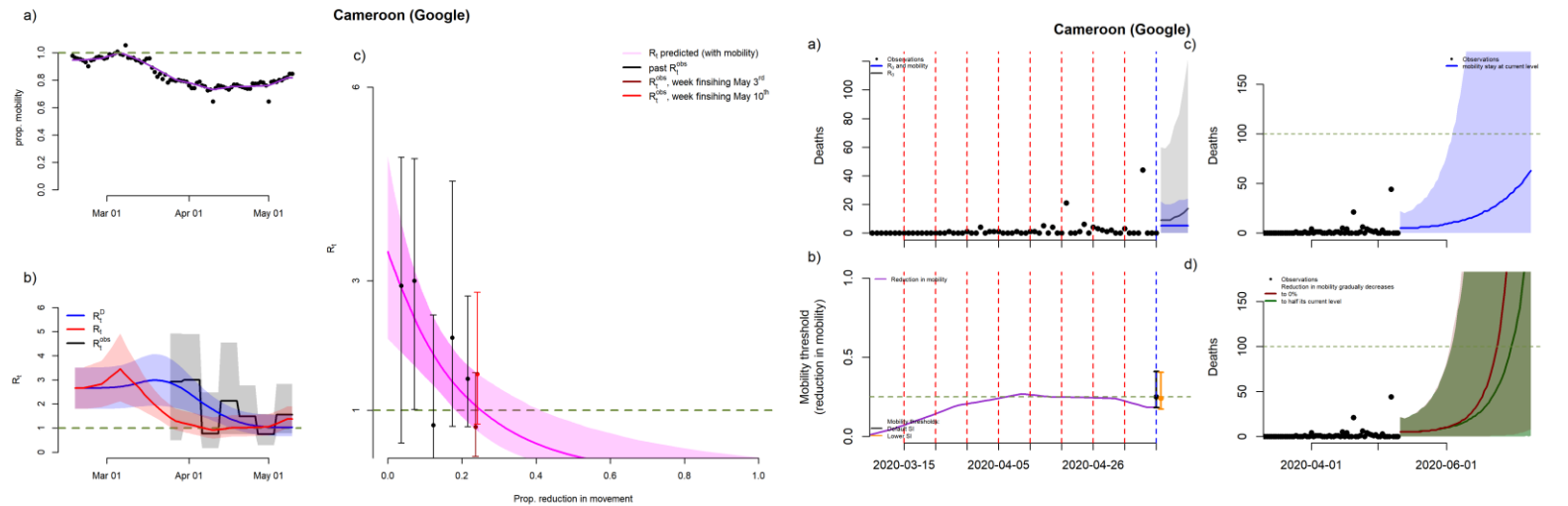


Figure SI.11: As in Figure 1-2 of main text.

Canada

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions in the last 4 weeks considered have been lower than the 95% CrI mobility threshold, suggesting that, on its own, not enough reduction in mobility is in place to ensure control. We see some evidence for dampening of the relationship between transmission and mobility based on Apple mobility only (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission may be under control, but uncertainty remain. Forecasts presented, particularly long-term ones, can therefore not be trusted.

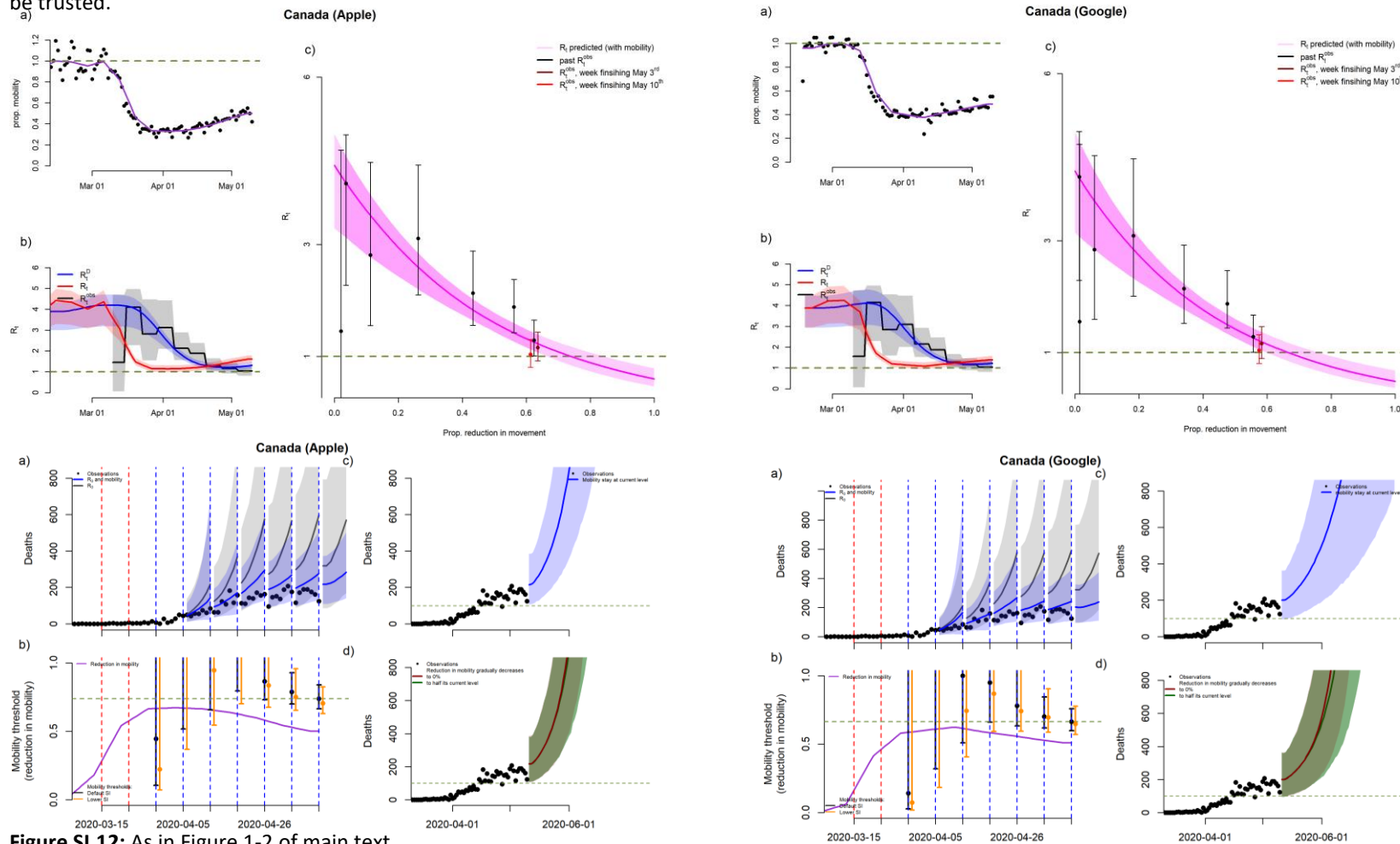


Figure SI.12: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Chile

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above/within the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google), suggesting relatively high reduction in mobility is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer is, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction or alternative control strategies are needed to reach control.

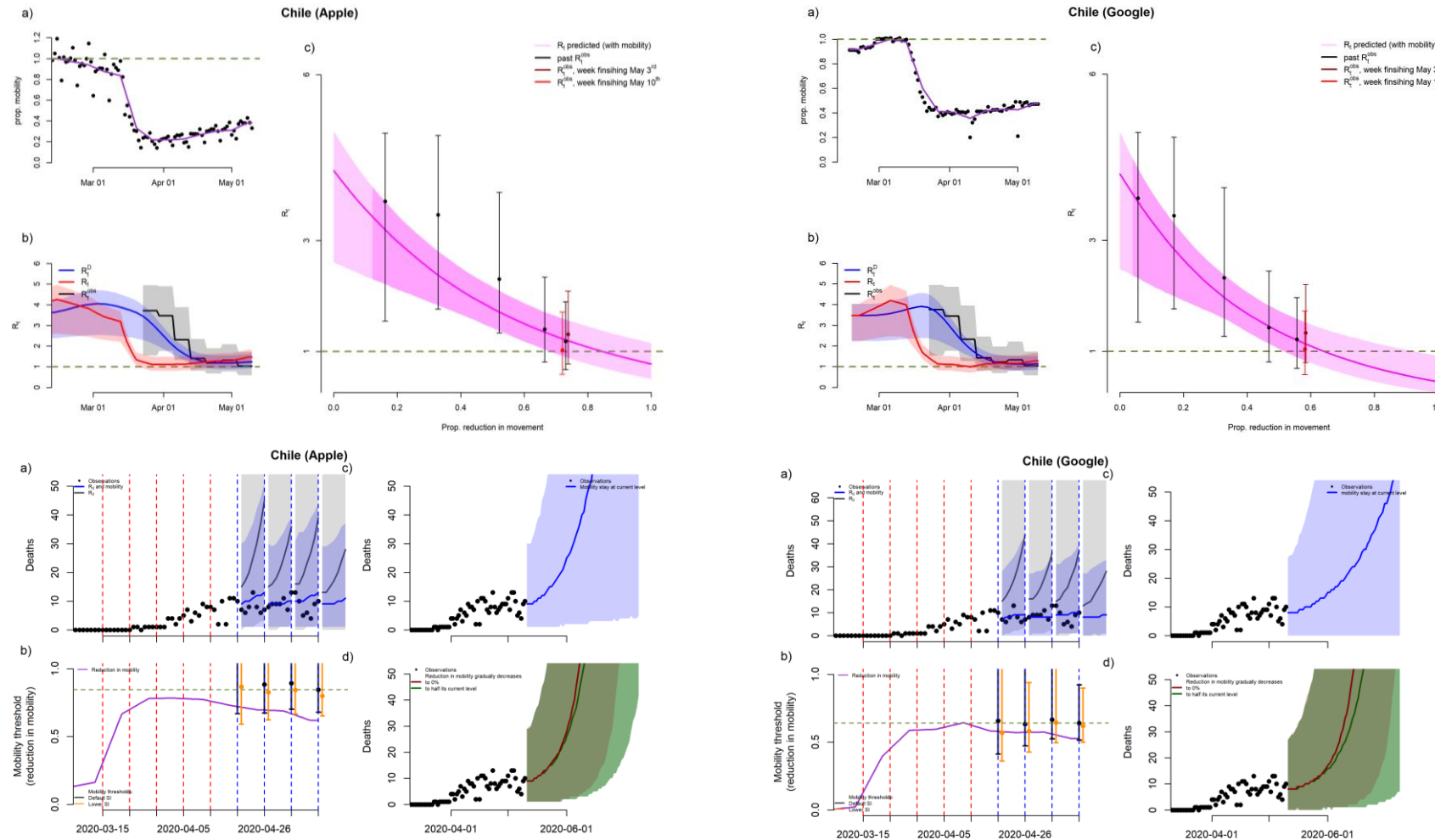


Figure SI.13: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Colombia

Current reductions in mobility observed are within/above the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high reduction in mobility is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows increasing mobility, which suggests increasing transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction or alternative control strategies are needed to reach control.

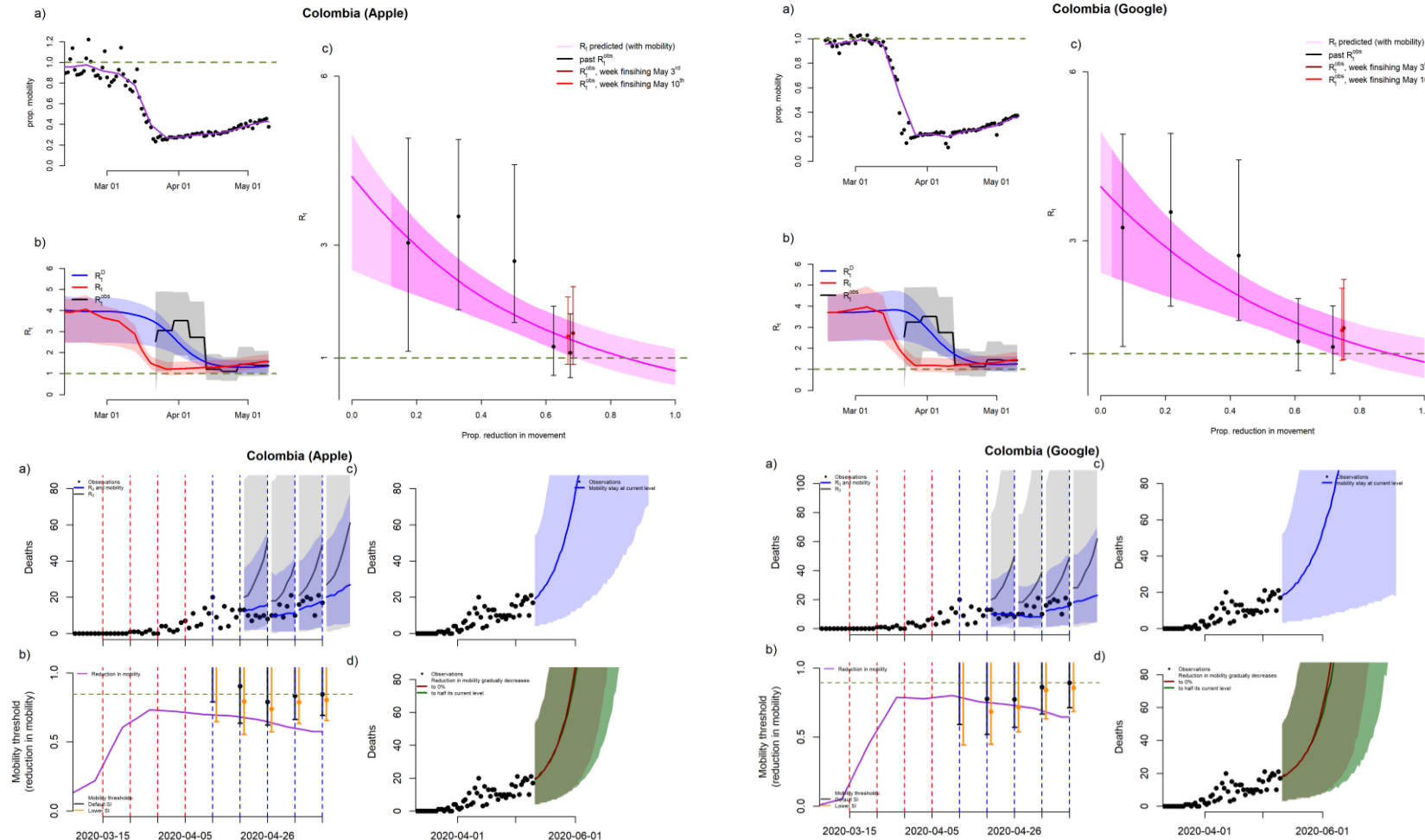


Figure SI.14: As in Figure 1-2 of main text.

Czechia

Current reductions in mobility observed are within/below the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are within/below the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google), suggesting relatively low reduction in mobility is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows increasing mobility, which suggests increasing transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

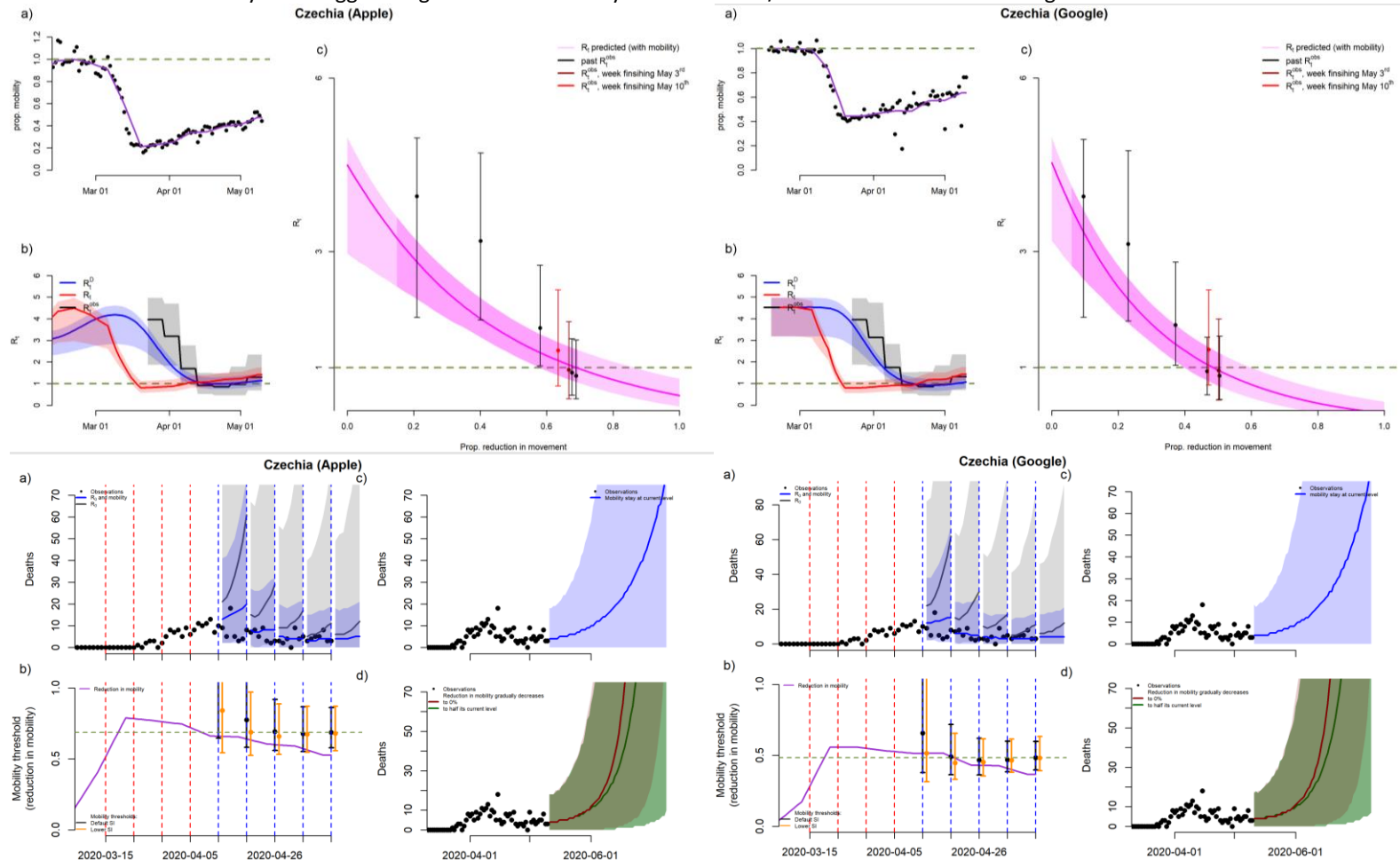


Figure SI.15: As in Figure 1-2 of main text.

Denmark

Current reductions in mobility observed are below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting that, on its own, not enough reduction in mobility is in place to ensure control. We see some evidence for the dampening of the relationship between transmission and mobility based on Apple mobility only (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission may be under control, but uncertainty remain. Forecasts presented, particularly long-term ones, can therefore not be trusted.

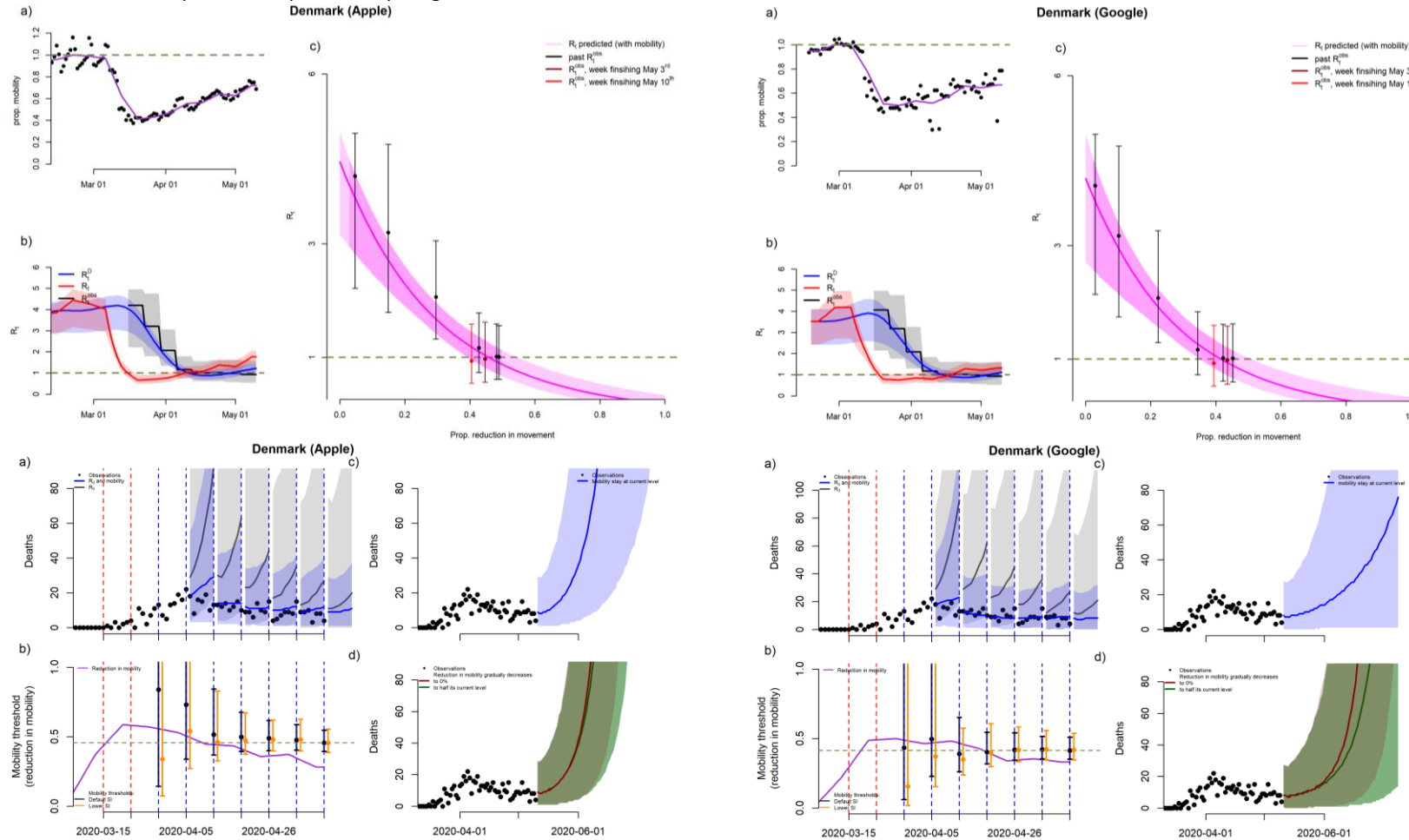


Figure SI.16: As in Figure 1-2 of main text.

Dominican Republic

Current reduction in mobility observed is above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction has been and is within the 95% CrI mobility threshold, suggesting enough reduction in mobility is in place to ensure control, but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

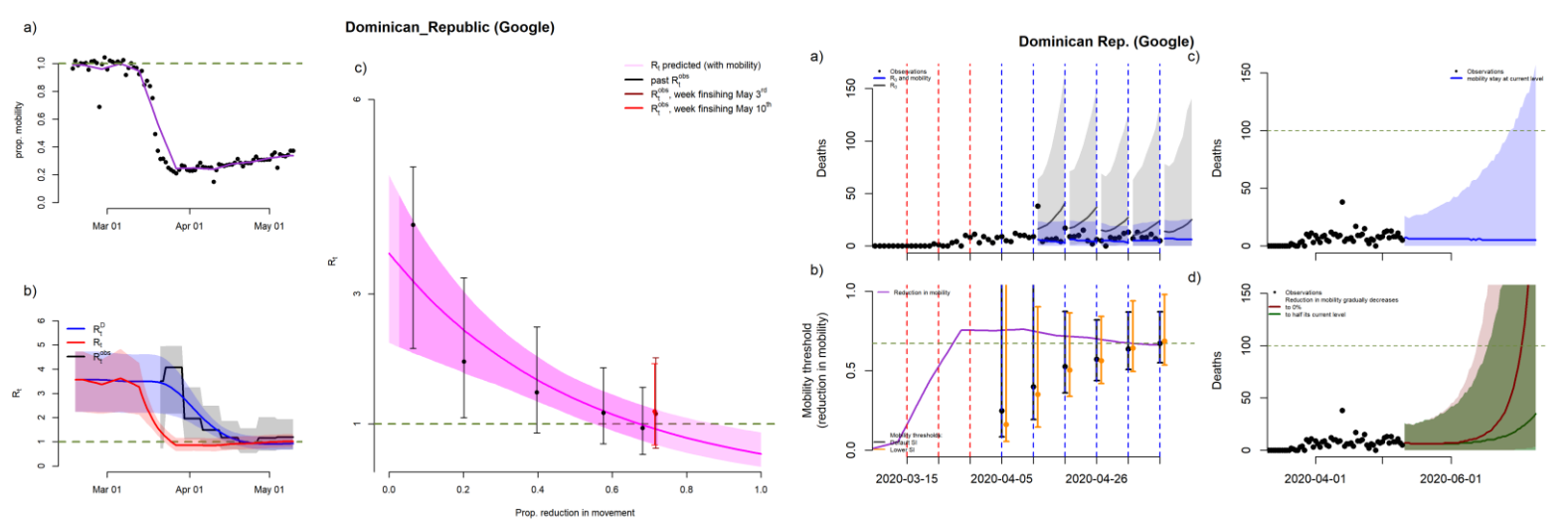


Figure SI.17: As in Figure 1-2 of main text.

Ecuador

Reporting of deaths seems highly variable in time, and results should be interpreted with caution. Current reduction in mobility observed is within the higher interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is above the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively high reduction in mobility is necessary to ensure control. Mobility reduction has been and is within the 95% CrI threshold, suggesting enough reduction in mobility may be in place to ensure control, but uncertainty remains. We see weak evidence for dampening of the relationship between transmission and mobility. Again, results are to be interpreted very cautiously given the seemingly unreliable nature of reported deaths.

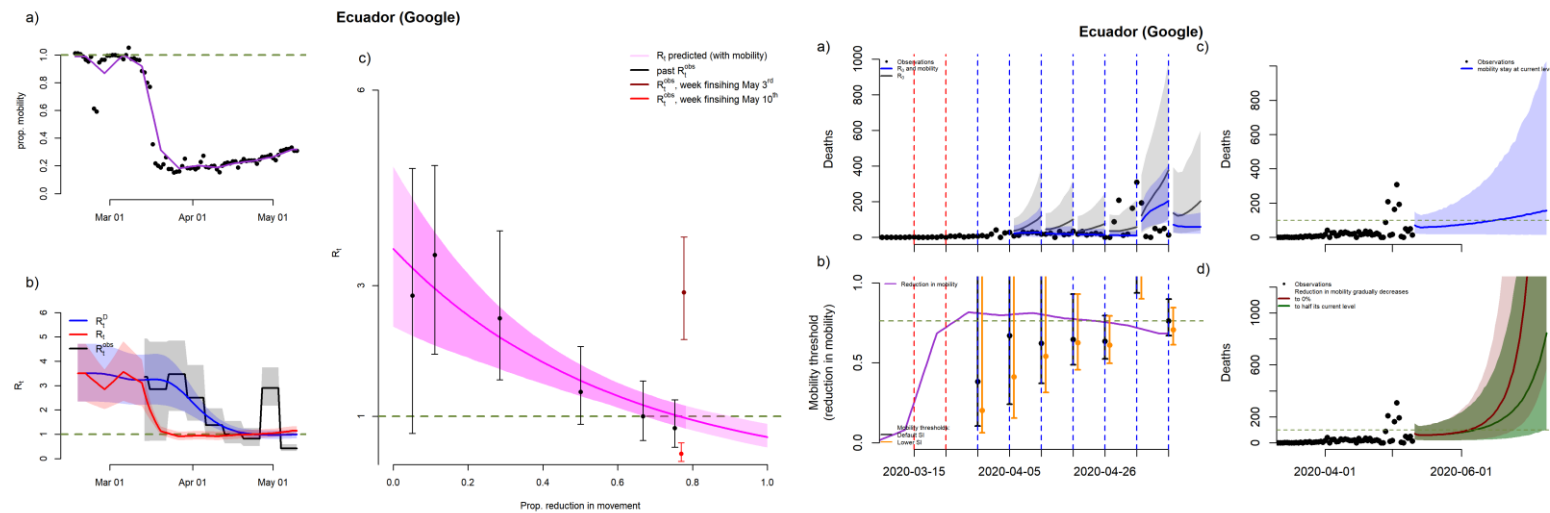


Figure SI.18: As in Figure 1-2 of main text.

Egypt

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are both within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

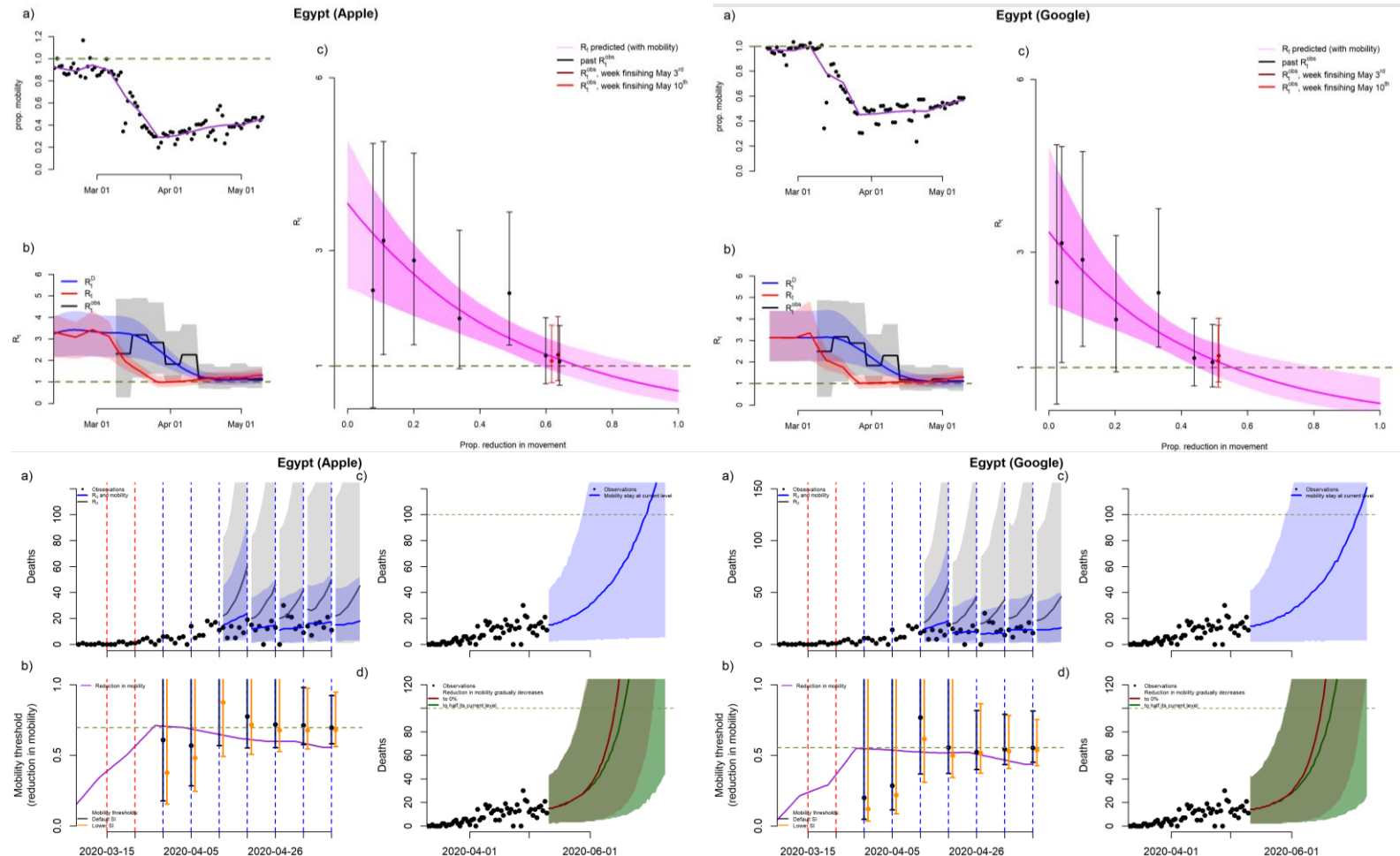


Figure SI.19: As in Figure 1-2 of main text.

Finland

Current reductions in mobility observed are below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low level of mobility reduction is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no strong evidence for dampening of the relationship between transmission and mobility. Some evidence from 2 weeks previous for a dampening, but still uncertain in the last week considered. Forecasts, especially long-term ones, should be interpreted with caution.

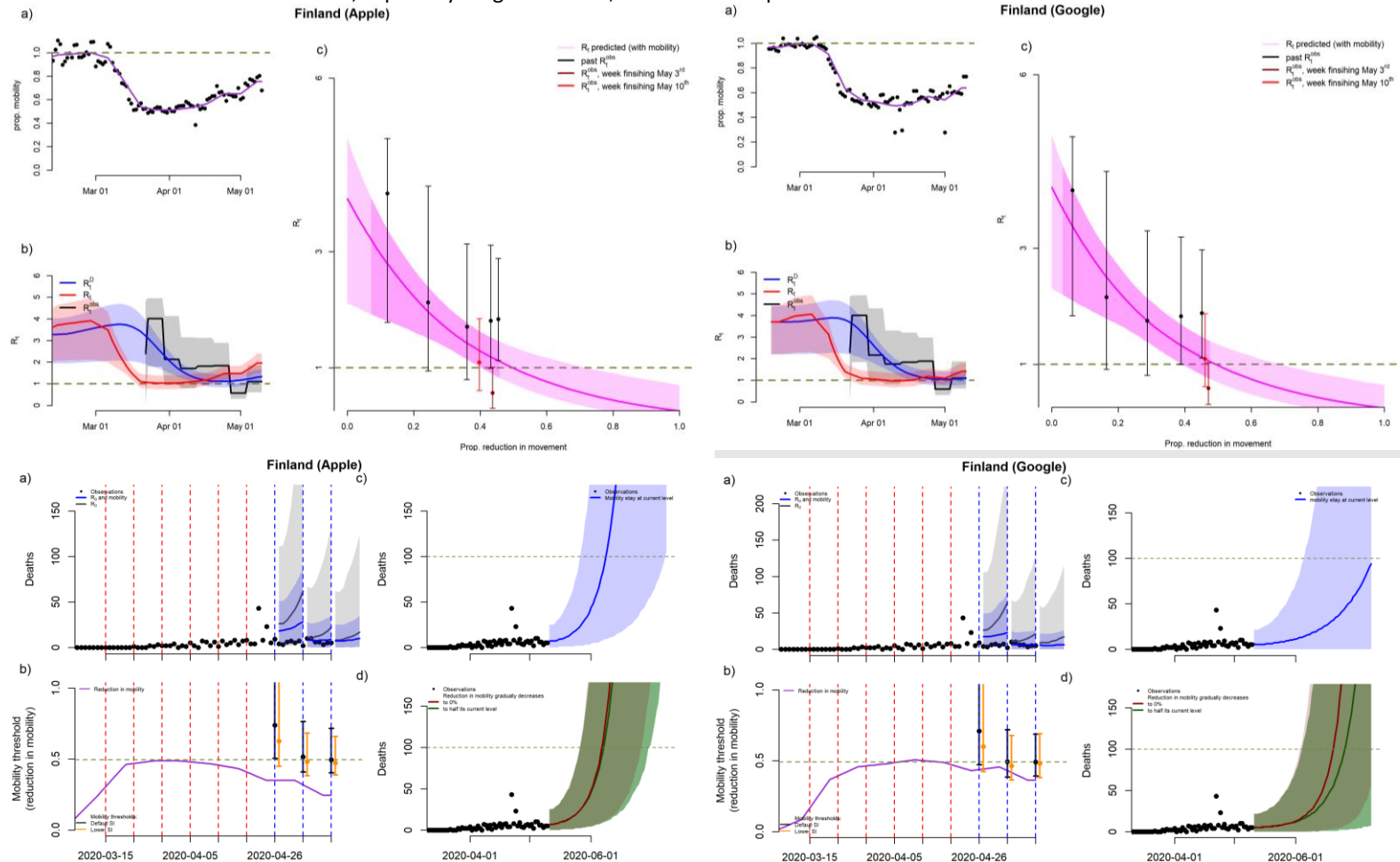


Figure SI.20: As in Figure 1-2 of main text.

France

Current reductions in mobility observed are above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions are above the 95% CrI mobility thresholds, suggesting that enough reduction in mobility is in place to ensure control. We see no evidence for the dampening of the relationship between transmission and mobility.

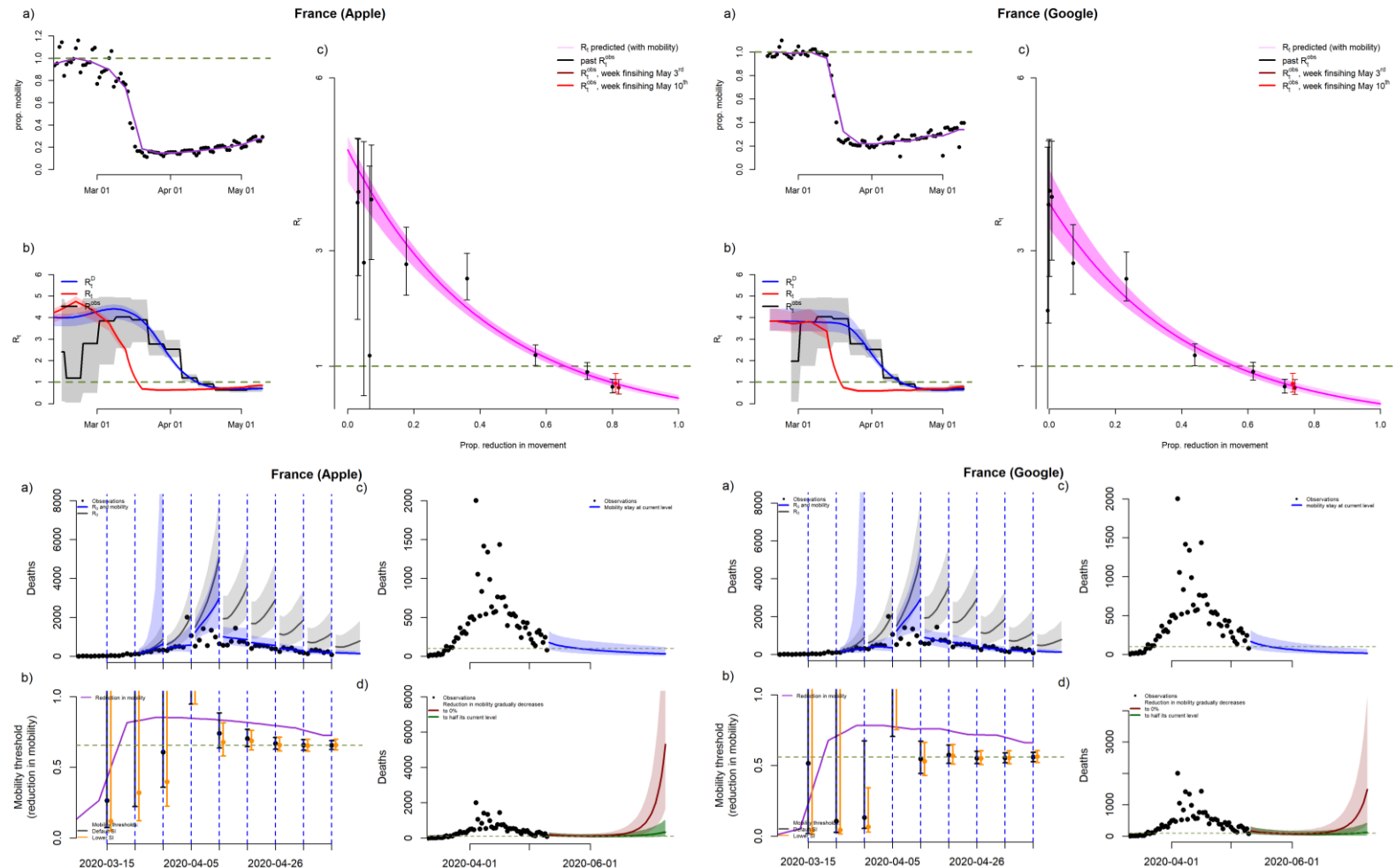


Figure SI.21: As in Figure 1-2 of main text.

Germany

Current reductions in mobility observed are below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low level of mobility reduction is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility thresholds, but no longer are, suggesting that, on its own, not enough reduction in mobility is in place to ensure control. We see good evidence for the dampening of the relationship between transmission and mobility, suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission may be under control. Forecasts presented, particularly long term ones, can therefore not be trusted.

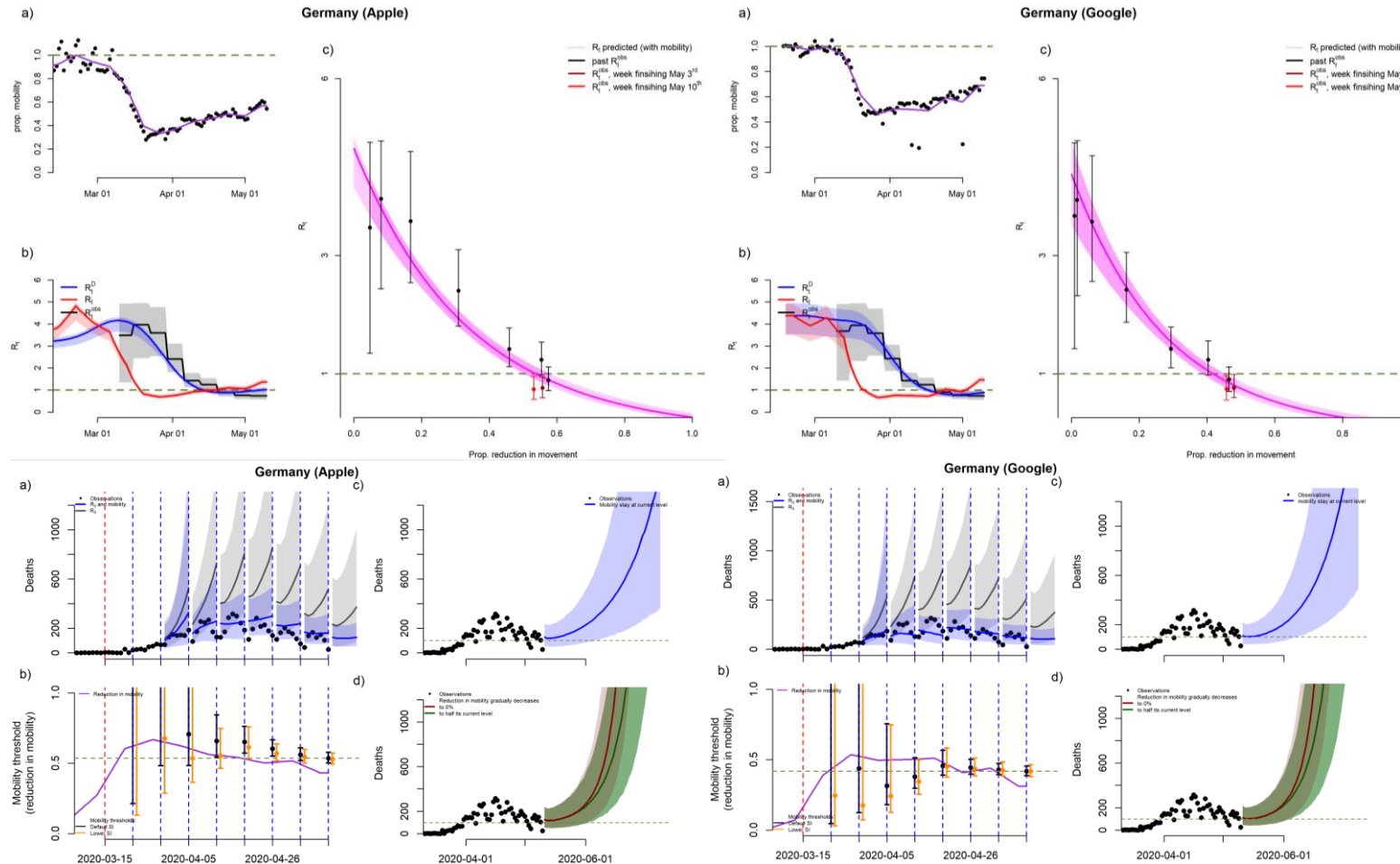


Figure SI.22: As in Figure 1-2 of main text.

Greece

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are both within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been and remain within the 95% CrI mobility thresholds, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. Recent trend shows an increase in mobility, suggesting increasing level of transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

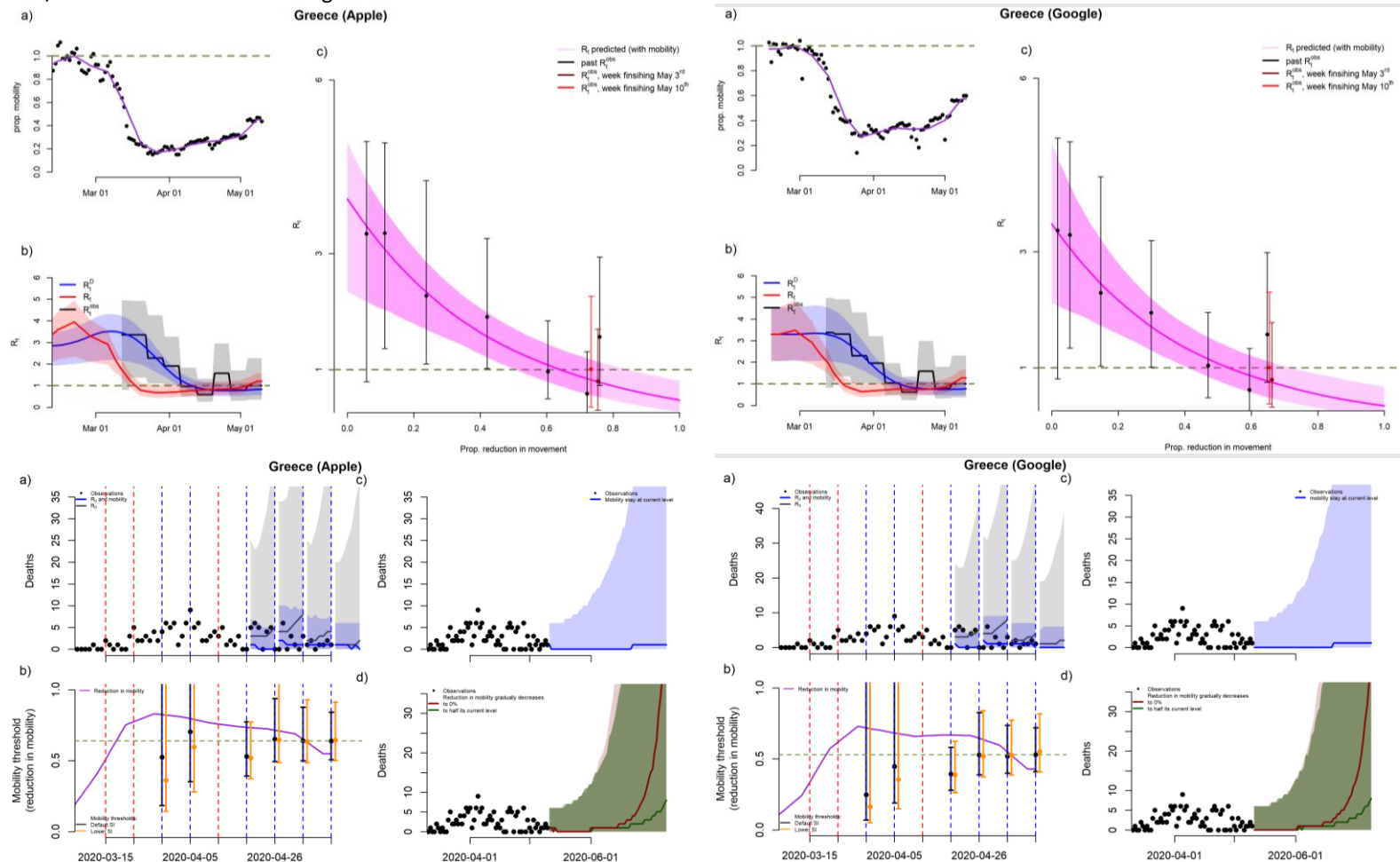


Figure SI.23: As in Figure 1-2 of main text.

Honduras

Current reduction in mobility observed is above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high mobility reduction is necessary to ensure control. Mobility reduction is within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

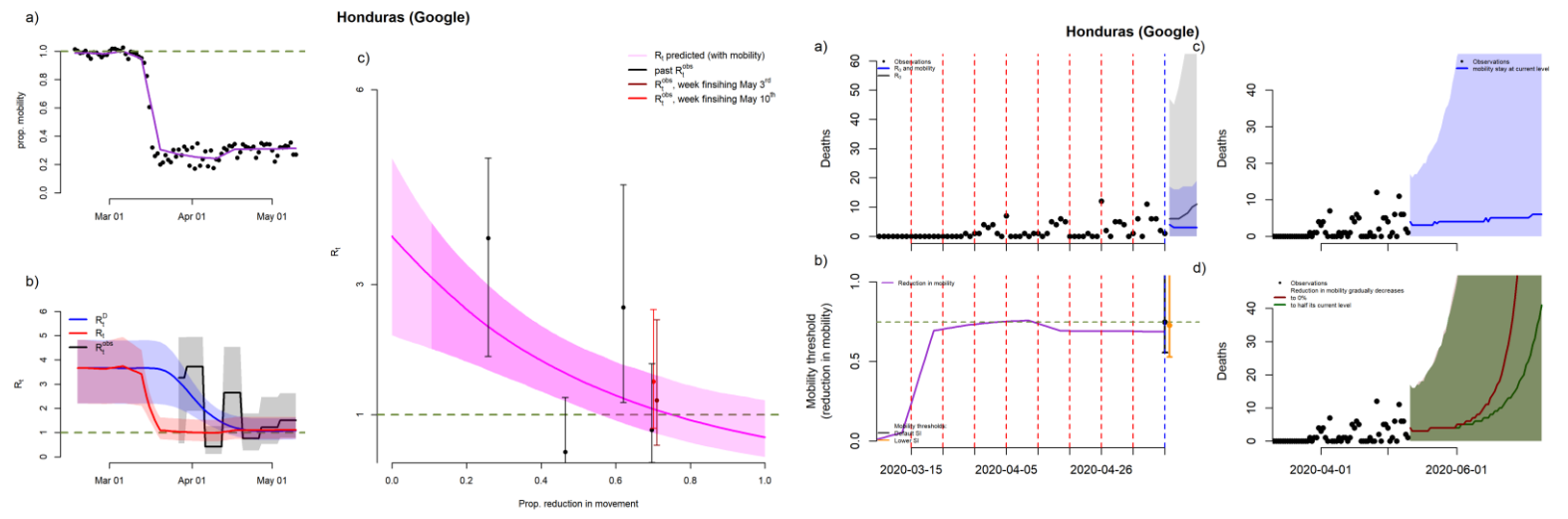


Figure SI.24: As in Figure 1-2 of main text.

Hungary

Current reductions in mobility observed are within/below the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are above/within the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively high level of mobility reduction is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility thresholds but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

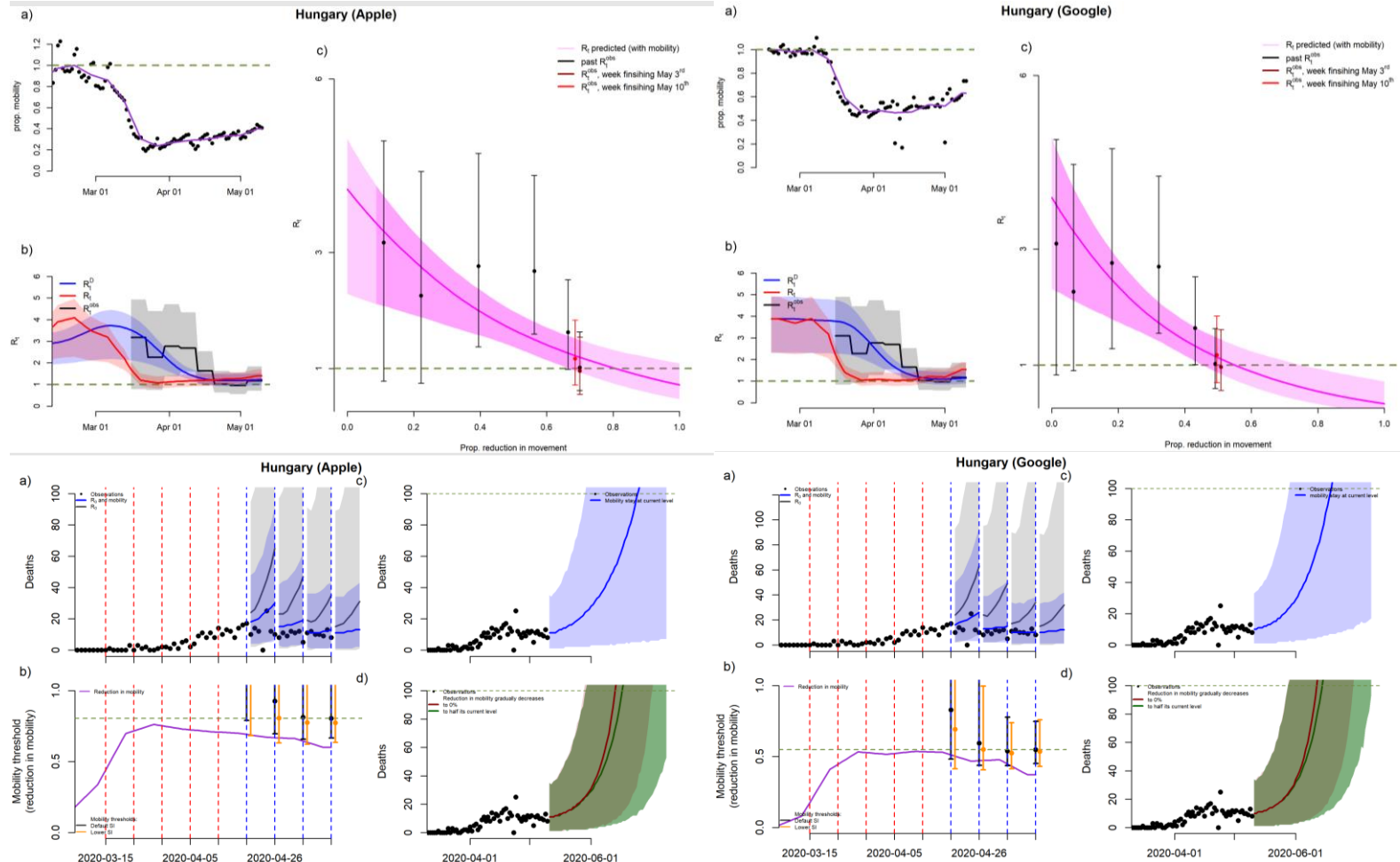


Figure SI.25: As in Figure 1-2 of main text.

India

Current reductions in mobility observed are above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high level of mobility reduction is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility thresholds but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

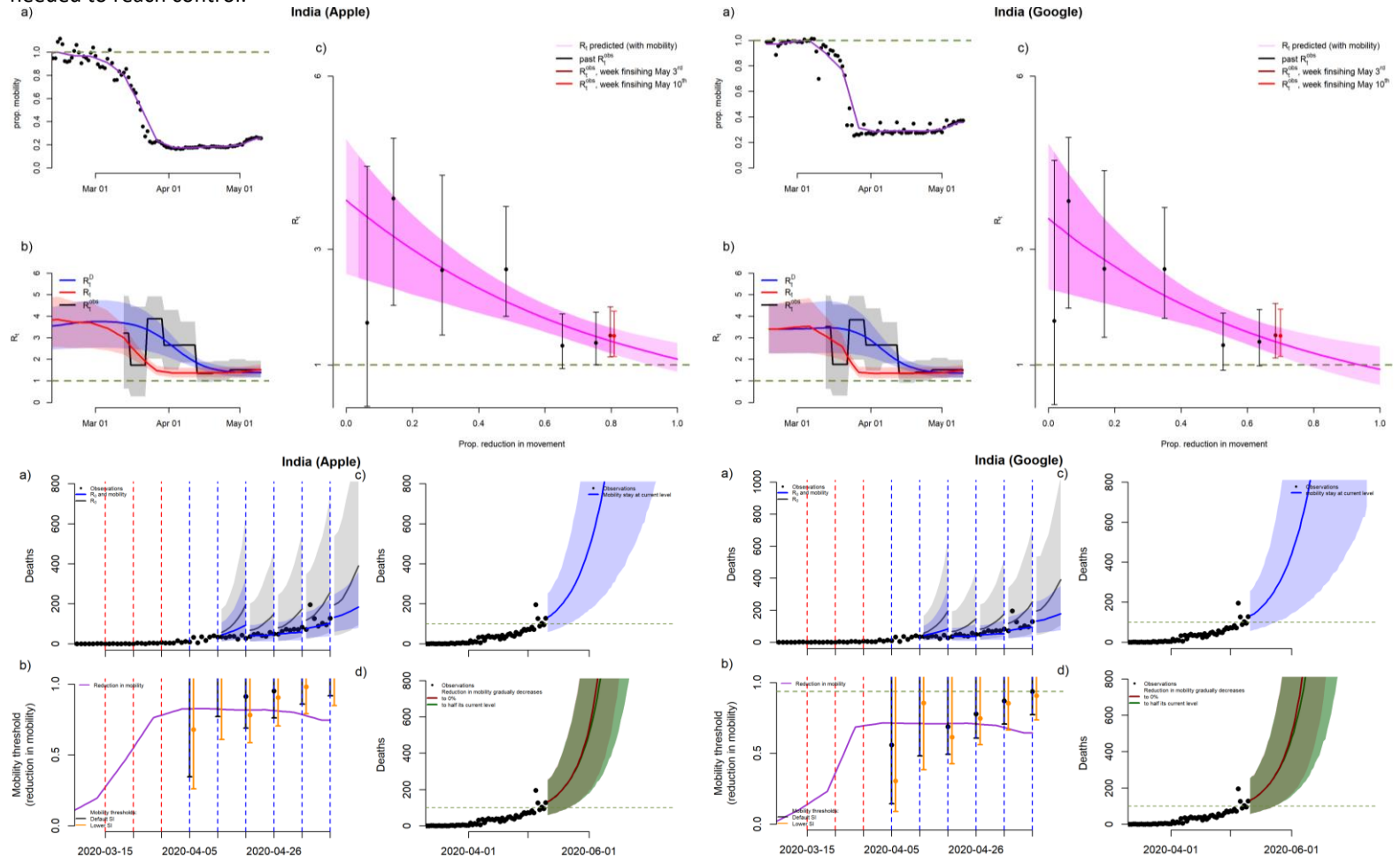


Figure SI.26: As in Figure 1-2 of main text.

Indonesia

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within/below the interquartile range of the median estimated country-specific mobility thresholds (Apple Google), suggesting relatively low level of mobility reduction is necessary to ensure control. Mobility reductions are within the 95% CrI mobility thresholds, suggesting enough reduction in mobility is in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

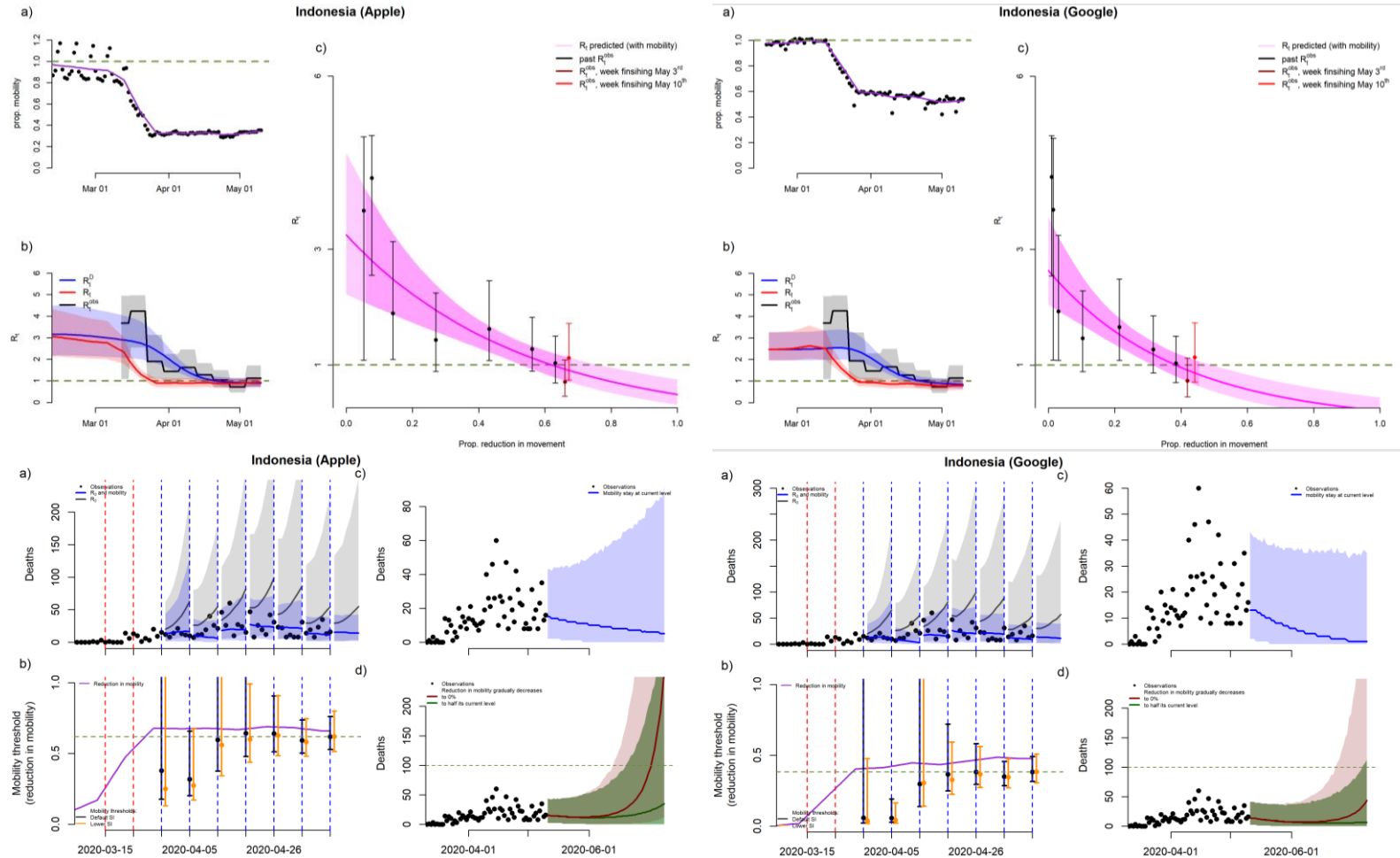


Figure SI.27: As in Figure 1-2 of main text.

Ireland

Current reductions in mobility observed are above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within/below the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions are within the 95% CrI mobility thresholds, suggesting enough reduction in mobility is likely in place to ensure control but uncertainty remain. We see good evidence for the dampening of the relationship between transmission and mobility (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission is under control. Forecasts presented, particularly long-term ones, can therefore not be trusted.

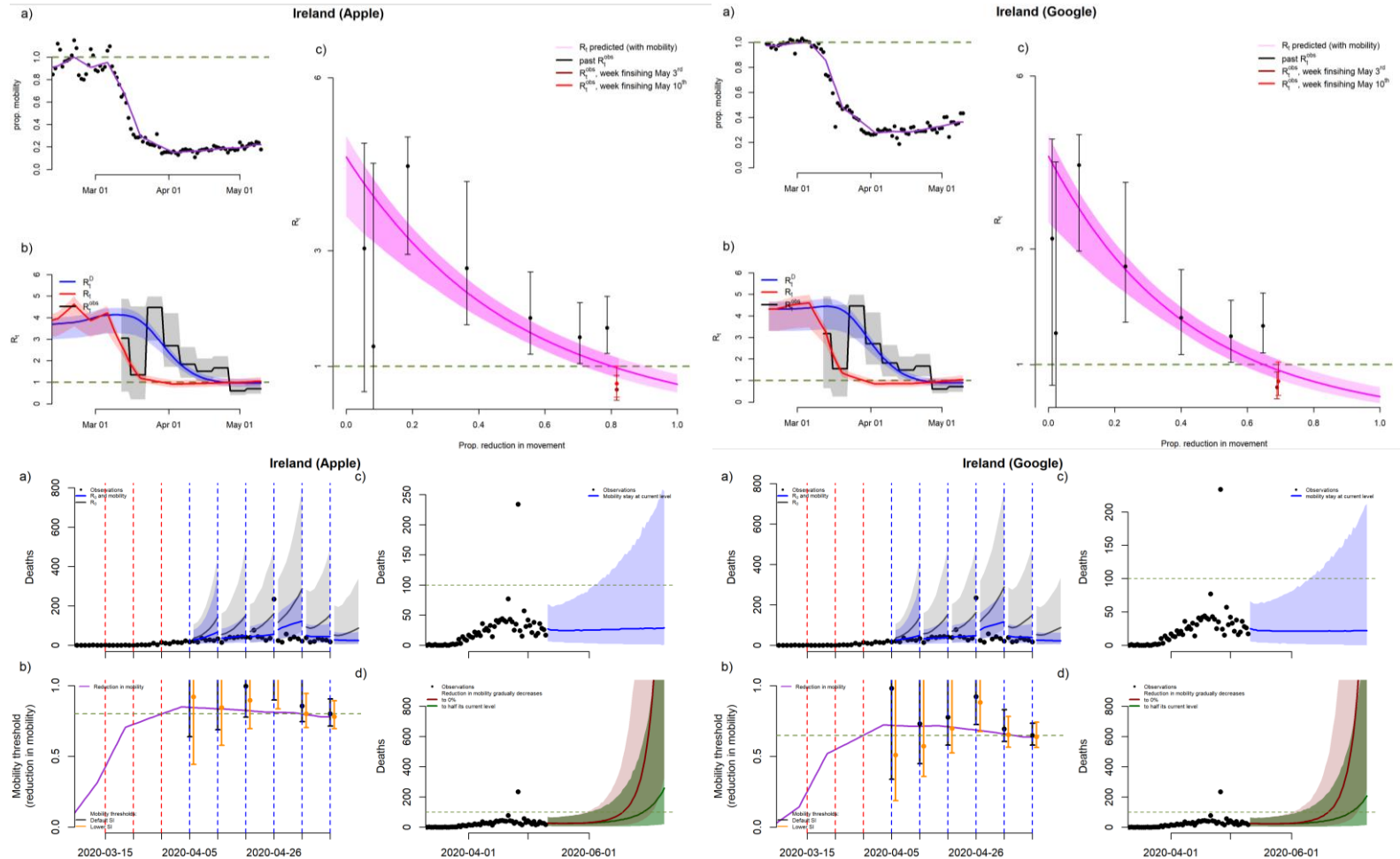


Figure SI.28: As in Figure 1-2 of main text.

Israel

Current reductions in mobility observed are below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows an increase in mobility, suggesting increasing level of transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

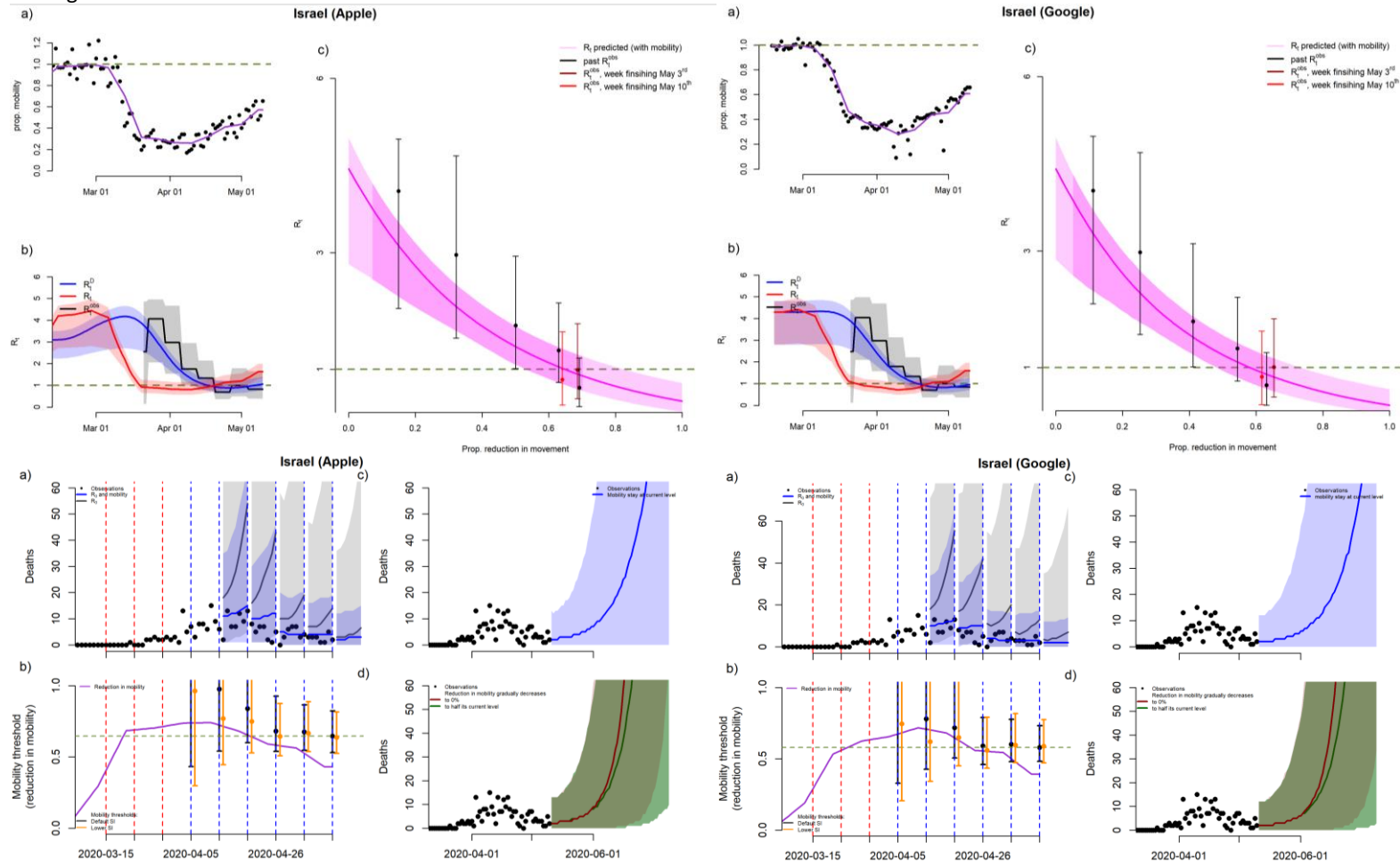


Figure SI.29: As in Figure 1-2 of main text.

Italy

Current reductions in mobility observed are above/within the interquartile range of the current country-specific reductions in mobility (Apple/Google). Both estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been above the 95% CrI mobility threshold but are now within, suggesting that enough reduction in mobility may be in place to ensure control, but uncertainty remains. Recent trend shows an increase in mobility, suggesting increasing level of transmission. We see no evidence for the dampening of the relationship between transmission and mobility.

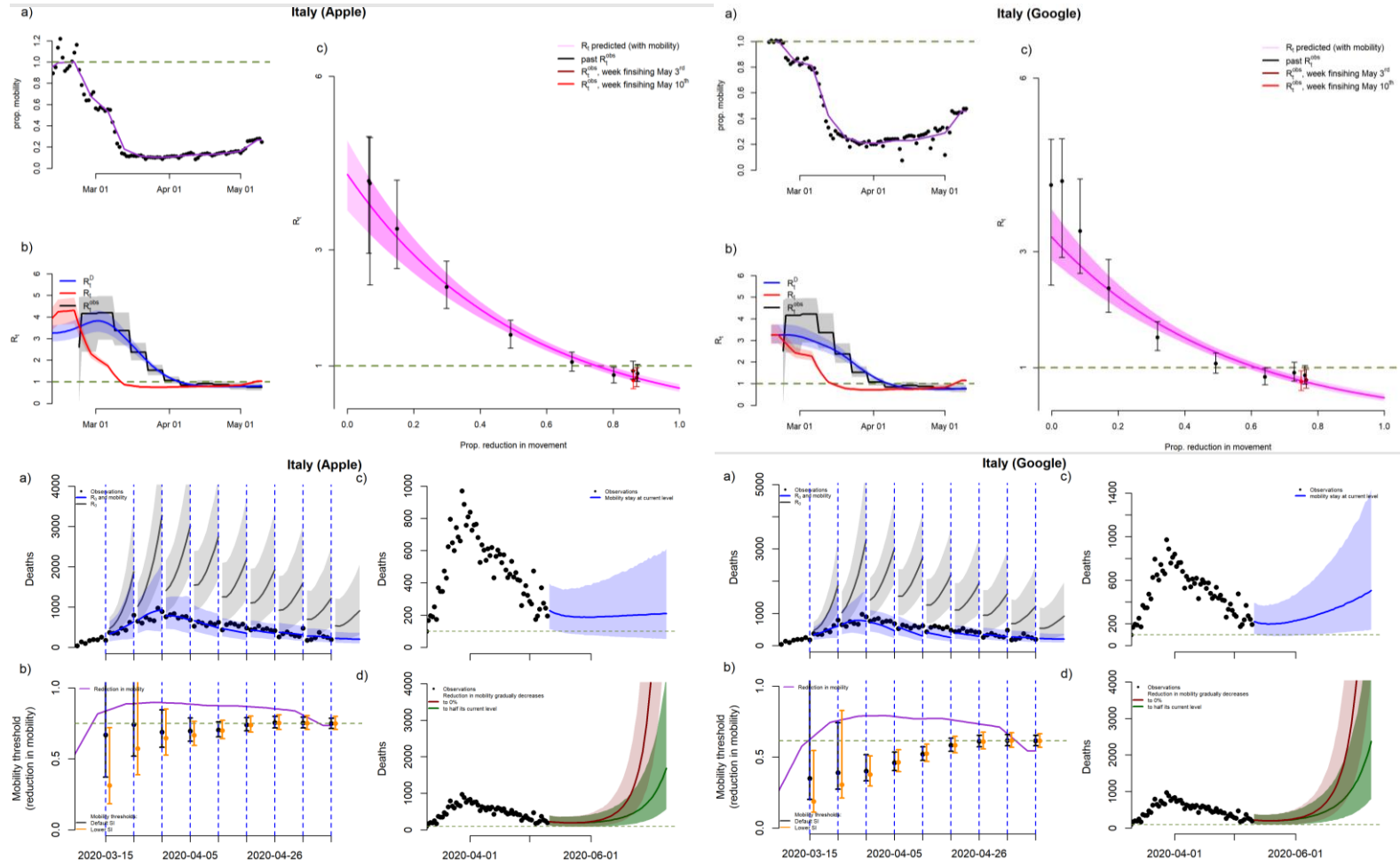


Figure SI.30: As in Figure 1-2 of main text.

Japan

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility is necessary to ensure control. Mobility reductions are within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

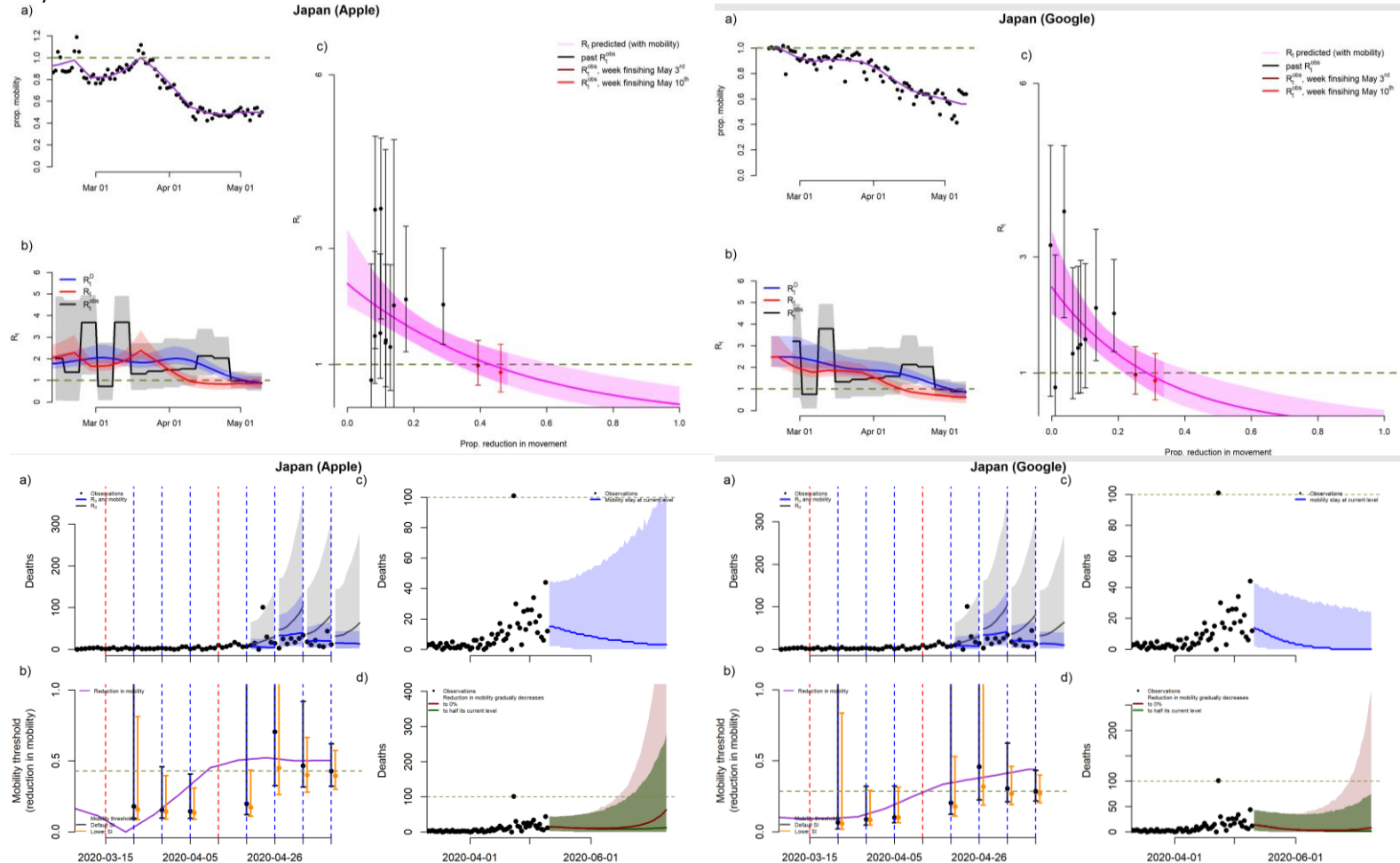


Figure SI.31: As in Figure 1-2 of main text.

Mexico

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above/within the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google), suggesting relatively high level of mobility reduction is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

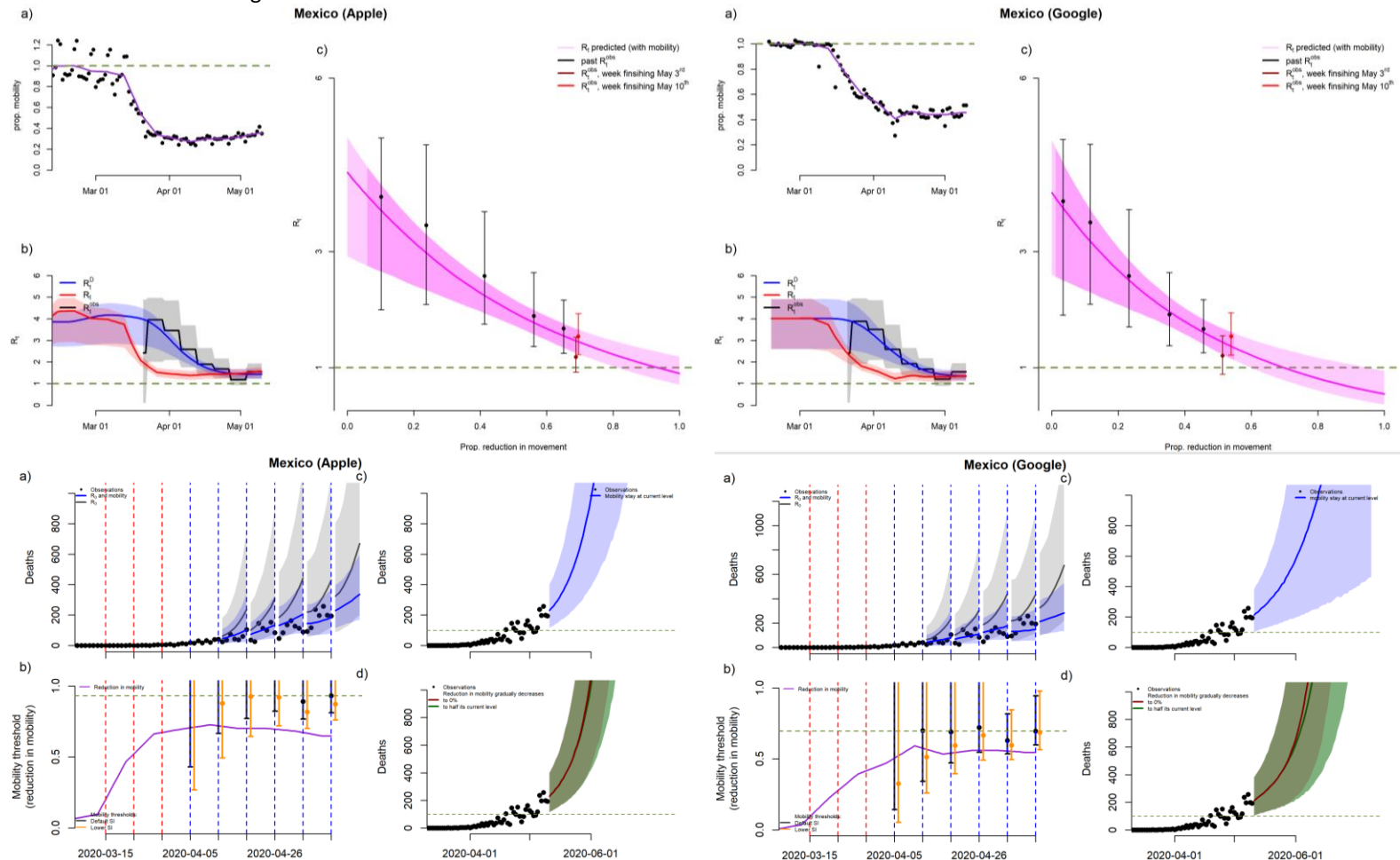


Figure SI.32: As in Figure 1-2 of main text.

Moldova

Current reduction in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction may have been within the 95% CrI mobility threshold but no longer is, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows an increase in mobility, suggesting increasing level of transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

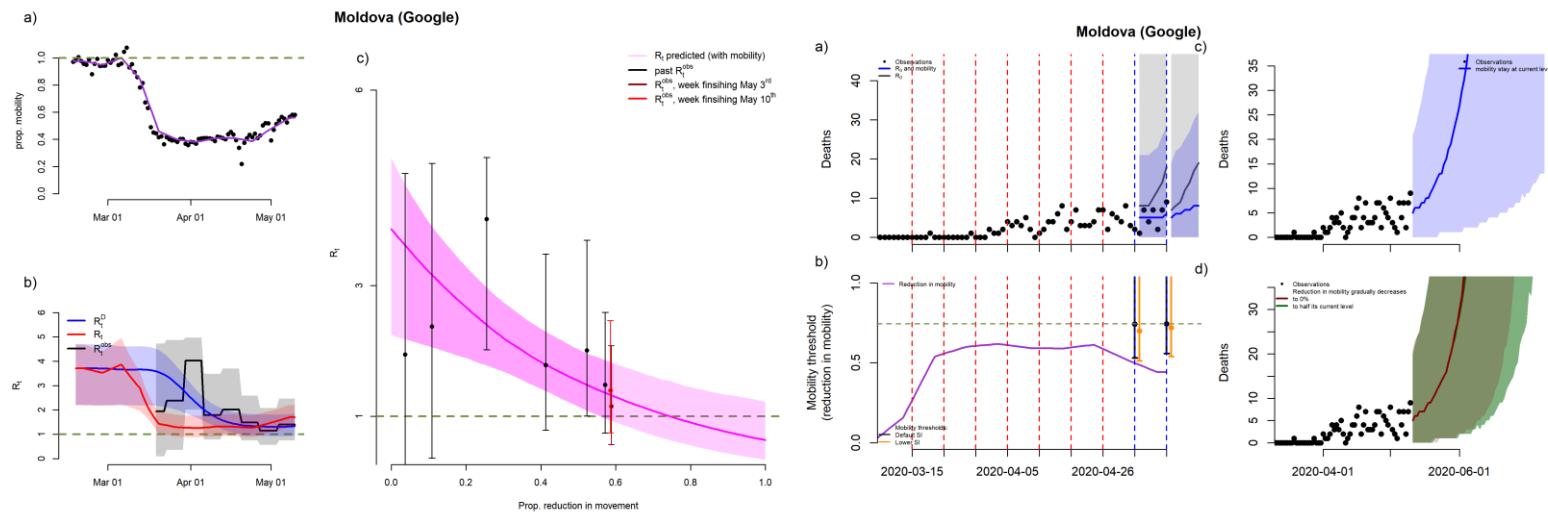


Figure SI.33: As in Figure 1-2 of main text.

Morocco

Current reduction in mobility observed is above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within/above the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google). Mobility reduction is within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control, but uncertainty remains. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

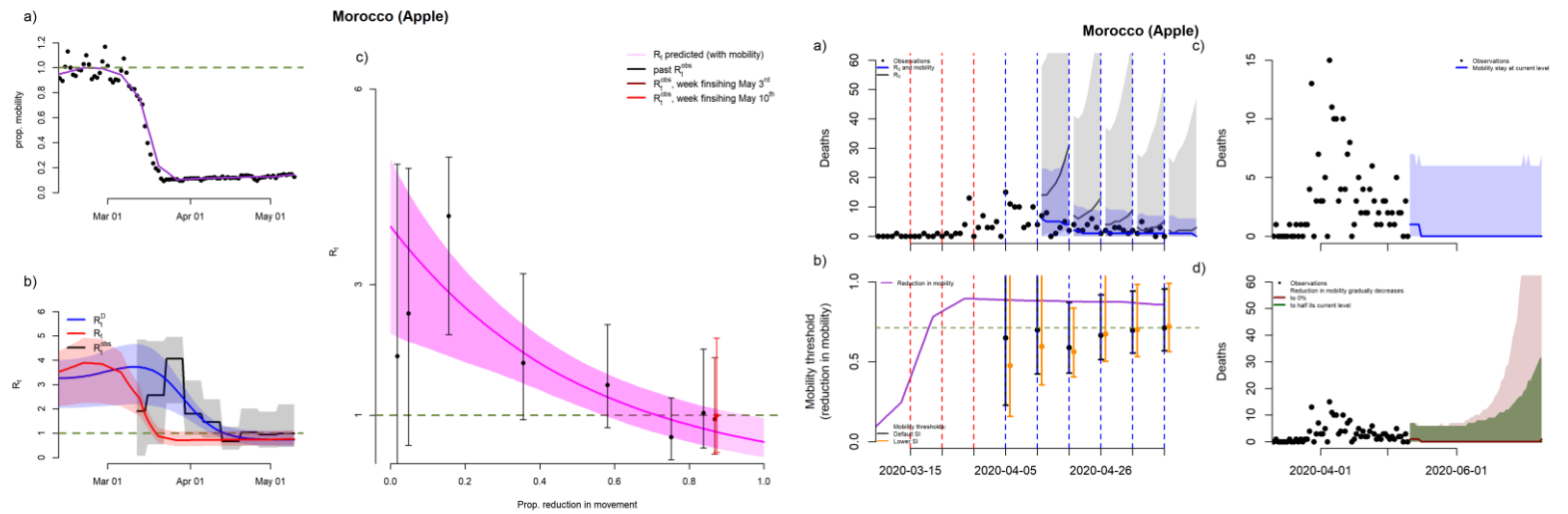


Figure SI.34: As in Figure 1-2 of main text.

Netherlands

Current reductions in mobility observed are within/below the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility is necessary to ensure control. Mobility reductions are within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

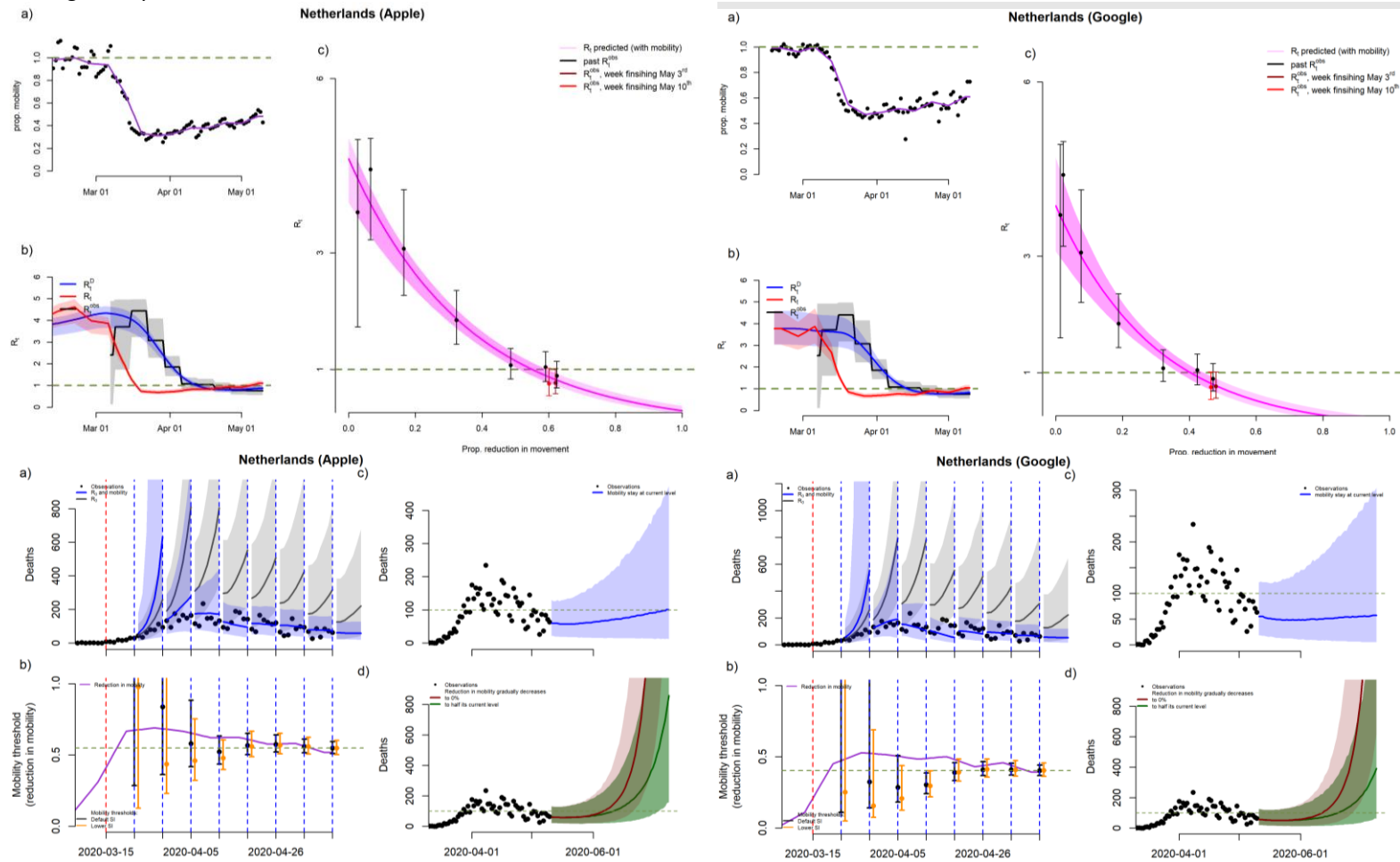


Figure SI.35: As in Figure 1-2 of main text.

Nigeria

Current reduction in mobility observed is below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high level of mobility reduction is necessary to ensure control. Mobility reduction is below the 95% CrI mobility threshold, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

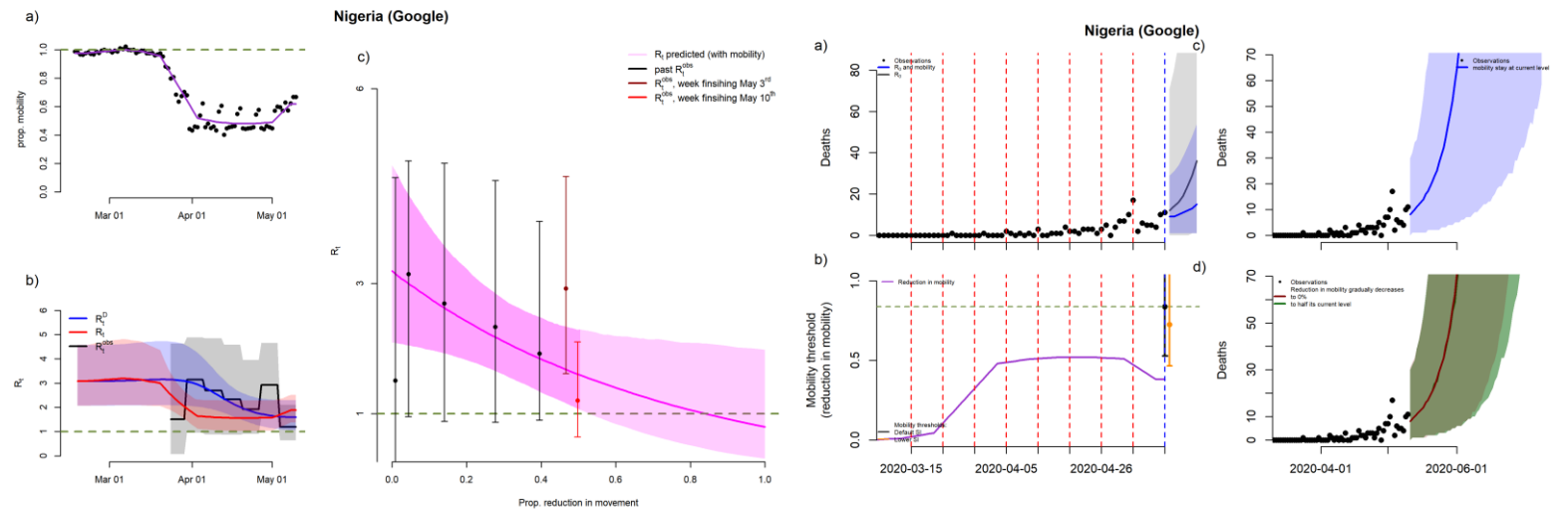


Figure SI.36: As in Figure 1-2 of main text.

Pakistan

Current reduction in mobility observed is below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high level of mobility reduction is necessary to ensure control. Mobility reduction is below the 95% CrI mobility threshold, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control

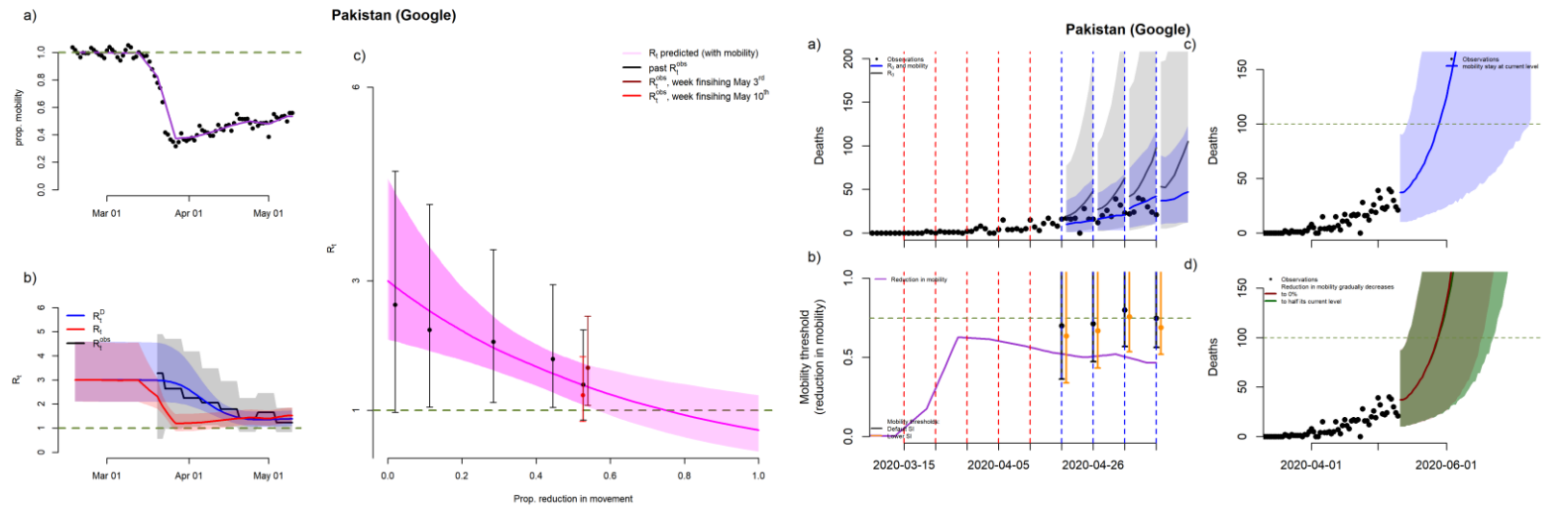


Figure SI.37: As in Figure 1-2 of main text.

Panama

Current reduction in mobility observed are above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high reduction in mobility is necessary to ensure control. Mobility reduction is within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

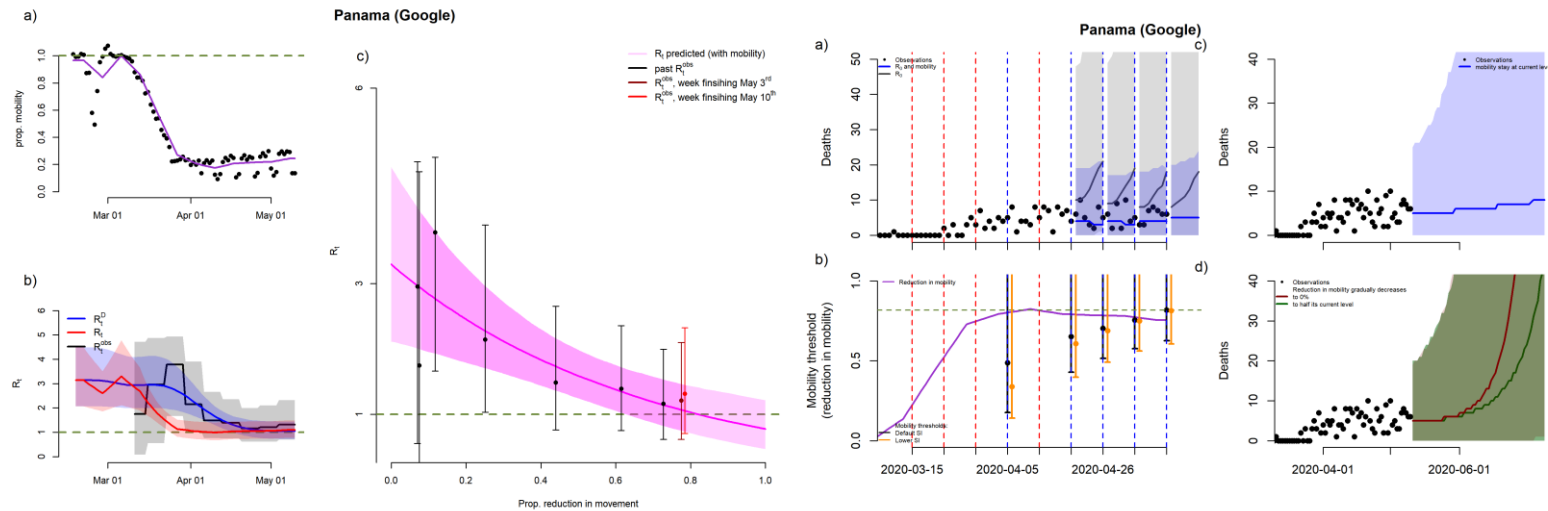


Figure SI.38: As in Figure 1-2 of main text.

Peru

Current reduction in mobility observed is above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high reduction in mobility is necessary to ensure control. Mobility reduction has been within the 95% CrI mobility threshold but no longer is, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

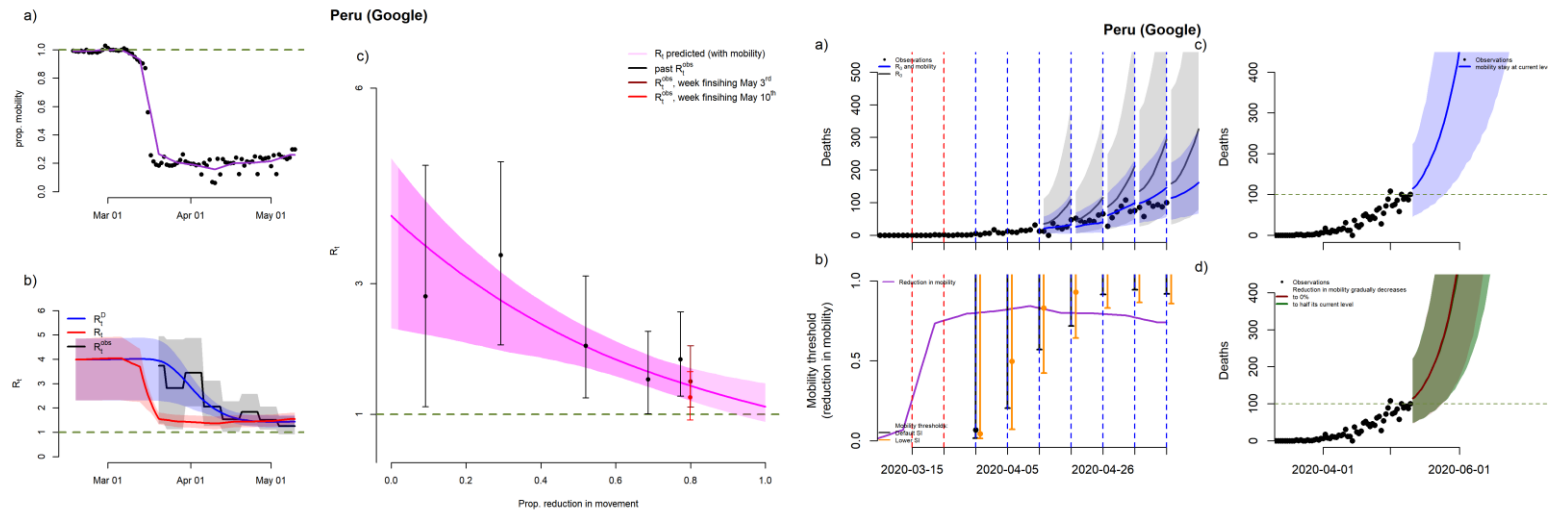


Figure SI.39: As in Figure 1-2 of main text.

Philippines

Current reductions in mobility observed are above the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above/within the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively high reduction in mobility is necessary to ensure control. Mobility reductions are within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

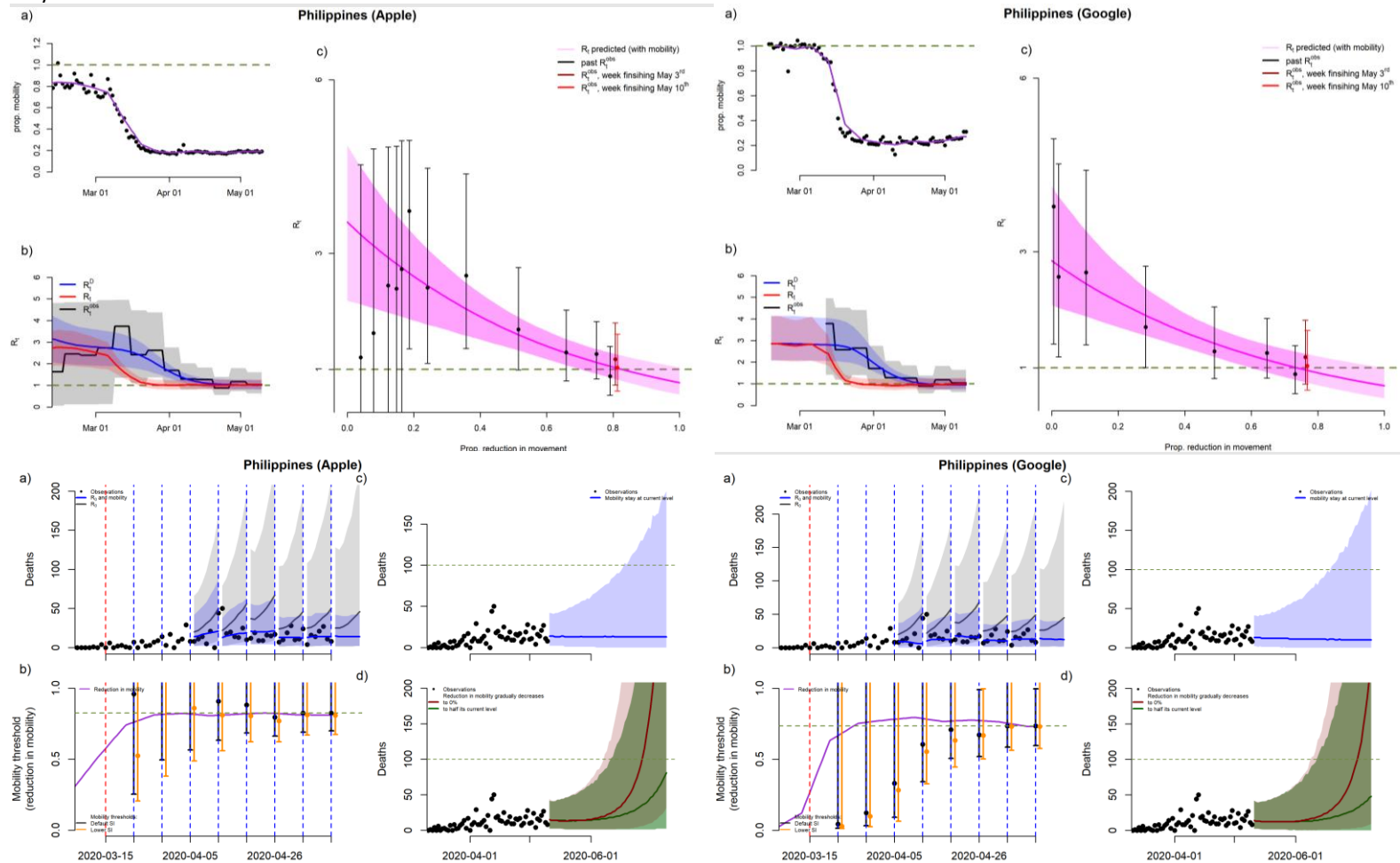


Figure SI.40: As in Figure 1-2 of main text.

Poland

Current reductions in mobility observed are below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction is below the 95% CrI mobility threshold, suggesting not enough reduction in mobility, on its own, is in place to ensure control. We see some evidence for the dampening of the relationship between transmission and mobility based on Apple mobility only (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission may be under control, but uncertainty remain. Forecasts presented, particularly long-term ones, can therefore not be trusted.

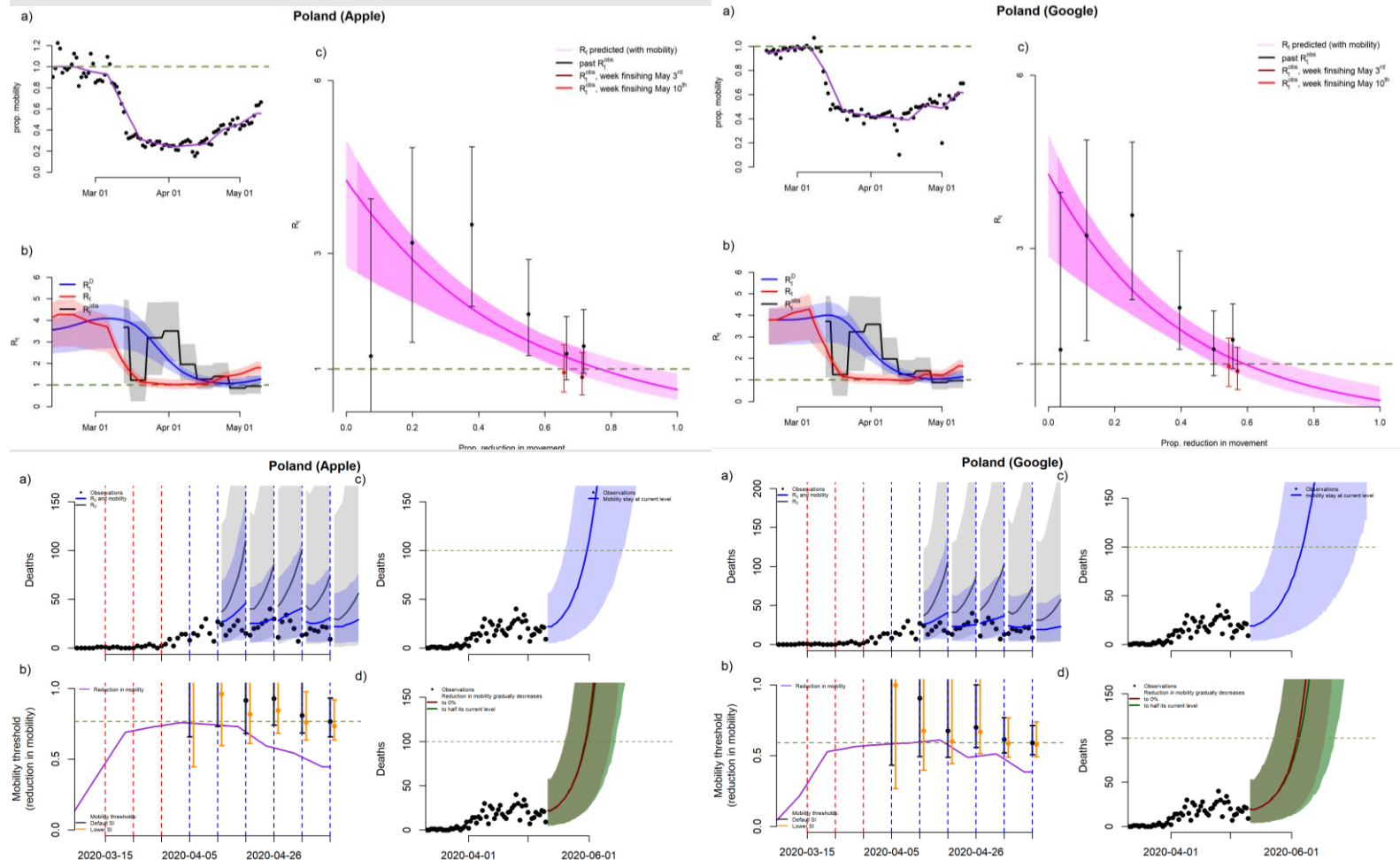


Figure SI.41: As in Figure 1-2 of main text.

Portugal

Current reduction in mobility observed are above/within the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions are within the 95% CrI mobility threshold, suggesting enough reduction in mobility may be in place to ensure control but uncertainty remain. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies may be needed to reach control.

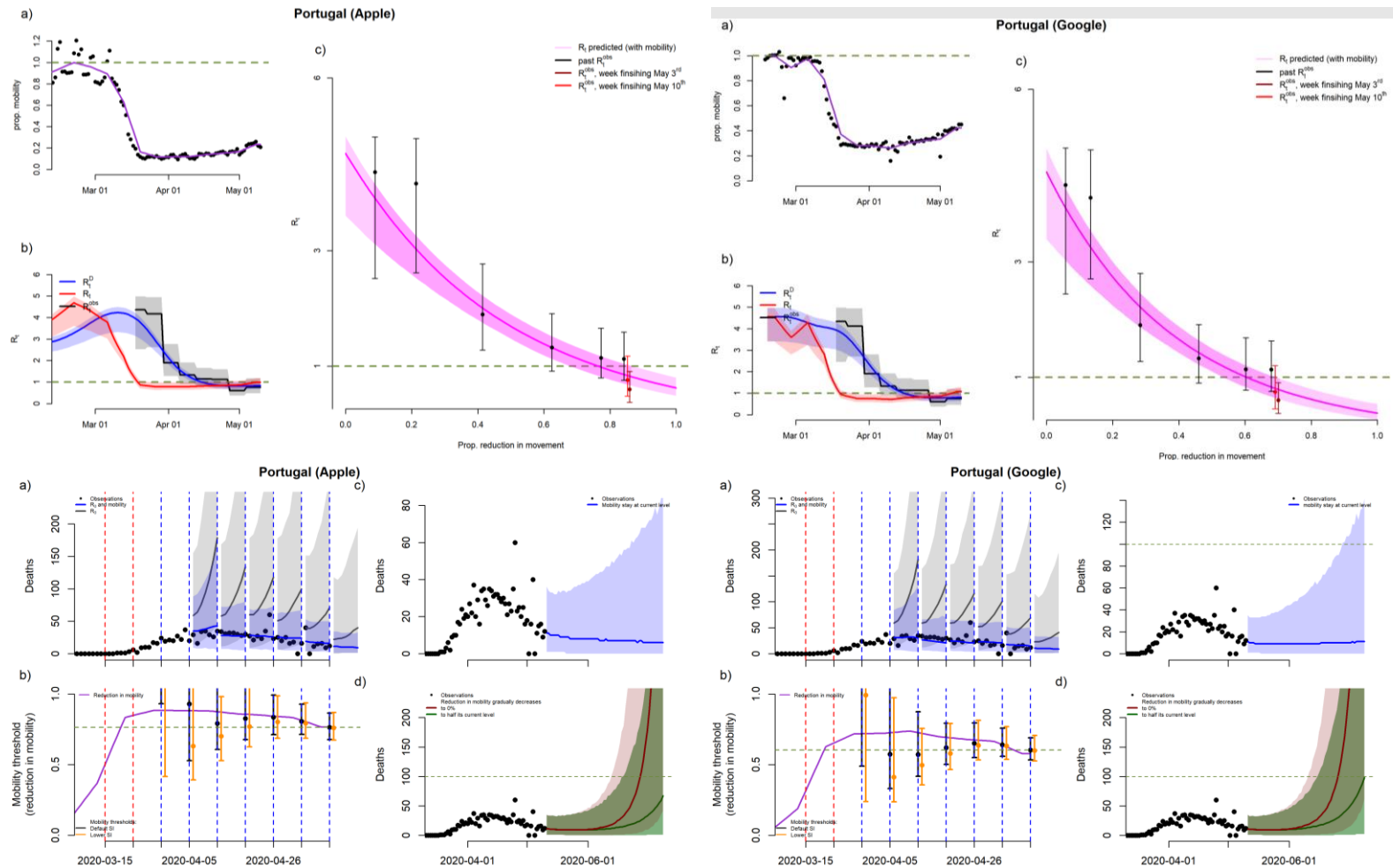


Figure SI.42: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Romania

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

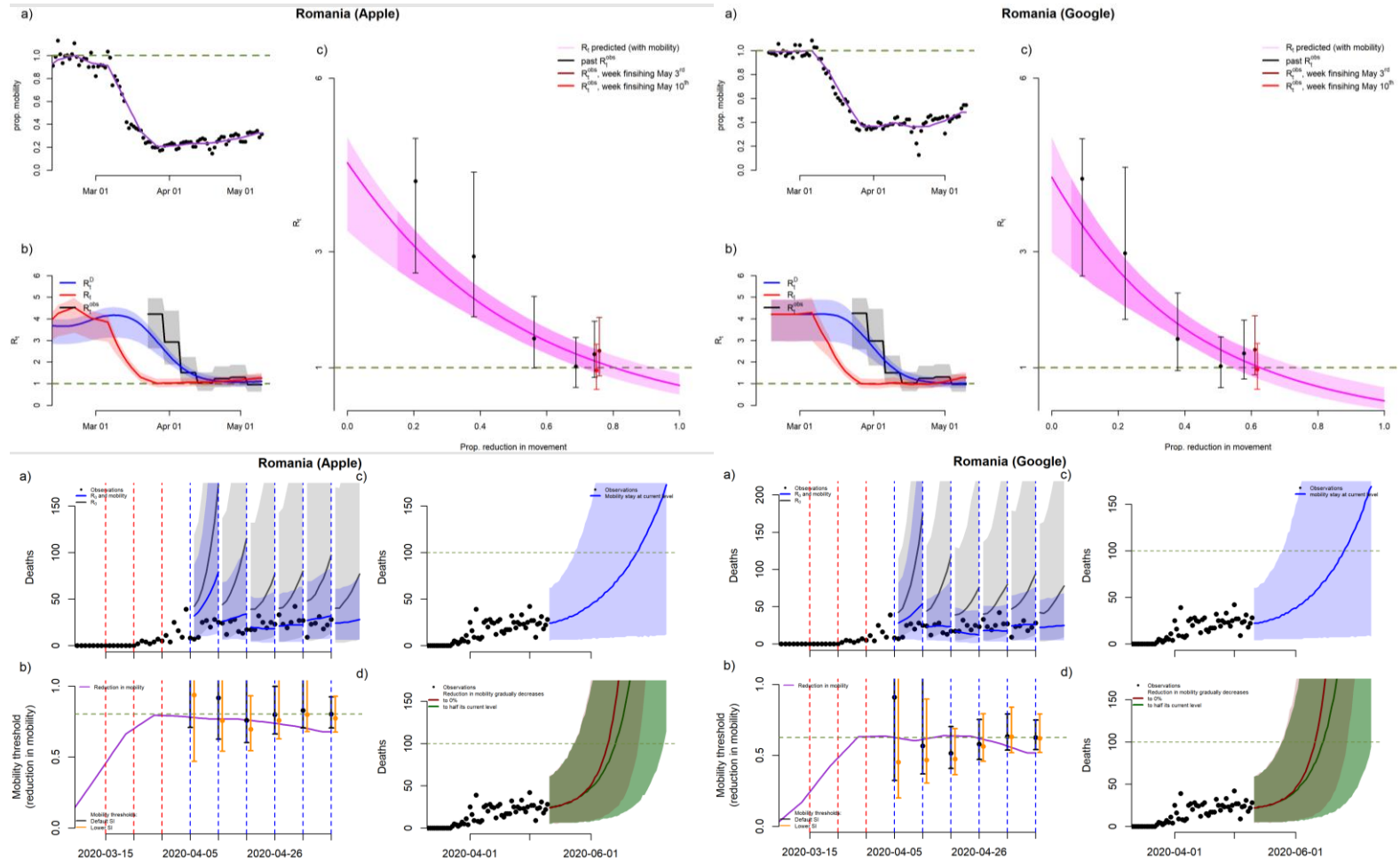


Figure SI.43: As in Figure 1-2 of main text.

Russia

Current reduction in mobility observed is below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reduction has been within the 95% CrI mobility threshold but no longer is, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

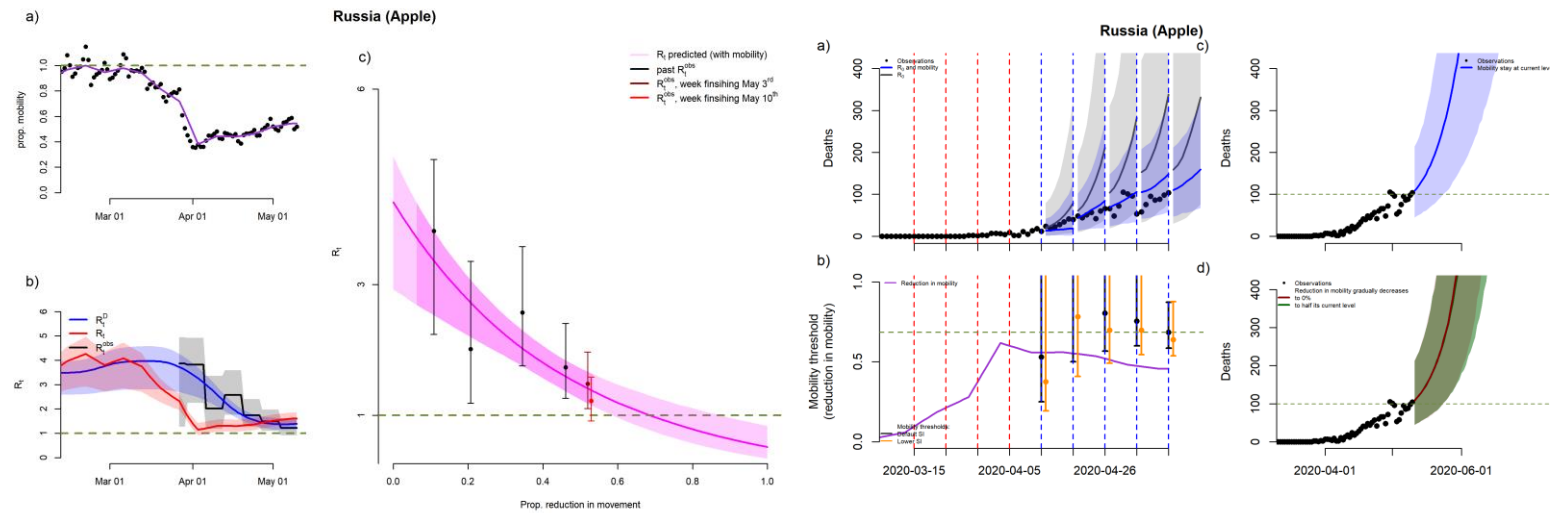


Figure SI.44: As in Figure 1-2 of main text.

Saudi Arabia

Current reductions in mobility observed are below/within the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are within/above the interquartile range of the median estimated country-specific mobility thresholds (Apple/Google), suggesting relatively high reduction in mobility is necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

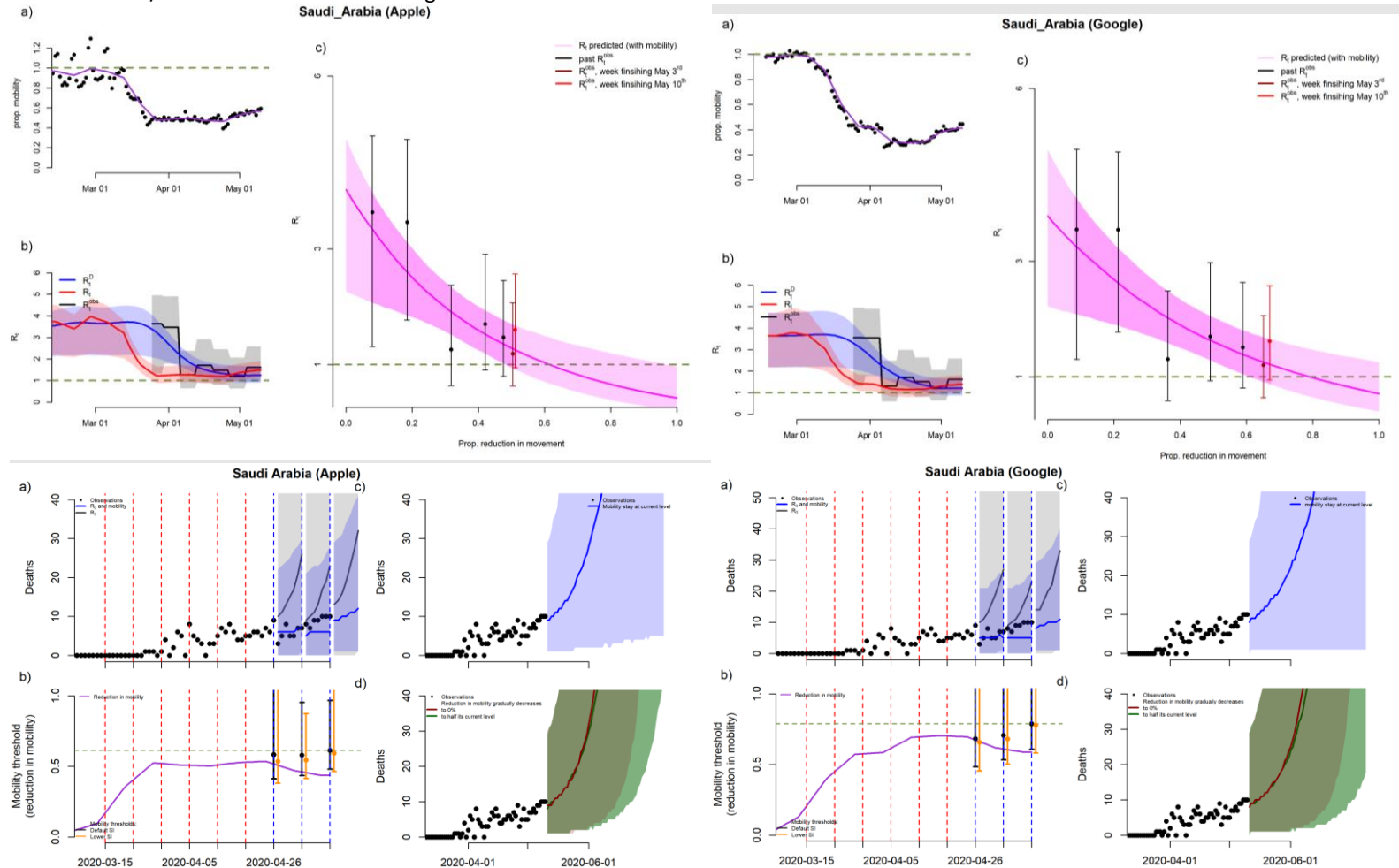


Figure SI.45: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Serbia

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. Recent trend shows an increase in mobility, suggesting increasing level of transmission. So far, we see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

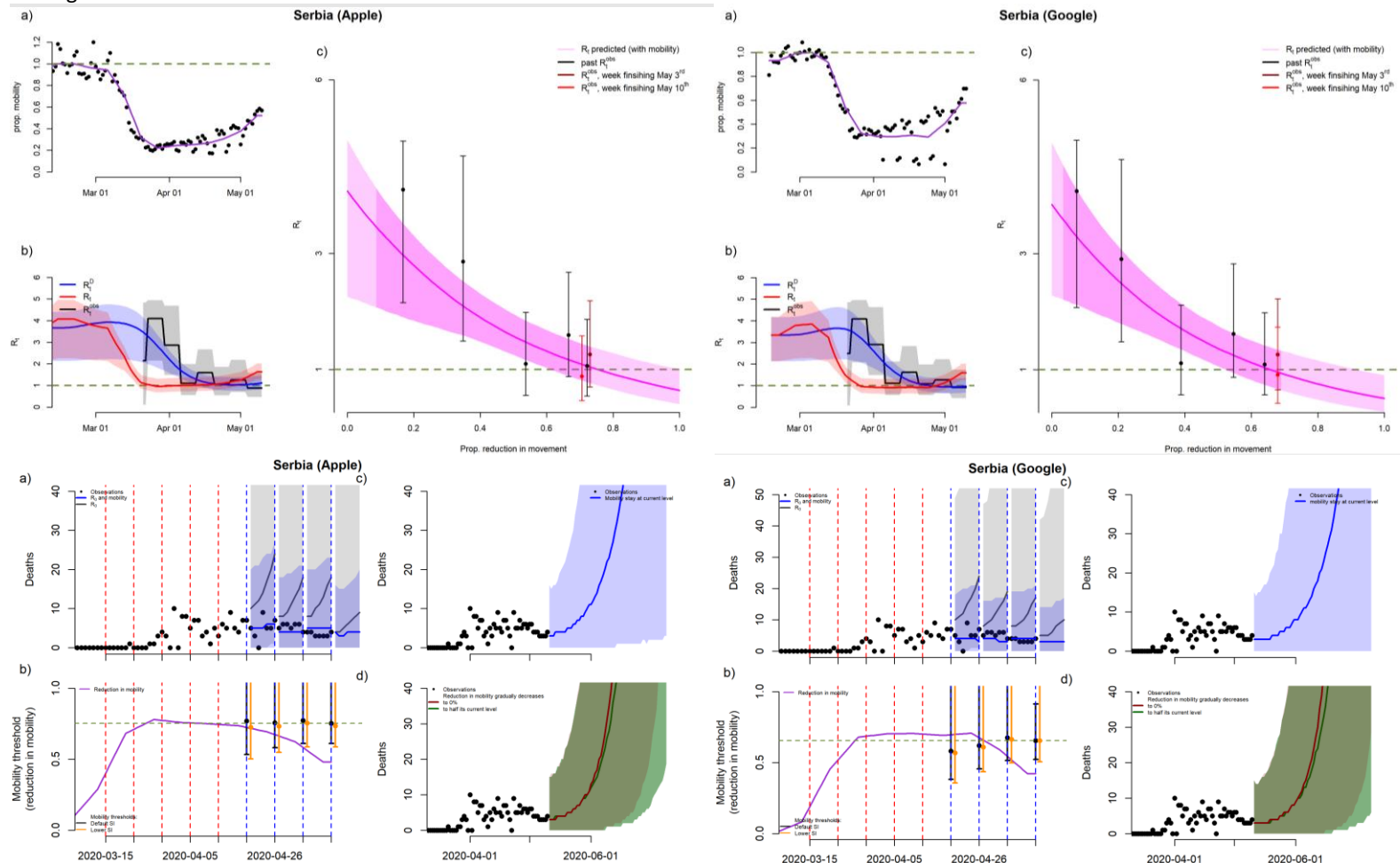


Figure SI.46: As in Figure 1-2 of main text.

South Africa

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high reduction in mobility are necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility has been reached to ensure control. Recent trend shows an increase in mobility, suggesting increasing level of transmission. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction and/or alternative control strategies are needed to reach control.

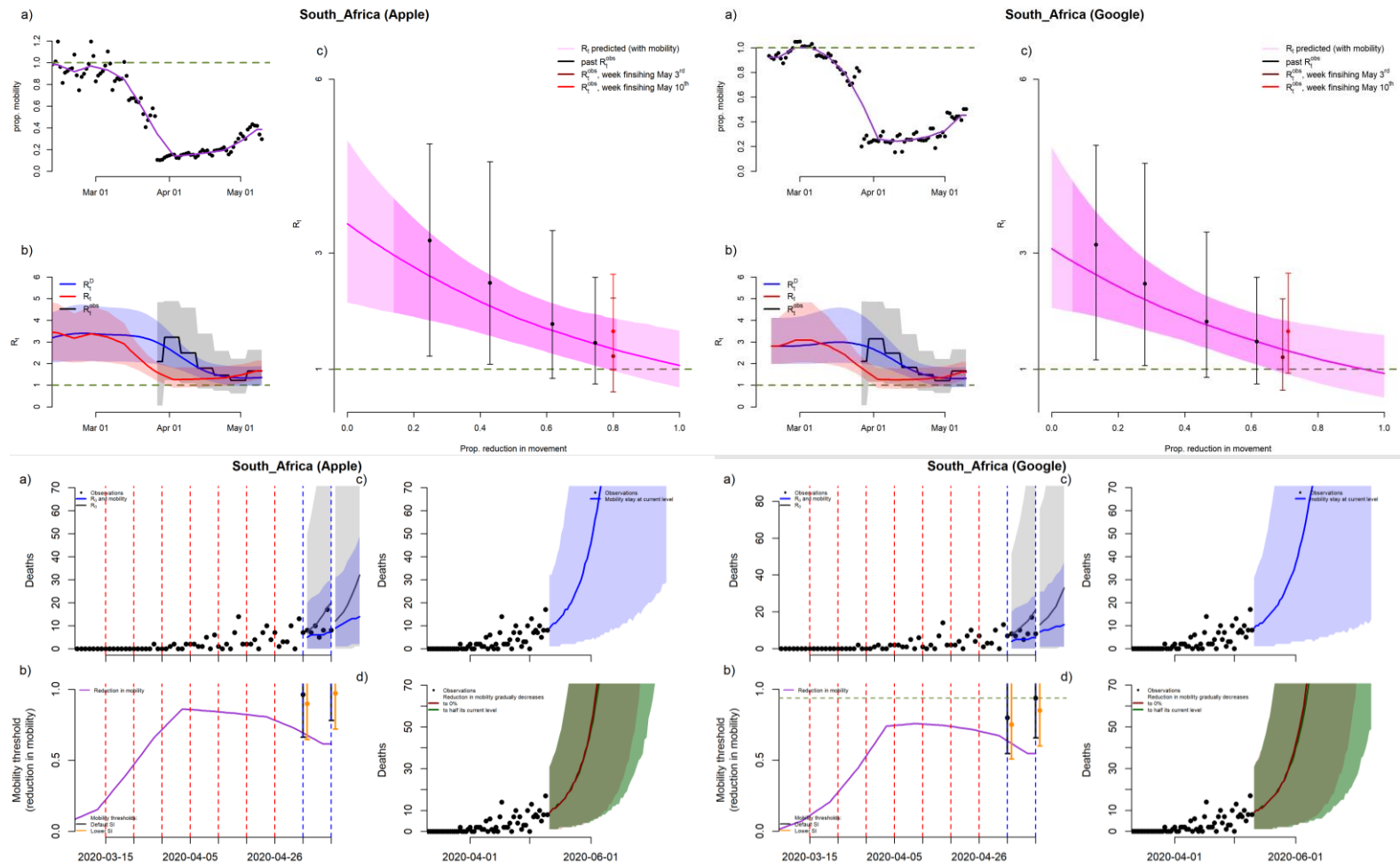


Figure SI.47: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Spain

Current reductions in mobility observed are above the interquartile range of the current country-specific reductions in mobility. Both estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been and remain above the 95% CrI mobility threshold, suggesting that enough reduction in mobility is in place to ensure control. We see no evidence for the dampening of the relationship between transmission and mobility. The recent increase in mobility (Google estimates) is concerning.

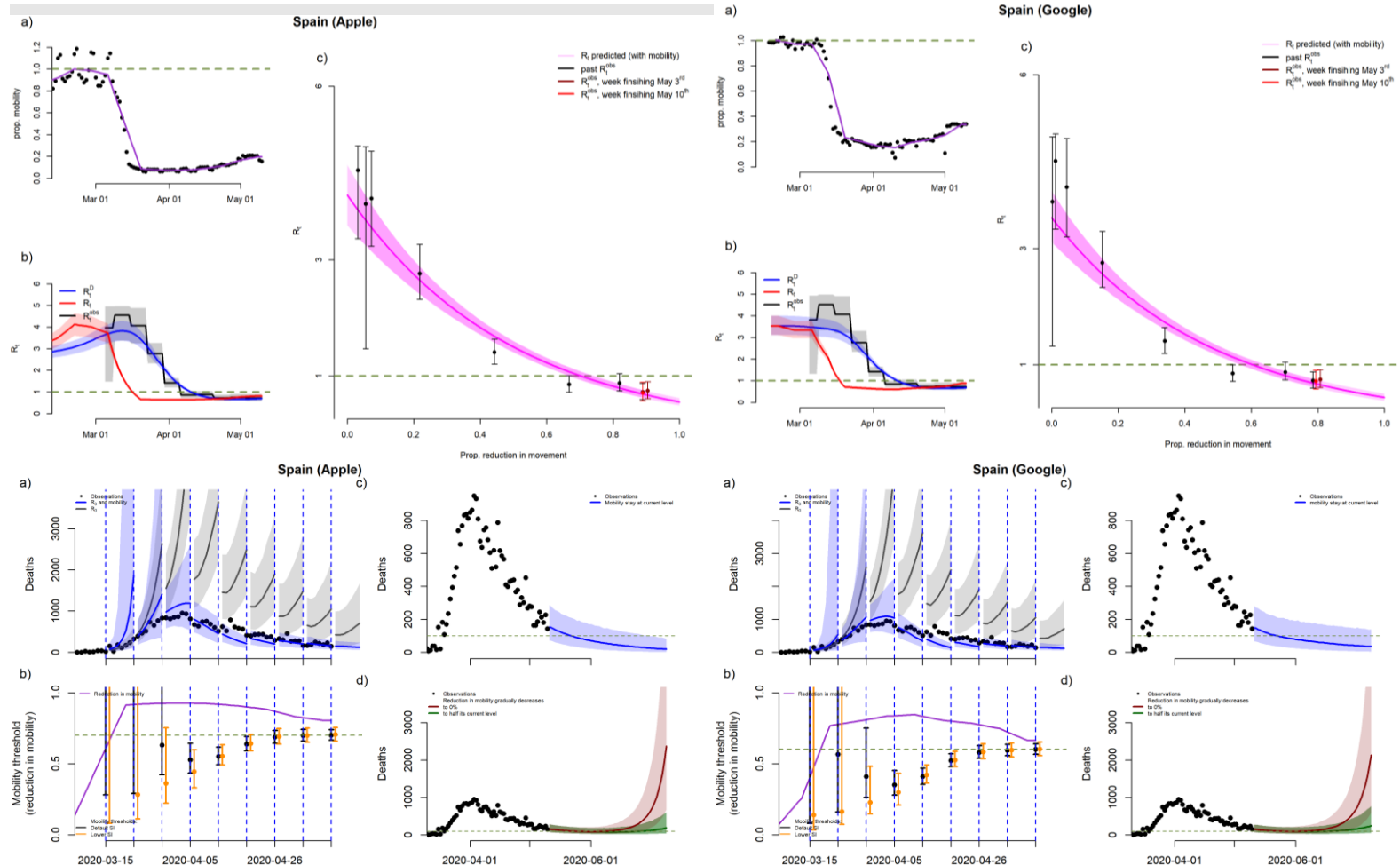


Figure SI.48: As in Figure 1-2 of main text.

Sweden

Current reductions in mobility observed are below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility may ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility, on its own, is in place to ensure control on its own. We see some evidence for the dampening of the relationship between transmission and mobility based on Apple mobility only (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission may be under control, but uncertainty remain. Forecasts presented, particularly long-term ones, can therefore not be trusted.

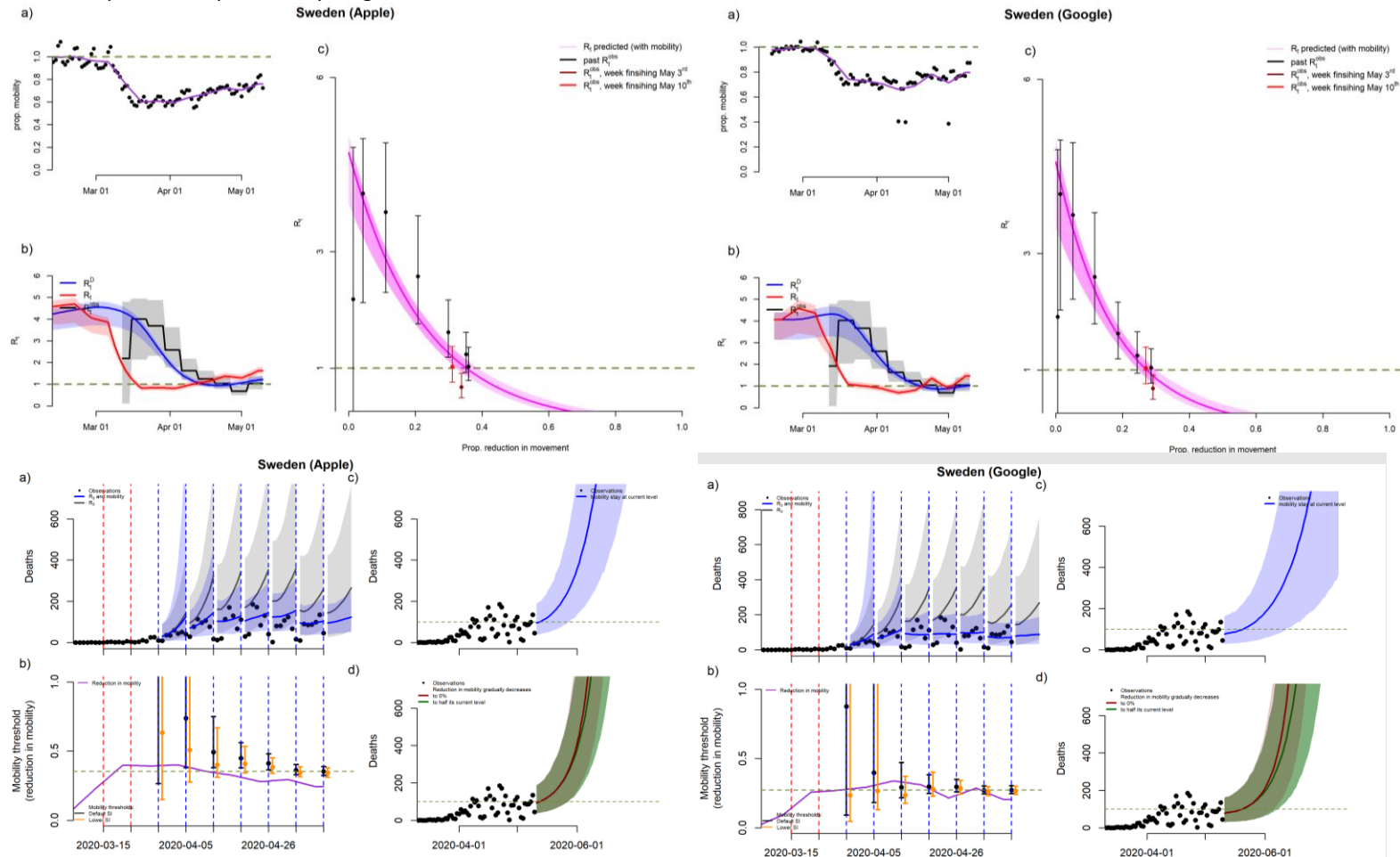


Figure SI.49: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Switzerland

Current reductions in mobility observed are below/within the interquartile range of the current country-specific reductions in mobility (Apple/Google). The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility may ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility, on its own, is in place to ensure control on its own. We see good evidence for the dampening of the relationship between transmission and mobility (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission is under control. Forecasts presented, particularly long-term ones, can therefore not be trusted.

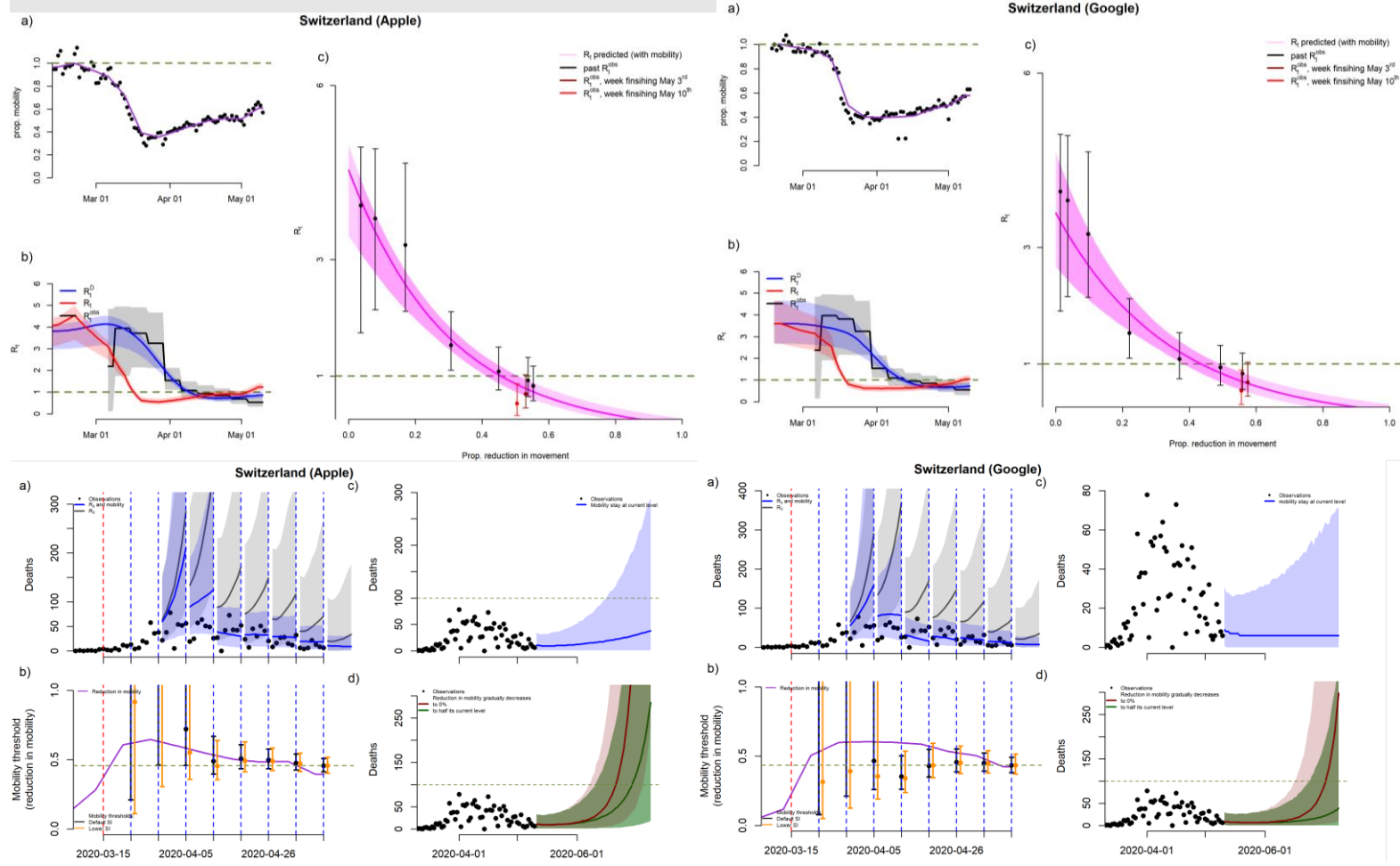


Figure SI.50: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Turkey

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been and remain within the 95% CrI mobility threshold, suggesting enough reduction in mobility is likely in place to ensure control, but uncertainty remain. We see some evidence for the dampening of the relationship between transmission and mobility based on Apple mobility only (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission is under control. Forecasts presented, particularly long-term ones, can therefore not be trusted.

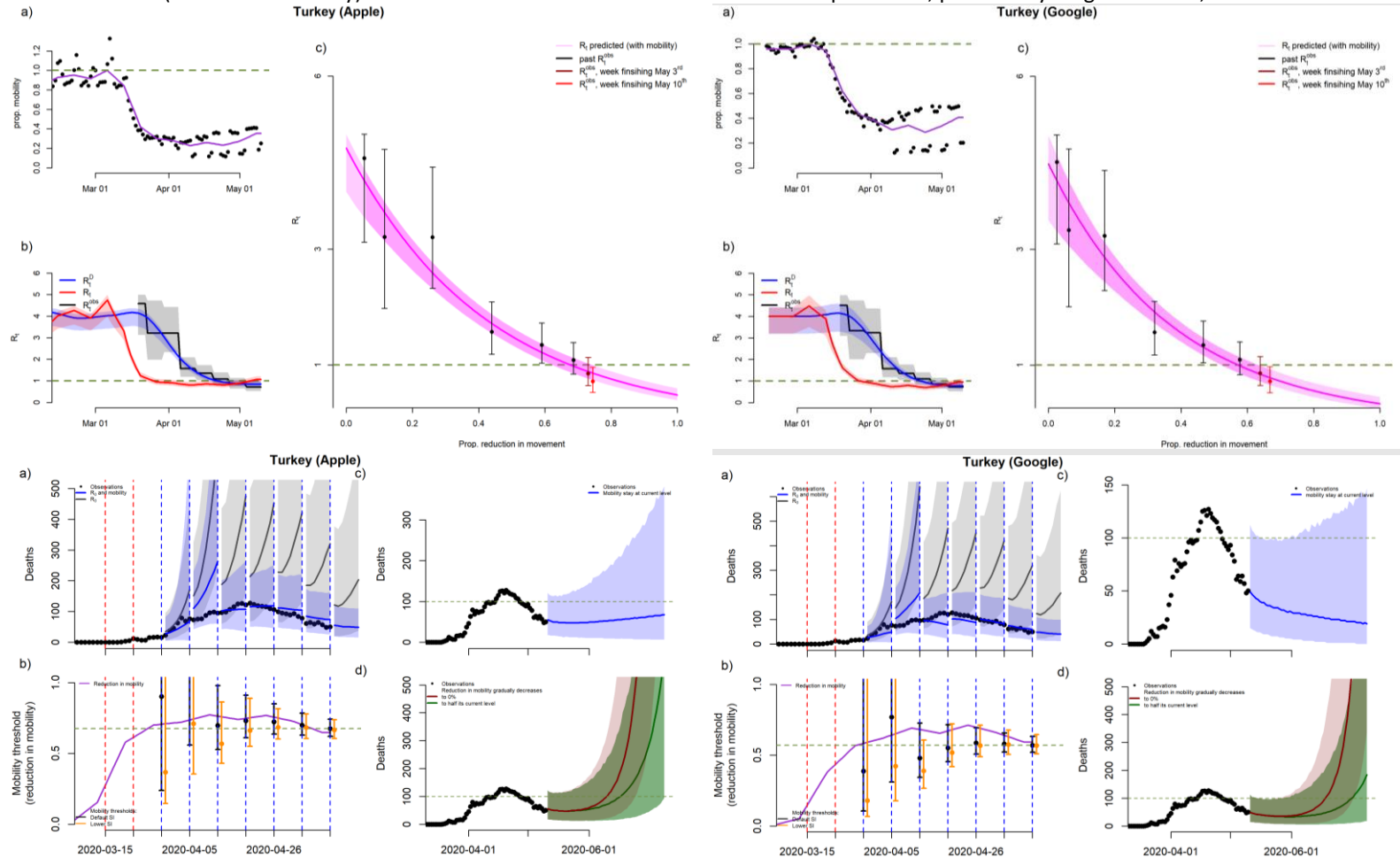


Figure SI.51: As in Figure 1-2 of main text.

Ukraine

Current reduction in mobility observed is below the interquartile range of the current country-specific reductions in mobility. The estimated median mobility threshold is below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively reduction in mobility is necessary to ensure control. Mobility reduction has been within the 95% CrI mobility threshold but no longer is, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction or alternative control strategies are needed to reach control.

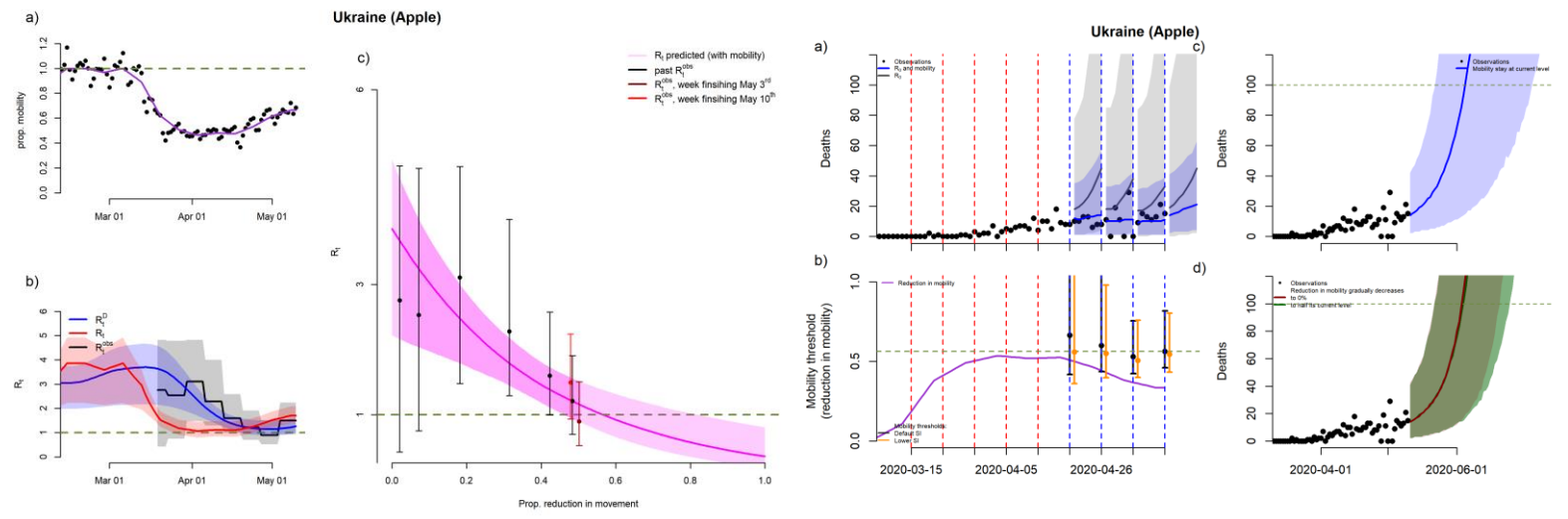


Figure SI.52: As in Figure 1-2 of main text.

United Arab Emirates

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are above the interquartile range of the median estimated country-specific mobility thresholds, suggesting high reduction in mobility is necessary to ensure control. Mobility reductions are below the 95% CrI mobility threshold, suggesting not enough reduction in mobility is in place to ensure control. We see no evidence for dampening of the relationship between transmission and mobility. This suggests higher level of mobility restriction or alternative control strategies are needed to reach control.

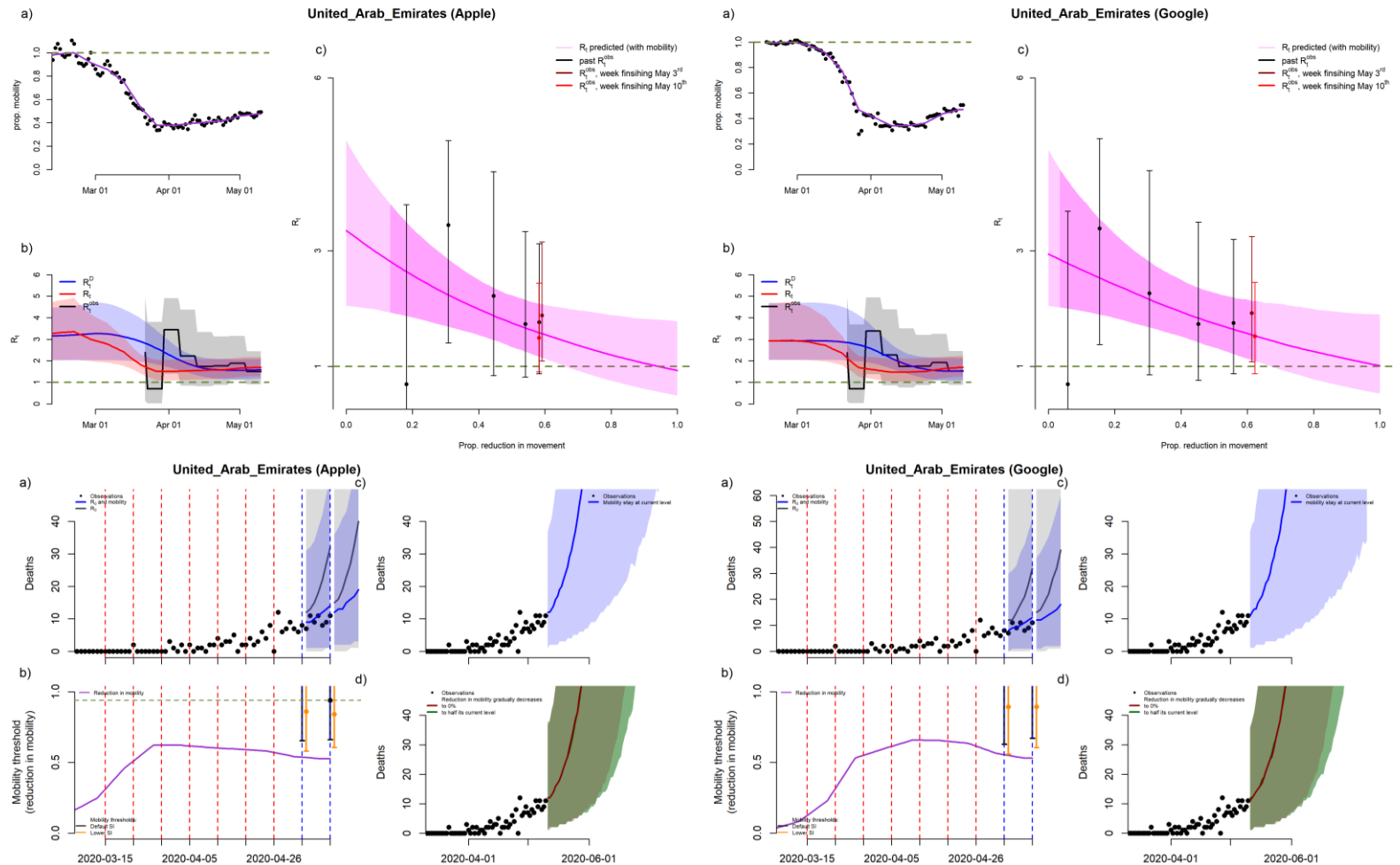


Figure SI.53: As in Figure 1-2 of main text.

United Kingdom

Current reduction in mobility observed are above the interquartile range of the current country-specific reductions in mobility. Both estimated median mobility thresholds are within the interquartile range of the median estimated country-specific mobility thresholds. Mobility reductions have been and remain above the 95% CrI mobility threshold, suggesting that enough reduction in mobility is in place to ensure control. We see some evidence for the dampening of the relationship between transmission and mobility based on Apple mobility only (in the last week considered), suggesting that alternative control strategies have been implemented and, based on death (and so with a delay) current transmission is under control. Forecasts presented, particularly long-term ones, should be viewed with caution.

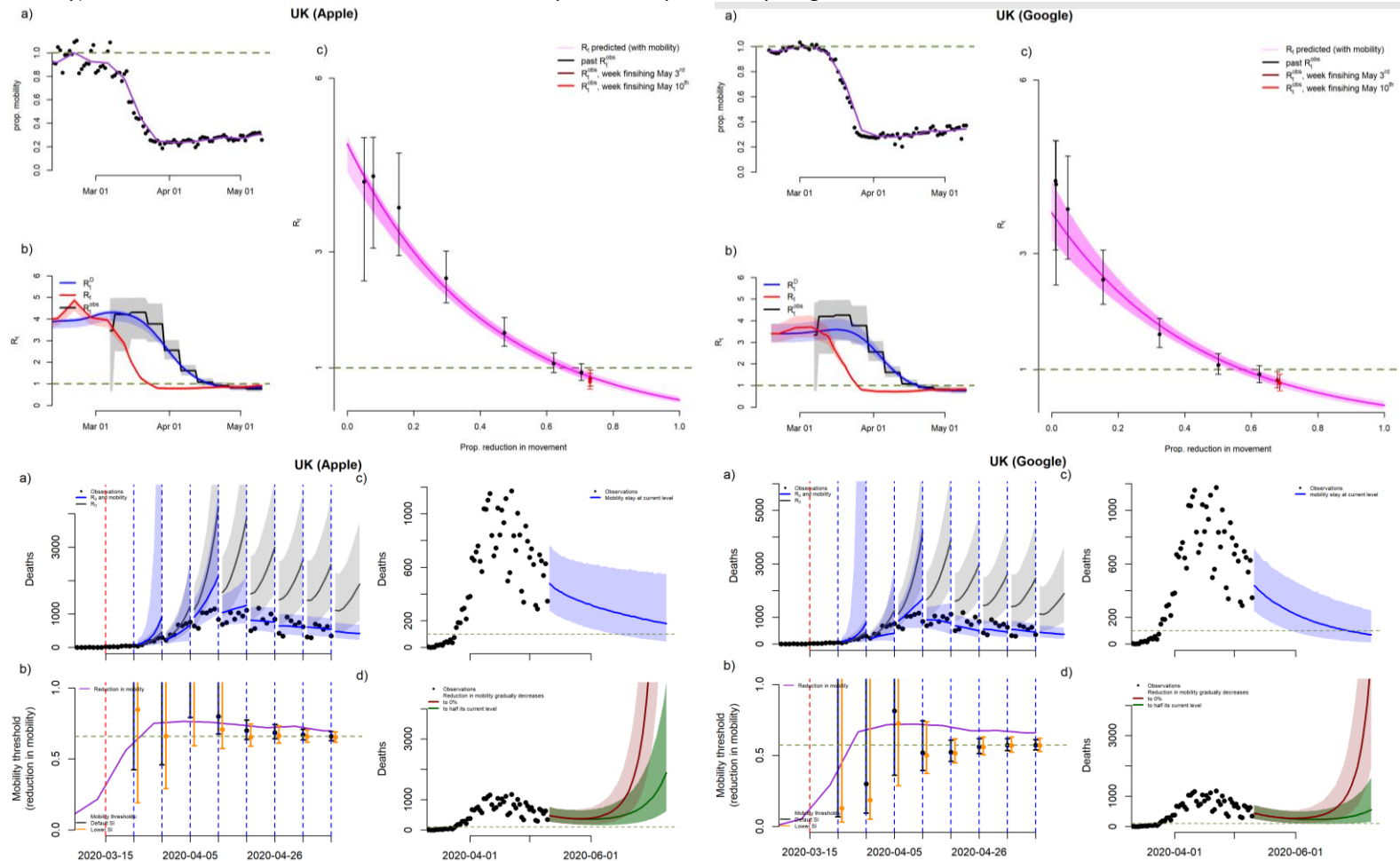


Figure SI.54: As in Figure 1-2 of main text.

United States of America

Current reductions in mobility observed are within the interquartile range of the current country-specific reductions in mobility. The estimated median mobility thresholds are below the interquartile range of the median estimated country-specific mobility thresholds, suggesting relatively low reduction in mobility are necessary to ensure control. Mobility reductions have been within the 95% CrI mobility threshold but no longer are, suggesting not enough reduction in mobility is in place to ensure control. We see no clear evidence for dampening of the relationship between transmission and mobility. Possibly few weeks prior to the last week considered evidence of dampening was emerging but seem to longer hold.

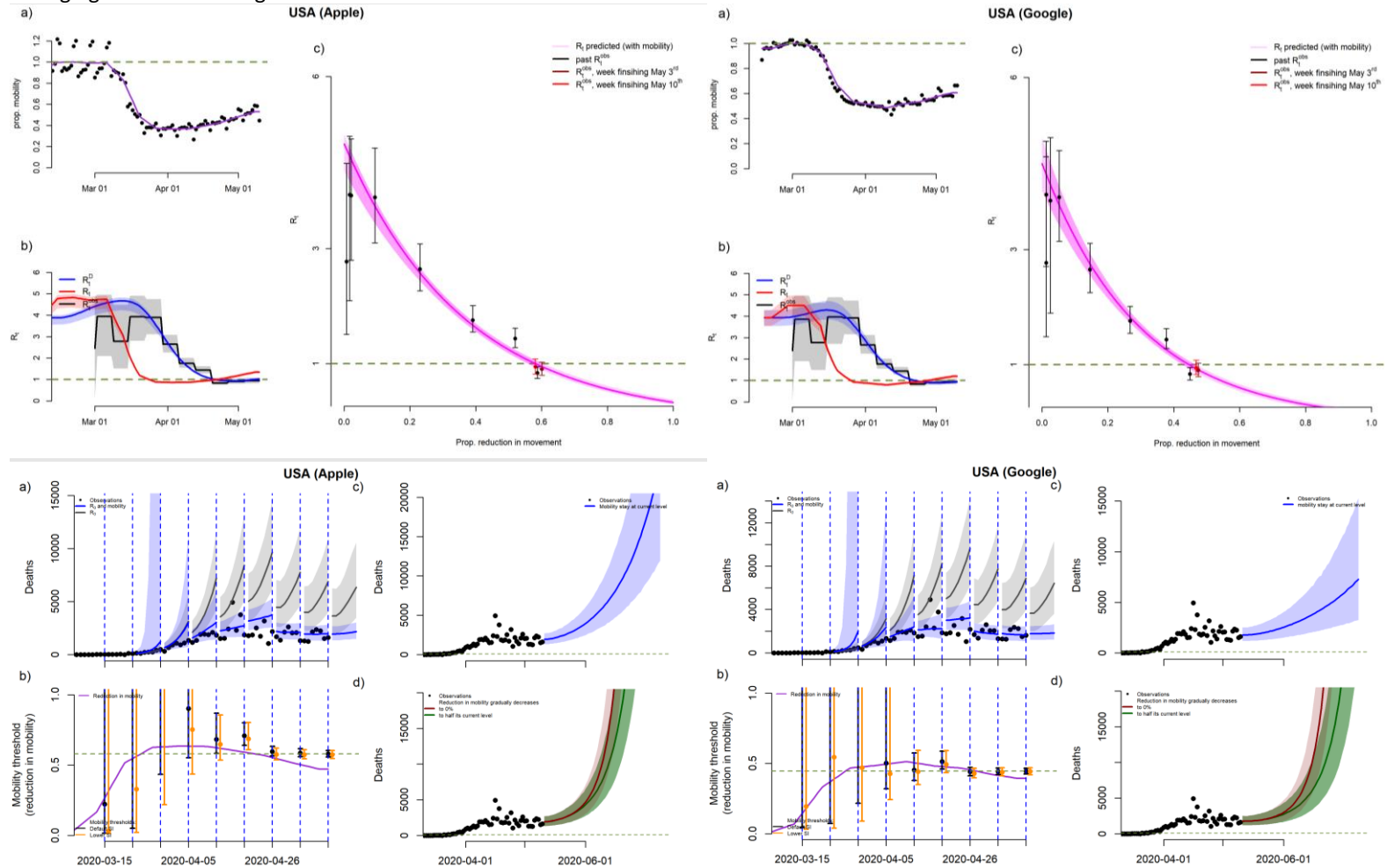


Figure SI.55: As in Figure 1-2 of main text.

DOI: <https://doi.org/10.25561/79643>

Sensitivity of mobility thresholds to serial interval and Likelihood formulation

We found that the estimated mobility thresholds and how those relates to observed mobility are consistent across assumptions of serial and likelihood formulation.

Table SI.3: sensitivity of estimated thresholds to serial interval distribution and likelihood

country	Apple mobility					Google mobility				
	Latest mobility	default	Lower SI	Poisson	Poisson and Lower SI	Latest mobility	default	Lower SI	Poisson	Poisson and Lower SI
Afghanistan	-	-	-	-	-	41.5	- ; 95%CrI [64 ; -]	- ; 95%CrI [59.2 ; -]	56.2 ; 95%CrI [42.8 ; 88]	50.3 ; 95%CrI [39.4 ; 71.8]
Argentina	74.6	- ; 95%CrI [- ; -]	- ; 95%CrI [99.4 ; -]	88.2 ; 95%CrI [78.6 ; -]	86 ; 95%CrI [75.3 ; -]	59.1	- ; 95%CrI [81.8 ; -]	- ; 95%CrI [80.7 ; -]	74.3 ; 95%CrI [65.2 ; 89.7]	71.9 ; 95%CrI [62 ; 86.1]
Austria	49.1	71 ; 95%CrI [58.7 ; 85.9]	73 ; 95%CrI [59.6 ; 93.9]	57.8 ; 95%CrI [54.7 ; 61]	57.5 ; 95%CrI [54.3 ; 61.2]	38.8	60.5 ; 95%CrI [50.9 ; 74.7]	63.3 ; 95%CrI [51.4 ; 83.3]	49.7 ; 95%CrI [46.7 ; 53.2]	49.9 ; 95%CrI [46.1 ; 54.2]
Bangladesh	-	-	-	-	-	58.7	- ; 95%CrI [72.3 ; -]	- ; 95%CrI [73.2 ; -]	62.7 ; 95%CrI [55.2 ; 73.3]	62.4 ; 95%CrI [54.1 ; 76.1]
Belarus	-	-	-	-	-	26.9	81 ; 95%CrI [41.7 ; -]	91 ; 95%CrI [41.1 ; -]	27.9 ; 95%CrI [22.8 ; 38.5]	26.7 ; 95%CrI [21.5 ; 36.8]
Belgium	58.2	61.3 ; 95%CrI [57.9 ; 64.8]	61 ; 95%CrI [57.7 ; 64.5]	63.1 ; 95%CrI [62.1 ; 64.1]	62.1 ; 95%CrI [61.2 ; 63]	53.5	56.7 ; 95%CrI [53.6 ; 59.8]	56.1 ; 95%CrI [52.8 ; 59.7]	57.8 ; 95%CrI [56.8 ; 58.7]	57.3 ; 95%CrI [56.4 ; 58.3]
Bolivia	-	-	-	-	-	78.3	- ; 95%CrI [- ; -]	- ; 95%CrI [- ; -]	- ; 95%CrI [88.7 ; -]	- ; 95%CrI [81.7 ; -]
Brazil	62.9	89.7 ; 95%CrI [83.7 ; 99.9]	83.6 ; 95%CrI [77.7 ; 97.1]	91 ; 95%CrI [89 ; 93.6]	90.7 ; 95%CrI [87.5 ; 96.1]	44.1	69.3 ; 95%CrI [63.4 ; 79.3]	66.6 ; 95%CrI [60.5 ; 79.2]	76.3 ; 95%CrI [73.1 ; 80.4]	76.9 ; 95%CrI [73 ; 81.9]
Cameroon	-	-	-	-	-	18.4	26.9 ; 95%CrI [17.7 ; 51.2]	24.7 ; 95%CrI [17.1 ; 42.1]	34.8 ; 95%CrI [26.5 ; 66]	31.1 ; 95%CrI [24 ; 48.6]
Canada	50	72 ; 95%CrI [66.2 ; 79.7]	68.4 ; 95%CrI [63.1 ; 75.4]	70.2 ; 95%CrI [68.6 ; 71.9]	67.6 ; 95%CrI [66 ; 69.7]	51	64.6 ; 95%CrI [59.9 ; 70.5]	62.1 ; 95%CrI [57 ; 69.4]	63.4 ; 95%CrI [62 ; 65.3]	62.2 ; 95%CrI [60.4 ; 64.6]

Chile	61.8	- ; 95%CrI [94.3 ; -]	- ; 95%CrI [90.7 ; -]	76.3 ; 95%CrI [70.2 ; 84.3]	74.2 ; 95%CrI [67.3 ; 84.8]	52.6	90.2 ; 95%CrI [67.2 ; -]	89.2 ; 95%CrI [66.4 ; -]	58.5 ; 95%CrI [53.3 ; 65.8]	57.5 ; 95%CrI [51.4 ; 67.1]
Colombia	57.4	- ; 95%CrI [85.5 ; -]	- ; 95%CrI [80.4 ; -]	76.6 ; 95%CrI [71 ; 83.9]	73.6 ; 95%CrI [68 ; 82.1]	64.5	- ; 95%CrI [85.3 ; -]	- ; 95%CrI [81.7 ; -]	82.6 ; 95%CrI [75.4 ; 94.4]	81.8 ; 95%CrI [73.2 ; 96]
Czechia	52.7	- ; 95%CrI [79.2 ; -]	- ; 95%CrI [81.2 ; -]	63.8 ; 95%CrI [58.6 ; 69.6]	62.9 ; 95%CrI [57.5 ; 69.2]	36.6	71.9 ; 95%CrI [54.9 ; -]	75.5 ; 95%CrI [56.5 ; -]	44.3 ; 95%CrI [40.6 ; 48.5]	44 ; 95%CrI [39.9 ; 48.6]
Denmark	28.1	60.4 ; 95%CrI [49 ; 81.7]	60.8 ; 95%CrI [48 ; 83.4]	43 ; 95%CrI [40.4 ; 45.8]	42.9 ; 95%CrI [39.9 ; 46.7]	33.2	52.6 ; 95%CrI [42.9 ; 70.7]	54 ; 95%CrI [43 ; 78]	38.4 ; 95%CrI [35.8 ; 41.6]	38.4 ; 95%CrI [35.2 ; 42]
Dominican Rep.	-	-	-	-	-	66.4	86.2 ; 95%CrI [65.3 ; -]	89.3 ; 95%CrI [65.4 ; -]	64.6 ; 95%CrI [58.1 ; 72.4]	63.8 ; 95%CrI [56.1 ; 74.2]
Ecuador	-	-	-	-	-	68.3	54.8 ; 95%CrI [47.7 ; 62.5]	51.2 ; 95%CrI [44.4 ; 58.6]	95.5 ; 95%CrI [88.4 ; -]	87.1 ; 95%CrI [81 ; 94.9]
Egypt	55.5	84 ; 95%CrI [65.8 ; -]	80.7 ; 95%CrI [64.4 ; -]	67.9 ; 95%CrI [62.8 ; 75.5]	67 ; 95%CrI [61.2 ; 76.5]	43.7	62.5 ; 95%CrI [50 ; 83.3]	61.4 ; 95%CrI [47.4 ; 84.5]	54 ; 95%CrI [49.2 ; 61.4]	53.4 ; 95%CrI [47.4 ; 62.2]
Finland	24.5	69.8 ; 95%CrI [51.7 ; -]	69.4 ; 95%CrI [51.4 ; -]	46.6 ; 95%CrI [42.3 ; 53]	45.6 ; 95%CrI [40.8 ; 53.4]	36.3	66.3 ; 95%CrI [49.4 ; -]	65.8 ; 95%CrI [49.9 ; -]	46.7 ; 95%CrI [42.4 ; 52.7]	46 ; 95%CrI [40.8 ; 54.1]
France	72.6	64.3 ; 95%CrI [62.3 ; 66.6]	63.5 ; 95%CrI [61 ; 66.3]	66.6 ; 95%CrI [66 ; 67.1]	66.5 ; 95%CrI [65.9 ; 67.2]	66.2	54.3 ; 95%CrI [52.1 ; 56.5]	53.4 ; 95%CrI [50.8 ; 56.2]	56.2 ; 95%CrI [55.7 ; 56.8]	56.5 ; 95%CrI [55.8 ; 57.2]
Germany	43.1	52.7 ; 95%CrI [49.5 ; 56]	51.8 ; 95%CrI [48.7 ; 55.2]	54 ; 95%CrI [53.2 ; 54.9]	53.2 ; 95%CrI [52.3 ; 54.1]	31	41 ; 95%CrI [38.3 ; 43.8]	40.6 ; 95%CrI [37.5 ; 44.1]	42.1 ; 95%CrI [41.3 ; 42.9]	42 ; 95%CrI [41.1 ; 43]
Greece	54.9	- ; 95%CrI [85.3 ; -]	- ; 95%CrI [91.3 ; -]	60 ; 95%CrI [51.7 ; 70.2]	59.5 ; 95%CrI [49.8 ; 72.7]	42.9	98.6 ; 95%CrI [69 ; -]	- ; 95%CrI [72.8 ; -]	49.3 ; 95%CrI [41.2 ; 59.2]	48.9 ; 95%CrI [40.3 ; 61.6]
Honduras	-	-	-	-	-	68.6	- ; 95%CrI [75.2 ; -]	- ; 95%CrI [75.7 ; -]	80.5 ; 95%CrI [66 ; -]	76.1 ; 95%CrI [61.2 ; -]
Hungary	60.1	- ; 95%CrI [81.1 ; -]	- ; 95%CrI [79.7 ; -]	73.4 ; 95%CrI [68 ; 79.8]	71.6 ; 95%CrI [66 ; 79.7]	37.1	67.8 ; 95%CrI [53.3 ; 93.2]	67.5 ; 95%CrI [52.4 ; -]	50.4 ; 95%CrI [46.6 ; 54.9]	49.9 ; 95%CrI [45.4 ; 56.5]
India	74.5	- ; 95%CrI [93.4 ; -]	97.7 ; 95%CrI [85.2 ; -]	- ; 95%CrI [- ; -]	- ; 95%CrI [96.6 ; -]	64.4	90.5 ; 95%CrI [77.8 ; -]	83.9 ; 95%CrI [72.3 ; -]	96 ; 95%CrI [88.9 ; -]	93.8 ; 95%CrI [85.6 ; -]
Indonesia	66	66.5 ; 95%CrI [55.9 ; 84.7]	68.8 ; 95%CrI [55.1 ; 93.9]	61.8 ; 95%CrI [57.7 ; 66.6]	61.4 ; 95%CrI [56.2 ; 67.8]	47.6	41.2 ; 95%CrI [33 ; 56.2]	43.1 ; 95%CrI [32.8 ; 61.5]	37.9 ; 95%CrI [34.7 ; 41.6]	37.3 ; 95%CrI [33.9 ; 41.3]
Ireland	77.9	80.2 ; 95%CrI [70.5 ; 91.4]	78.4 ; 95%CrI [68.6 ; 89.9]	80.1 ; 95%CrI [77.4 ; 83.2]	78.2 ; 95%CrI [75.4 ; 81.3]	63.7	65.1 ; 95%CrI [57 ; 74.3]	63.9 ; 95%CrI [55.8 ; 73.5]	65.7 ; 95%CrI [63.4 ; 68.4]	64.8 ; 95%CrI [62 ; 68.2]

Israel	43	- ; 95%CrI [75 ; -]	- ; 95%CrI [76.9 ; -]	60.9 ; 95%CrI [55.5 ; 67.1]	60.2 ; 95%CrI [54.8 ; 67.2]	39.2	88.4 ; 95%CrI [67.1 ; -]	91.9 ; 95%CrI [67.5 ; -]	54.7 ; 95%CrI [49.7 ; 60]	53.9 ; 95%CrI [48.8 ; 60.5]
Italy	73.6	74 ; 95%CrI [71.7 ; 76.5]	73.7 ; 95%CrI [70.5 ; 76.9]	74.2 ; 95%CrI [73.5 ; 74.9]	73.8 ; 95%CrI [72.9 ; 74.6]	54.3	59.9 ; 95%CrI [57.3 ; 62.4]	59.5 ; 95%CrI [56.2 ; 63]	60.1 ; 95%CrI [59.4 ; 60.8]	59.6 ; 95%CrI [58.7 ; 60.5]
Japan	50.3	43.7 ; 95%CrI [33.9 ; 59.2]	41.2 ; 95%CrI [32.3 ; 58.4]	45.3 ; 95%CrI [39.7 ; 52.8]	42.6 ; 95%CrI [37.4 ; 49.7]	43.9	28.4 ; 95%CrI [22.6 ; 37.9]	27 ; 95%CrI [21.5 ; 35.9]	30.1 ; 95%CrI [26.5 ; 35.1]	28.4 ; 95%CrI [25.1 ; 32.7]
Mexico	64.8	91.6 ; 95%CrI [81.4 ; -]	83.3 ; 95%CrI [75.1 ; 97.9]	90.3 ; 95%CrI [87.3 ; 94.8]	89.4 ; 95%CrI [84.4 ; 96.4]	54.5	67.4 ; 95%CrI [59.9 ; 78.9]	62.7 ; 95%CrI [55.2 ; 74.2]	73.4 ; 95%CrI [69 ; 81.2]	74.7 ; 95%CrI [68.5 ; 85.3]
Moldova	-	-	-	-	-	44.2	- ; 95%CrI [90.4 ; -]	- ; 95%CrI [89.4 ; -]	64.6 ; 95%CrI [56.6 ; 78.6]	63 ; 95%CrI [54.6 ; 79]
Morocco	85.9	- ; 95%CrI [93.7 ; -]	- ; 95%CrI [96.1 ; -]	65.4 ; 95%CrI [58.5 ; 73.5]	65.2 ; 95%CrI [56.9 ; 75.2]	-	-	-	-	-
Netherlands	51.7	54.7 ; 95%CrI [50.9 ; 59]	54.3 ; 95%CrI [50 ; 59.3]	54.6 ; 95%CrI [53.5 ; 55.7]	54.6 ; 95%CrI [53.3 ; 56.1]	39.1	39.7 ; 95%CrI [36.5 ; 43.2]	39.6 ; 95%CrI [35.6 ; 44.1]	40 ; 95%CrI [39 ; 41.1]	39.9 ; 95%CrI [38.6 ; 41.2]
Nigeria	-	-	-	-	-	38.2	- ; 95%CrI [80.8 ; -]	- ; 95%CrI [71.4 ; -]	77.4 ; 95%CrI [58.1 ; -]	69.2 ; 95%CrI [52.4 ; -]
Pakistan	-	-	-	-	-	46.6	75.6 ; 95%CrI [59 ; -]	69.9 ; 95%CrI [54.9 ; -]	74.3 ; 95%CrI [64.8 ; 95.6]	69.7 ; 95%CrI [60.8 ; 83.1]
Panama	-	-	-	-	-	75.5	- ; 95%CrI [93.6 ; -]	- ; 95%CrI [92.4 ; -]	74.7 ; 95%CrI [64.3 ; 90.2]	73.8 ; 95%CrI [62.3 ; 91.4]
Peru	-	-	-	-	-	74.1	- ; 95%CrI [92.2 ; -]	98.3 ; 95%CrI [85.3 ; -]	- ; 95%CrI [98.2 ; -]	- ; 95%CrI [94.4 ; -]
Philippines	81	94.1 ; 95%CrI [77.3 ; -]	93 ; 95%CrI [74.4 ; -]	80.3 ; 95%CrI [75.6 ; 86.6]	79.5 ; 95%CrI [73.9 ; 87.4]	73.1	83.6 ; 95%CrI [65.9 ; -]	84.2 ; 95%CrI [65.5 ; -]	72.9 ; 95%CrI [66.6 ; 80.9]	71.4 ; 95%CrI [64.4 ; 80.1]
Poland	44.6	85.3 ; 95%CrI [70.8 ; -]	83.8 ; 95%CrI [69 ; -]	71.7 ; 95%CrI [68.3 ; 75.7]	70.3 ; 95%CrI [66.5 ; 75.6]	38.5	65.6 ; 95%CrI [55.2 ; 80.3]	64.3 ; 95%CrI [53.8 ; 80.1]	56 ; 95%CrI [53.2 ; 59.3]	55.1 ; 95%CrI [51.8 ; 59.2]
Portugal	76.6	82.3 ; 95%CrI [71.8 ; 96.6]	82.8 ; 95%CrI [70.7 ; 97]	75.6 ; 95%CrI [72.4 ; 78.9]	75.2 ; 95%CrI [71.3 ; 79.4]	57.7	64.5 ; 95%CrI [55.9 ; 75.5]	64.8 ; 95%CrI [55 ; 77.2]	59.8 ; 95%CrI [57.1 ; 62.8]	59.4 ; 95%CrI [56.3 ; 63.1]
Romania	67.8	90.2 ; 95%CrI [76.1 ; -]	88.8 ; 95%CrI [73.2 ; -]	76.5 ; 95%CrI [72.9 ; 80.6]	74.5 ; 95%CrI [70.6 ; 79.2]	51.7	69.3 ; 95%CrI [57.7 ; 87.5]	68.3 ; 95%CrI [56.8 ; 90.4]	60.1 ; 95%CrI [56.8 ; 63.8]	59.5 ; 95%CrI [55.3 ; 64.2]
Russia	45.6	68.7 ; 95%CrI [58.7 ; 83.3]	64.1 ; 95%CrI [55.1 ; 76.6]	64.1 ; 95%CrI [61.1 ; 68.6]	62.8 ; 95%CrI [59.2 ; 68.6]	-	-	-	-	-

Saudi Arabia	43.6	- ; 95%CrI [71.9 ; -]	- ; 95%CrI [68.5 ; -]	55.9 ; 95%CrI [49.5 ; 67.6]	56.1 ; 95%CrI [47.7 ; 70.4]	58.8	- ; 95%CrI [87.8 ; -]	- ; 95%CrI [85.1 ; -]	72.2 ; 95%CrI [62.7 ; 91.4]	71 ; 95%CrI [60.1 ; 92.1]
Serbia	48.1	- ; 95%CrI [89.9 ; -]	- ; 95%CrI [92.3 ; -]	67.4 ; 95%CrI [61.2 ; 75.7]	66.4 ; 95%CrI [59.6 ; 75.2]	42.2	- ; 95%CrI [77.7 ; -]	- ; 95%CrI [78.2 ; -]	59.2 ; 95%CrI [52.5 ; 66.7]	58.8 ; 95%CrI [50.3 ; 69.3]
South_Africa	61.4	- ; 95%CrI [- ; -]	- ; 95%CrI [- ; -]	- ; 95%CrI [86.5 ; -]	98.1 ; 95%CrI [80.9 ; -]	54.7	- ; 95%CrI [89.8 ; -]	- ; 95%CrI [84.1 ; -]	97.5 ; 95%CrI [77.6 ; -]	90.1 ; 95%CrI [71.7 ; -]
Spain	80.5	68.3 ; 95%CrI [65.6 ; 71]	68.1 ; 95%CrI [64.7 ; 71.6]	68.5 ; 95%CrI [67.8 ; 69.3]	68.3 ; 95%CrI [67.4 ; 69.3]	66.4	57.8 ; 95%CrI [55.2 ; 60.4]	57.5 ; 95%CrI [54.3 ; 61]	58.1 ; 95%CrI [57.4 ; 58.8]	57.8 ; 95%CrI [56.9 ; 58.7]
Sweden	24.2	32.1 ; 95%CrI [29.3 ; 35.2]	31 ; 95%CrI [28.2 ; 34.1]	36.6 ; 95%CrI [35.7 ; 37.6]	35.7 ; 95%CrI [34.8 ; 36.6]	20.3	25.1 ; 95%CrI [22.6 ; 27.5]	23.9 ; 95%CrI [21.6 ; 26.4]	28.6 ; 95%CrI [27.8 ; 29.4]	28.5 ; 95%CrI [27.5 ; 29.5]
Switzerland	39.4	47.2 ; 95%CrI [41.6 ; 54]	46.9 ; 95%CrI [41.1 ; 54.5]	46.7 ; 95%CrI [45 ; 48.4]	46.7 ; 95%CrI [44.6 ; 49]	42.3	44.5 ; 95%CrI [38.3 ; 51.7]	44.3 ; 95%CrI [37.4 ; 53.1]	44 ; 95%CrI [42 ; 46.1]	43.7 ; 95%CrI [41.2 ; 46.5]
Turkey	64.7	69.2 ; 95%CrI [63.4 ; 75.5]	68.6 ; 95%CrI [62.4 ; 75.9]	66.1 ; 95%CrI [64.6 ; 67.7]	65.4 ; 95%CrI [63.6 ; 67.3]	59.3	58.2 ; 95%CrI [53.3 ; 63.8]	57.9 ; 95%CrI [51.9 ; 64.9]	56 ; 95%CrI [54.5 ; 57.6]	55.4 ; 95%CrI [53.7 ; 57.5]
UK	69.8	64.6 ; 95%CrI [62.7 ; 66.5]	63.6 ; 95%CrI [61.2 ; 65.8]	66 ; 95%CrI [65.5 ; 66.5]	65.6 ; 95%CrI [65 ; 66.2]	65.9	55.7 ; 95%CrI [53.5 ; 58]	54.8 ; 95%CrI [52 ; 57.5]	57.6 ; 95%CrI [57 ; 58.2]	57.2 ; 95%CrI [56.5 ; 58]
Ukraine	33.6	71 ; 95%CrI [53.5 ; -]	68.1 ; 95%CrI [51.3 ; -]	55 ; 95%CrI [50 ; 64.3]	54.8 ; 95%CrI [48.3 ; 65.7]	-	-	-	-	-
United_Arab_Emirates	52.6	- ; 95%CrI [- ; -]	- ; 95%CrI [- ; -]	87.7 ; 95%CrI [69.7 ; -]	76.6 ; 95%CrI [63.5 ; -]	53	- ; 95%CrI [97.9 ; -]	- ; 95%CrI [90.4 ; -]	93 ; 95%CrI [71.5 ; -]	81.9 ; 95%CrI [66.2 ; -]
USA	47.1	56.5 ; 95%CrI [55.5 ; 57.6]	55.4 ; 95%CrI [54.2 ; 56.8]	58.4 ; 95%CrI [58.1 ; 58.7]	57.7 ; 95%CrI [57.4 ; 58.1]	39.3	43.5 ; 95%CrI [42.6 ; 44.4]	42.7 ; 95%CrI [41.7 ; 43.9]	44.9 ; 95%CrI [44.6 ; 45.2]	44.7 ; 95%CrI [44.4 ; 45]

Modelling over-dispersion

Over-dispersion using a negative binomial likelihood is typically model in two ways³⁴, which differ in how the variance is linked to the mean:

$$NB1: var(X) = \mu_x + \frac{\mu_x}{\delta_1} = \omega_1 \mu_x \quad \text{where } \omega_1 = 1 + \frac{1}{\delta_1}$$

$$NB2: var(X) = \mu_x + \frac{\mu_x^2}{\delta_2} = \omega_2 \mu_x \quad \text{where } \omega_2 = 1 + \frac{\mu_x}{\delta_2}$$

While, arguably, NB2 has somehow more solid statistical foundation with this formulation being formally derived from X following a binomial distribution with heterogeneous μ_x following a gamma distribution, the NB1 is also very popular (generalized linear models) due to its simple interpretation (scaling the Poisson variance).

There are no clear rule on using one formulation or another, and if the range of observed X is not too wide, both formulations will give similar results.

However, when the range of X spans multiple order of magnitude, the formulation will affect the regression parameter estimates (see Figure SI.56 below).

NB1; $\omega_1 \sim 13$

NB2; $\delta_2 \sim 5$

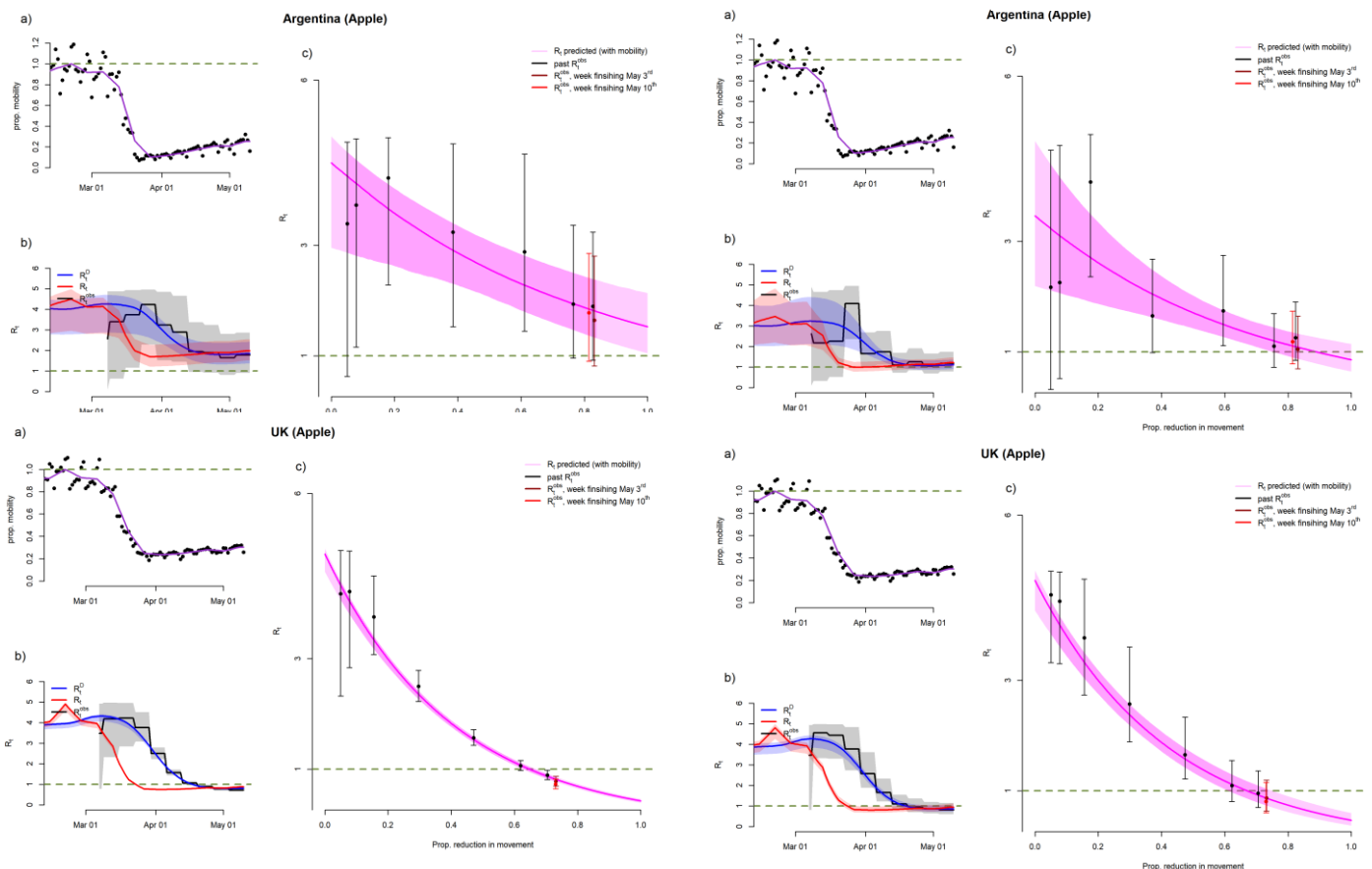


Figure SI.56: Estimated R_t 's using NB1 or NB2 for Argentina (low-incidence setting) and the UK (high-incidence setting). Results based on Apple mobility.

Which in turns has implications on forecasts (figure (SI.XX below)

NB1; $\omega_1 \sim 13$

NB2; $\delta_2 \sim 5$

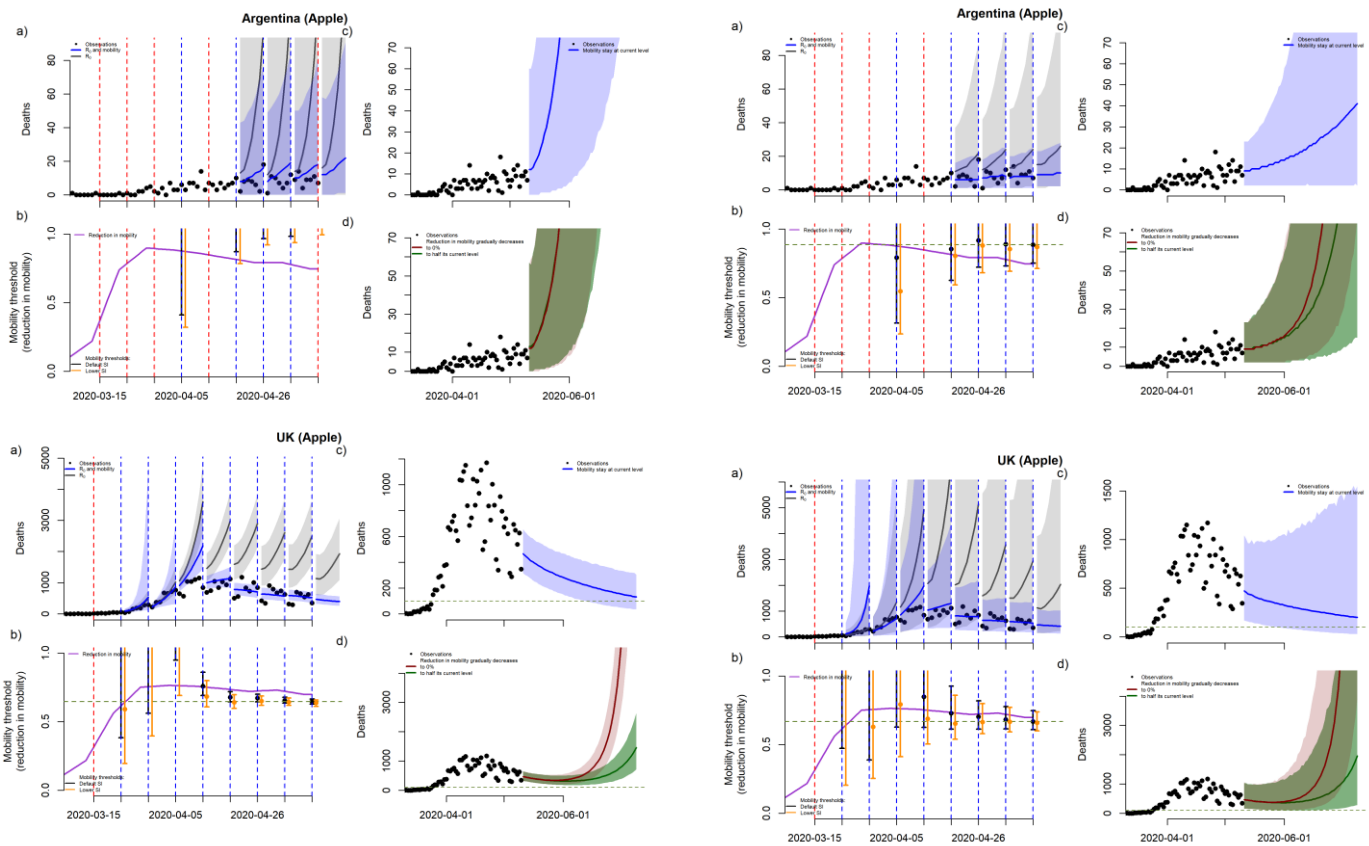


Figure SI.57: forecasted incidence of deaths using NB1 or NB2 for Argentina (low-incidence setting) and the UK (high-incidence setting). Results based on Apple mobility.

From the estimated R_t 's and forecasts, the NB1 tend to over-estimate R_t and the variance in forecasts when the incidence is low (i.e. Argentina). The NB2 tends to over-estimate the uncertainty in R_t and the variance in forecasts when the incidence is high (i.e. UK).

This suggests that:

- When incidence is low, $var(X)$ is over-estimated with NB1, but reasonable for NB2,
- When incidence is high, $var(X)$ is over-estimated with NB2, but reasonable for NB1.

We therefore propose that instead of 'scaling' the variance by μ_x^2 (NB2) or μ_x (NB1), we use an alternative formation where the increase variance slows down as μ_x increases (Table SI.4):

$$NBsqr: var(X) = \mu_x + \frac{\mu_x^2}{\delta_{sqr} \sqrt{\mu_x}} = \omega_{sqr} \mu_x \quad \text{where} \quad \omega_{sqr} = 1 + \frac{\sqrt{\mu_x}}{\delta_{sqr}}$$

Table SI.4: factor to multiply the mean to obtain the variance given estimated over-dispersion under different NB model.

	NB1	NBsqr	NB2
X (incidence)	$\omega_1 = 1 + \frac{1}{\delta_1} \sim 13$ With estimated $\delta_1 \sim 0.08$	$\omega_{sqr} = 1 + \frac{\sqrt{\mu_x}}{\delta_{sqr}}$ With estimated $\delta_{sqr} \sim 0.8$	$\omega_2 = 1 + \frac{\mu_x}{\delta_2}$ With estimated $\delta_2 \sim 5$
1	13	2.3	1.2
10	13	5.0	3
20	13	6.6	5
50	13	9.8	11
100	13	13.5	21
500	13	29.0	101
1000	13	40.5	201

The NBsqr model outlined seems to better capture the link between variance and mean (Figure SI.58 below). This could reflect the fact that the variance is reflecting 2 processes of heterogeneity:

- Heterogeneity in transmissibility (i.e. super spreading), which would be linked to NB2, see³⁵, and would impact more incidence when incidence is small.
- Heterogeneity in reporting, which would be link to NB1 as the variance would not necessarily dramatically increase as incidence increase.

Based on DIC, we confirmed the improved fit (NB1 DIC = 39,115. NB2 DIC = 36,060, NBsqr DIC = 35,916).

NBsqrt; $\delta_{sqrt} \sim 0.8$

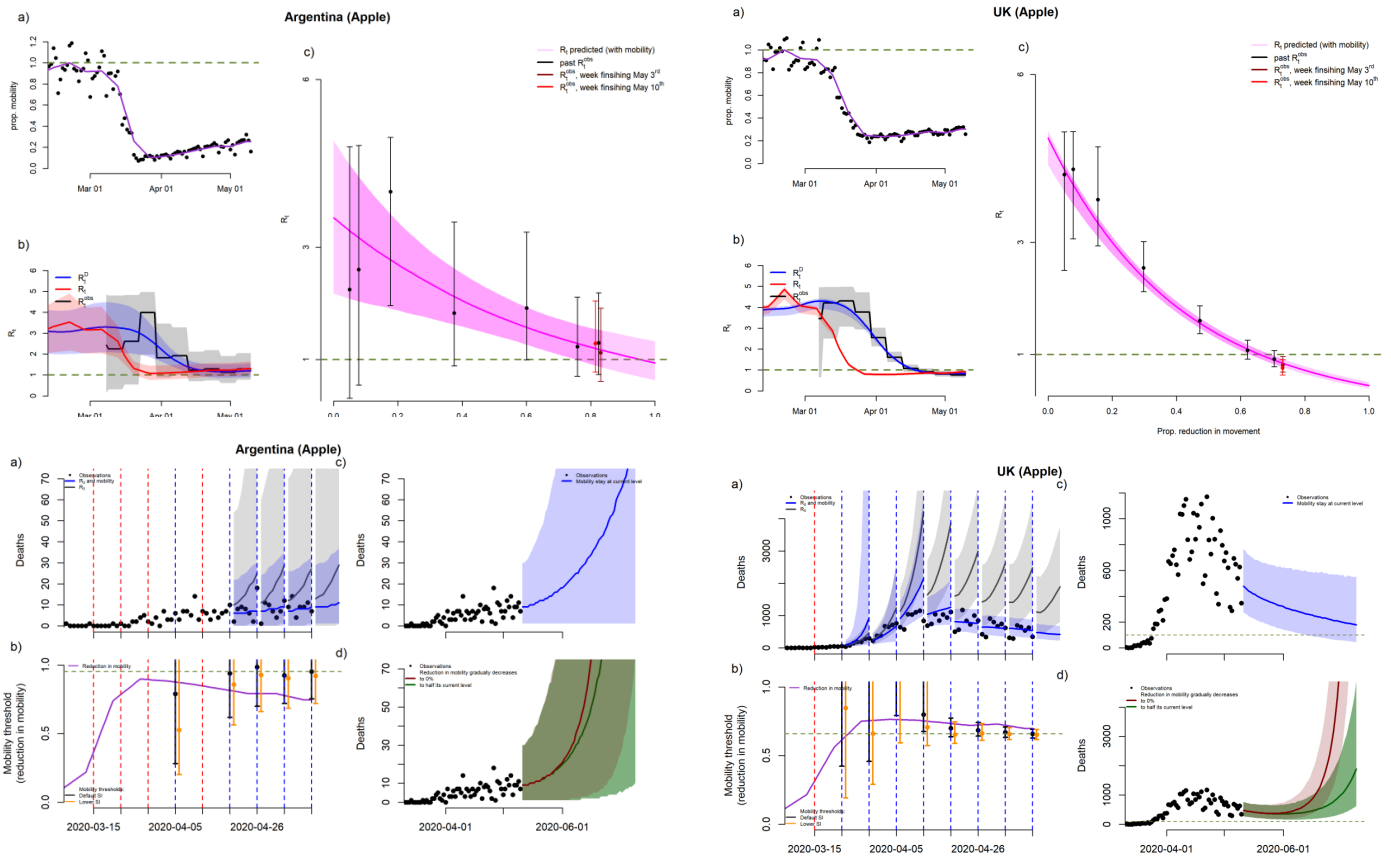


Figure SI.58: Estimated Rt's and forecasted incidences of deaths using NBsqrt for Argentina (low-incidence setting) and the UK (high-incidence setting). Results based on Apple mobility.

Modelling over-dispersion

We first characterise incidence of reported deaths:

$$D_{t,i} \sim P \left(R_{t,i}^D \sum_{s=0}^t [D_{s,i} w_{t-s}] \right)$$

If we do the same for incidence of infections:

$$I_{t,i} \sim P \left(R_{t,i}^I \sum_{s=0}^t [I_{s,i} w_{t-s}] \right)$$

Relating deaths to infections, we have:

$$\begin{aligned} R_{t,i}^D &\sim \frac{D_{t,i}}{\sum_{s=0}^t [D_{s,i} w_{t-s}]} = \frac{IFR \sum_{s=0}^t [I_{s,i} h(t-s)]}{\sum_{s=0}^t [D_{s,i} w_{t-s}]} \\ &= \frac{\sum_{s=0}^t [R_{s,i}^I h(t-s) (\sum_{x=0}^s [I_{x,i} w_{s-x}])] }{\sum_{s=0}^t [w_{t-s} (\sum_{x=0}^s [I_{x,i} h(s-x)])]} \end{aligned}$$

Re-arranging the sum at the bottom, we have:

$$= \frac{\sum_{s=0}^t [R_{s,i}^I h(t-s) (\sum_{x=0}^s [I_{x,i} w_{s-x}])]}{\sum_{s=0}^t [h(t-s) (\sum_{x=0}^s [I_{x,i} w_{s-x}])]}$$

Where $O_s = \sum_{x=0}^s [I_{x,i} w_{s-x}]$ is the overall infectivity on day s, so:

$$= \frac{\sum_{s=0}^t [R_{s,i}^I h(t-s) O_s]}{\sum_{s=0}^t [h(t-s) O_s]}$$

$\sum_{s=0}^t [h(t-s) O_s]$ can be interpreted as an average overall infectivity (weighted by the infection-death delay) at time t: $E[O_t]$, so we have:

$$R_{t,i}^D \sim \sum_{s=0}^t \left[R_{s,i}^I h(t-s) \frac{O_s}{E[O_t]} \right]$$

Therefore, when O_s is constant then $R_{t,i}^D = \sum_{s=0}^t [R_{s,i}^I h(t-s)]$, as used in the analysis.

The simplified equation is therefore an approximation. When, epidemic is growing, more weight should be put on recent mobility, so our approximation under-estimate slightly recent change in mobility. When the epidemic is declining, more weight should be put on past mobility, so our approximation over-estimate slightly recent changes in mobility. Effectively when estimating $R_{t,i}^D$ at time t: when $R=1$, the largest weight is put on $R_{s,i}^I$ when $s=t-14$ days (i.e. 14 days being mode of the h distribution); when $R=1.5$, the largest weight is put on $R_{s,i}^I$ when $s=t-11$ days; when $R=0.8$, the largest weight is put on $R_{s,i}^I$ when $s=t-16$ days.

Given uncertainty surrounding transmission, the unknown O_s (we use an estimate of the overall infectivity linked to deaths but not infections), the delay between infection and deaths, and the serial interval, we believe we can confidently use the approximation. The only situation were the approximation would significantly fail, would be if we were observing rapid fluctuations (i.e. decrease followed by increase) in mobility with a 2-3 days period. What we observed are smooth change in mobility, and while the reduction in mobility may be sharp, we never observe a reversion of the mobility reductions on such timescale.

Additional information for the inference

For epidemiological data:

We define a matrix of deaths on day t, for location i:

$$D = \begin{bmatrix} D_{1,1} & \dots & D_{1,i} & \dots & D_{1,n_loc} \\ D_{2,1} & \dots & D_{2,i} & \dots & D_{2,n_loc} \\ D_{3,1} & & & & D_{3,n_loc} \\ \vdots & & & & \\ D_{n_days,1} & \dots & D_{n_days,i} & & D_{n_days,n_loc} \end{bmatrix}$$

Overall transmissibility matrix:

$$O_t = \begin{bmatrix} \sum_{s=0}^1 [D_{s,1} w_{t-s}] & \sum_{s=0}^1 [D_{s,2} w_{t-s}] & \dots \\ \sum_{s=0}^2 [D_{s,1} w_{t-s}] & \sum_{s=0}^1 [D_{s,2} w_{t-s}] & \dots \\ \sum_{s=0}^3 [D_{s,1} w_{t-s}] & \sum_{s=0}^1 [D_{s,2} w_{t-s}] & \dots \\ \vdots & \vdots & \vdots \\ \sum_{s=0}^t [D_{s,1} w_{t-s}] & \dots & \dots \end{bmatrix} = W \cdot D$$

with

$$W = \begin{bmatrix} w_1 & 0 & 0 & \dots & 0 \\ w_2 & w_1 & 0 & \dots & 0 \\ w_3 & w_2 & w_1 & & 0 \\ \vdots & & & & \\ w_{n_days} & w_{n_days-1} & w_{n_days-2} & & w_{n_days} \end{bmatrix}$$

For mobility data:

We define a matrix of deaths reported on day t, for location i:

$$M = \begin{bmatrix} m_{1,1} & \dots & m_{1,i} & \dots & m_{1,n_loc} \\ m_{2,1} & \dots & m_{2,i} & \dots & m_{2,n_loc} \\ m_{3,1} & & & & m_{3,n_loc} \\ \vdots & & & & \\ m_{n_days,1} & \dots & m_{n_days,i} & & m_{n_days,n_loc} \end{bmatrix}$$

The mobility at time of death relevant to the time of infection:

$$M^D = \begin{bmatrix} \sum_{s=0}^1 [m_{s,1} h_{t-s}] & \sum_{s=0}^1 [m_{s,2} h_{t-s}] & \dots \\ \sum_{s=0}^2 [m_{s,1} h_{t-s}] & \sum_{s=0}^1 [m_{s,2} h_{t-s}] & \dots \\ \sum_{s=0}^3 [m_{s,1} h_{t-s}] & \sum_{s=0}^1 [m_{s,2} h_{t-s}] & \dots \\ \vdots & \vdots & \vdots \\ \sum_{s=0}^{n_days} [m_{s,1} h_{t-s}] & \dots & \dots \end{bmatrix} = H \cdot M$$

with

$$H = \begin{bmatrix} h_1 & 0 & 0 & \dots & 0 \\ h_2 & h_1 & 0 & \dots & 0 \\ h_3 & h_2 & h_1 & & 0 \\ \vdots & & & & \\ h_{n_days} & h_{n_days-1} & h_{n_days-2} & & h_{n_days} \end{bmatrix}$$

For the full model:

Given a vector of basic reproduction number and the parameter linking mobility and transmissibility, R_0 , β , the matrix of daily effective reproduction number is:

$$R = \log(R_0) - B (1 - M)$$

where B is a matrix, of size n_days, n_loc , with each column equal to β .

The reproduction number relevant at the time of death becomes:

$$R^{D,2} = H.R$$

The likelihood is computed from D and $Ot * R^{D,2}$ (with * the element by element product)

For short-term forecasts and longer-term scenarios, we augment the mobility matrix above for future dates, get the effective reproduction matrices (using the joint posterior distribution of estimate R_0 and β), obtain the new augmented matrices of reproduction number at time of death $R^{D,2}$, and finally compute the expected numbers of daily deaths in the future.

Using a Poisson/negative binomial random number generator, we get short-term forecasts or longer-term scenarios.