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Coronavirus Pandemic

Transmission dynamics of Covid-19 in Italy, Germany and Turkey considering social distancing, testing and quarantine

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Abstract

Introduction: There are significant differences in the active cases and fatality rates of Covid-19 for different European countries.
Methodology: The present study employs Monte Carlo based transmission growth simulations for Italy, Germany and Turkey. The probabilities of transmission at home, work and social networks and the number of initial cases have been calibrated to match the basic reproduction number and the reported fatality curves. Parametric studies were conducted to observe the effect of social distancing, work closure, testing and quarantine of the family and colleagues of positively tested individuals.
Results: It is observed that estimates of the number of initial cases in Italy compared to Turkey and Germany are higher. Turkey will probably experience about 30% less number of fatalities than Germany due its smaller elderly population. If social distancing and work contacts are limited to 25% of daily routines, Germany and Turkey may limit the number of fatalities to a few thousands as the reproduction number decreases to about 1.3 from 2.8. Random testing may reduce the number of fatalities by 10% upon testing least 5/1000 of the population. Quarantining of family and workmates of positively tested individuals may reduce the total number of fatalities by about 50%.
Conclusions: The fatality rate of Covid-19 is estimated to be about 1.5% based on the simulation results. This may further be reduced by limiting the number of non-family contacts to two, conducting tests more than 0.5% of the population and immediate quarantine of the contacts for positively tested individuals.

Key words: COVID-19; transmission; social distancing.

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Introduction

As of 16 April 2020 Covid-19 had spread to more than 200 countries with a total case number of about 2.1 million and a fatality rate of 6.5% [1]. All governments continue to take precautions to reduce the pandemic risk to human life by reducing the demand on their health care systems [2]. The key approach in developing such measures is conducting disease transmission simulations. A number of transmission models were developed to estimate the spread and to study the necessary non-medical interventions to mitigate the pandemics in the past [3-27]. In those simulation studies, two different approaches, namely, micro models and macro models were used. In the macro models, SEIR (Susceptible, Exposed, Infectious and Recovered) states are expressed as a set of differential equations and solved with respect to time in order to estimate pandemic dynamics [8,11,13-19]. The micro models employ Monte Carlo simulations for a random population with certain demographic characteristics, and consider possible house, work, school and social contacts [4,5,9,20-24]. Both approaches are extremely important to investigate the transmission dynamics of an infectious disease, estimate the demand on the health care system and identify the necessary precautions for risk mitigation. Based on such models, recent work [4,5] showed that social distancing and school/university closures are needed in order to limit the demand on the health care system and they may need to be enforced on and off for several months.

The numbers of Covid-19 cases and fatalities are continuously growing in many countries. The data show interesting peculiarities. European countries have significant increases in active cases but with different fatality rates. China and South Korea appear to have contained the spread. On the other hand, countries with relatively smaller ratios of elderly population such as Turkey are experiencing significant increases in active cases but a smaller number of fatalities. In this study, we compare the progress of the pandemic in Italy [28-30], Germany and Turkey based on transmission simulations in an attempt to uncover and examine the following issues:

i- The reasons of significant differences in active cases and fatality rates;

ii- The influence of social isolation and work closure factors to minimize the number of fatalities and reduce the demand on health care systems;

iii-The number of tests and possible quarantine schemes to control the spread of the pandemic. We develop a micro transmission model and estimate the probability of spreading by matching the target basic reproduction number. Estimated and actual fatalities are then compared with the reported results for the three countries.

Finally, a parametric study is conducted to study the influence of social and work closure factors, the number of tests conducted and quarantine schemes for the control of the pandemic.

Methodology

The transmission micro model is initiated by randomly generating a representative population (one million people in this study) with a given age distribution. The population is allocated to homes with a range of family size (one to six people). Kids and teens (between 7 and 18 years of age) are assigned to schools with three different sizes. People between 18 and 25 years of age are assigned to higher education institutions, work or are listed as unemployed. Excluding the unemployed, retired and disabled the remaining of the population acting as the work force is randomly distributed into jobs with different number of people (small, medium and large enterprises). Disease transmission can occur with different daily probabilities at the house (p_h), at work (p_w), at school/university (p_e) or through social contact (p_s). Number of daily interactions of individuals are randomly assigned based on past statistical information [25-27]. Five possible time recursive states are assigned to individuals: Susceptible, incubation, infectious, hospitalized, recovered/dead. The simulations are conducted with a time stepping of one day. Initial cases are assigned randomly on the first day. As the days progress, house, school, work and social interactions are checked for possible transmission. Upon coming in contact with an infectious individual, a random number is generated and compared with the probability of transmission. If infected, the susceptible individual is incubated. After 5 days of average incubation time, the individual is carried to the infectious state which prolongs probabilistically (two to eight days) with an average of five days [4,6,31]. The average hospitalization period is taken as a random number (6 to 14 days) after the end of infectious state with an average of 10 days [4]. The age based death percentage is used with a quartic function: ($\text{death ratio} = 0.002 + 6 \times 10^{-5}(Age - 10)^4/10^4$ for Age ≥ 45) fitted to actual data [1]. The probability of death of an individual is checked based on his/her age. The model input parameters are population size, age distribution, household sizes, work sizes, school sizes, and number of social contacts (Table 1). The best estimates of p_h, p_w, p_e, and p_s are obtained by matching the average reproduction number (R_0) to 2.8 [32-34]. Upon selecting the initial number of infectious people, the time-number of cumulative deaths of Italy, Germany and Turkey are compared with the reported results [1]. The model parameters based on available statistics [35] are presented in Table 1. Results are presented by using upper and lower bounds selected as mean ± standard deviation obtained from 200 Monte Carlo simulations (found as the minimum number for statistically representative results). The estimated number of cases are compared with the reported cases to observe the accuracy of total case detections. Non-medical interventions are studied by multiplying the disease transmission probabilities (p_w, p_e, and p_s) with an intervention factor (f_{sch}, f_{so}, f_{wo}) and between zero and one, one meaning no intervention, zero meaning complete shutdown at a given day.

Table 1. Model parameters.

Parameters	Details
Household	1 (5%), 2 (10%), 3 (10%), 4 (45%), 5 (15%), 6 (15%)
Age distribution	1-14 (13% Italy-Germany, 25% Turkey) 14-64 (64% Italy-Germany, 67% Turkey) ≥ 64 (23% Italy-Germany, 8% Turkey)
Schools	100-200 (10%) 200-300 (70%) 300-400 (20%)
Work	1-50 (60%) 50-250 (%25) 250-400 (%15)
Not working (unemployed / retired / disabled excluding students and children)	15%
Social interactions	1-5 (10%) 5-15 (45%) 15-25 (40%) 25-40 (4%) ≥ 40 (1%)
Daily transmission probabilities	$p_h = 3\%$, $p_w = p_e = p_s = 0.3\%$

Figure 1. Comparisons of simulation results and actual numbers of cumulative deaths and cases until 16 April 2020 (results are provided in the form of upper and lower bounds).

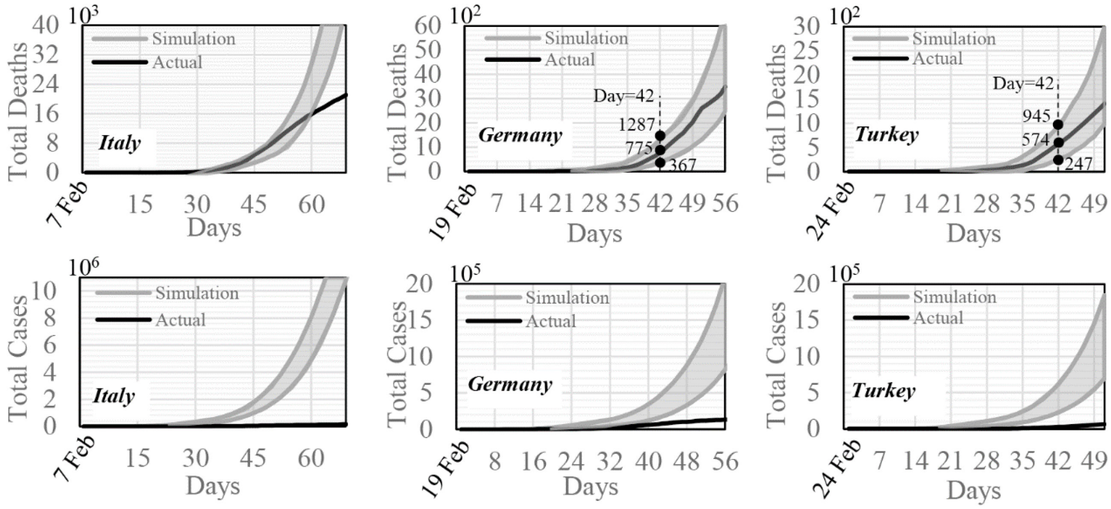
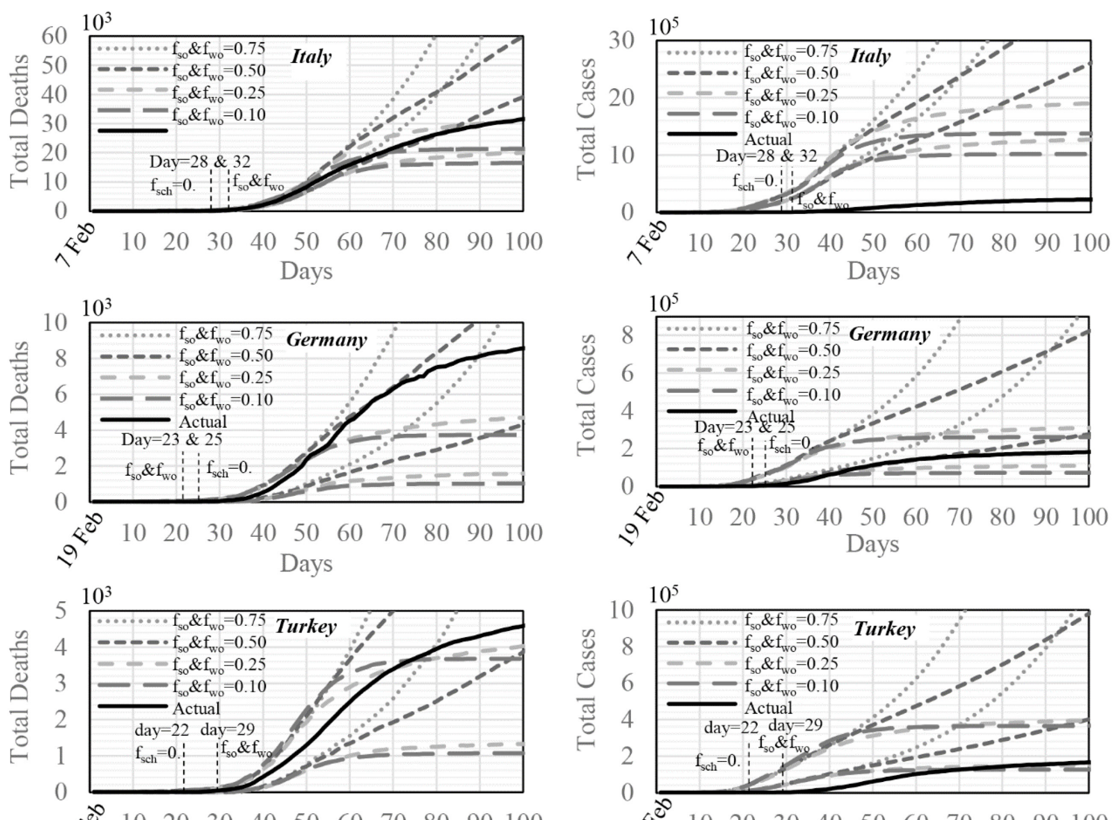


Figure 2. Effect of different non-medical interventions for four social and work distancing factors on number of total deaths and cases (results are provided in the form of upper and lower bounds).



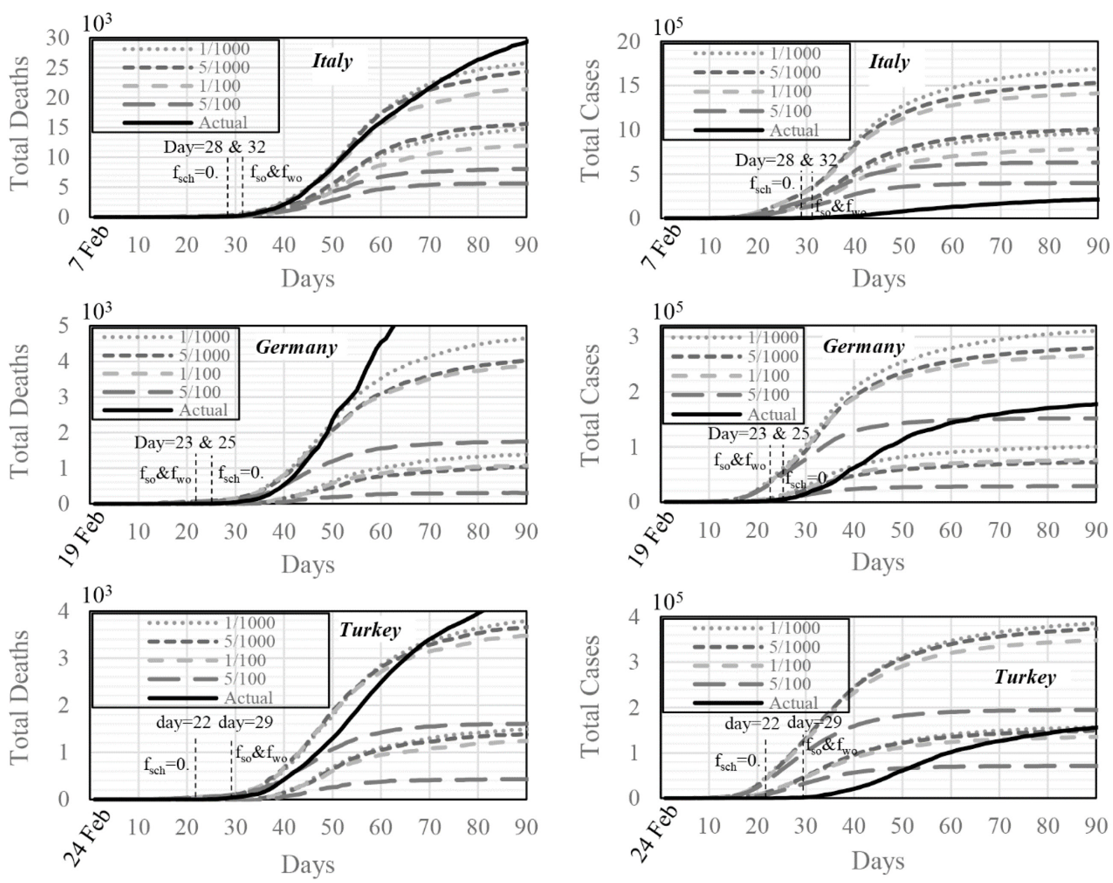
The efficiency of conducting random number tests as a percentage of the population is investigated by conducting simulations with different number of daily tests. Finally, by isolating the family and work of a tested positive person, the effect of proximity isolation is examined.

Results

The number of fatalities until 16 April 2020 for the three countries falls within the bounds of model estimations in the absence of non-medical interventions until the 60th day (Figure 1). For such a match, the number of initial cases of Italy (50) was selected as five times the initial number of cases in Turkey and Germany. This appears to one of the key reasons of the uncontrollable growth of case numbers in Italy compared to Germany and Turkey. If no interventions were made, Italy, Germany and Turkey would have on average about 13 million, 1.5 million and 1.3 million, respectively as shown on the last day presented in Figure 1. Thanks to the non-medical interventions, such a wild spread was avoided as shown in the next paragraph. For Germany and Turkey, the interventions do not appear to have affected the growth as of 16 April 2020 whereas Italy was able to reduce the exponential increase after about 60 days. As Germany and Turkey are estimated to have a similar initial number of infected cases, it is interesting to compare the number of fatalities. At the 42nd day, although Germany and Turkey have approximately similar number of estimated total cases (200-600 thousand), Turkey is expected to have about 30% less number of fatalities (mean 596 from simulation 574 actual) compared to Germany (mean 827 from simulation 775 actual). This can be attributed to the presence of about a 60% smaller number of people over 65 years old in Turkey compared to Germany.

The reported non-medical interventions for the three countries were school closing, partial work closing and social distancing. The interventions were applied on the reported dates [5] and simulations were re-conducted (Figure 2). For all the cases schools were completely shut down and social distancing and work closing parameters were taken as 0.75, 0.5, 0.25 and 0.1. It can be observed that actual fatality of Italy seems to correspond to the upper bound results of social

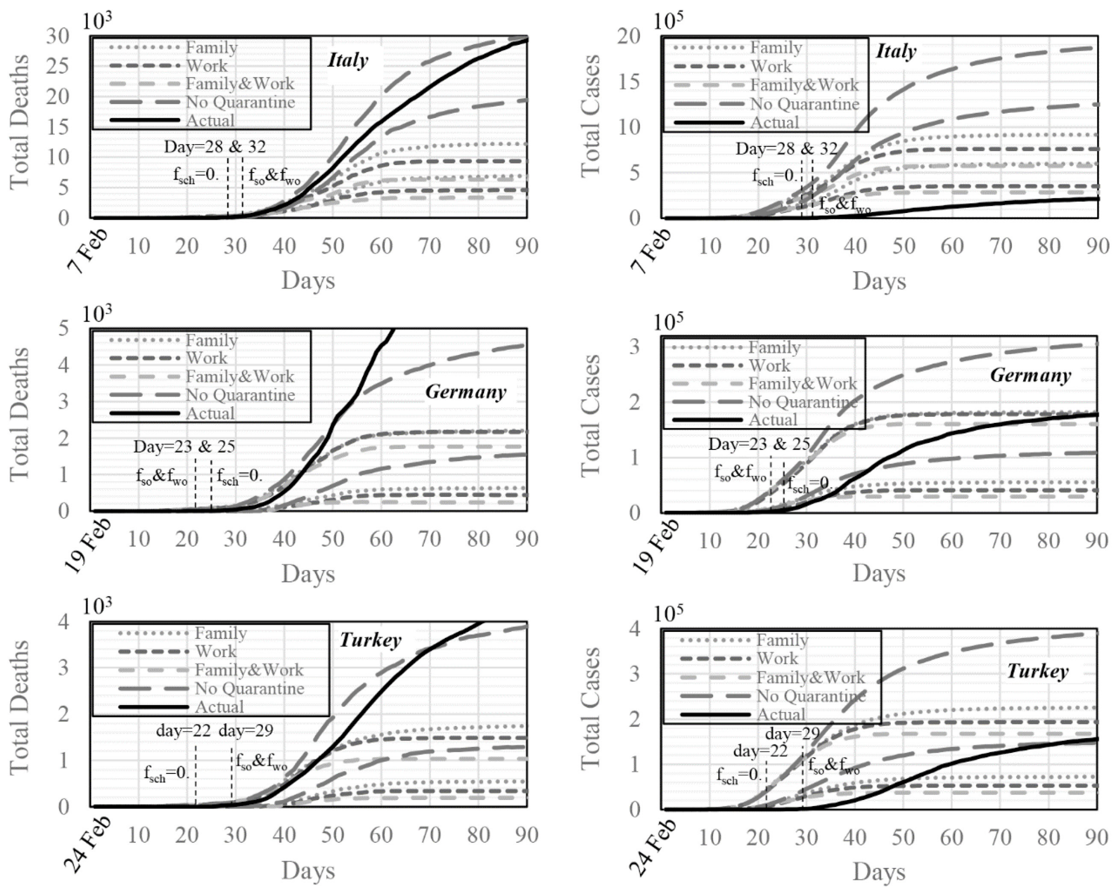
Figure 3. Effect of different number of random testing on total number cases and deaths (results are provided in the form of upper and lower bounds).



distancing and work closing parameters of 0.25 (f_{so} = f_{wo} = 0.25). Accordingly, Italy flattened the fatality curve at about 30 thousand with about 1.8 million total cases. For Germany, the actual data appears to follow the upper bound trend of f_{so} = f_{wo} = 0.50 case. If this interventions level is assumed to continue, Germany is expected to have about 10 thousand fatalities with about 300 thousand cases. With strict interventions similar to Italy, the number of total fatalities may be limited to is about 4 thousand in Turkey by the end of May 2020 which agrees reasonably well with the actual data. If f_{so} = f_{wo} = 0.50 and 0.75 are considered, the expected number of fatalities may increase more than ten times compared to the f_{so} = f_{wo} = 0.25 case. This result demonstrates the importance of these factors on the spread of the pandemic and the need of persistent social distancing. Among the three countries, Germany has the highest ratio of actual to total cases (50%) from the simulations for f_{so} = f_{wo} = 0.25 case. For f_{so} = f_{wo} = 0.25, assuming 20% of the cases requiring hospitalization while 50% of the hospitalized in need of intensive care units, 30 thousand people may be in need of intensive care units in Turkey and Germany. If social distancing and work conditions are slightly relaxed the demand on the health care system may overwhelm the capacity in these two countries. Towards the end of the epidemic, we estimate fatality rates of about 2.0%, 1.6% and 1.1% for Italy, Germany and Turkey, respectively.

The benefits of testing were studied by conducting daily random tests for 1/1000, 5/1000, 1/100 and 5/100 of the population (Figure 3). In these simulations, interventions were fixed at f_{so} = f_{wo} = 0.25 at the actual dates. For Germany and Turkey, testing ratios of 1/1000, 5/1000, 1/100 and 5/100 of the population can reduce the number of mean fatalities by about 1%, 10%, 15%, 60%, respectively compared to the case of no testing. It can be observed that random testing can be considered as effective if conducted over 5/1000 of the population. Such testing amounts can be achieved in smaller population regions to maximize the benefits, however they may not be feasible for metro cities. It appears that none of the three countries are currently capable of achieving such test numbers. As a final alternative of non-medical intervention, the effect of proximity quarantine was studied (Figure 4). In this case, the family, work and family/work contacts of the

Figure 4. Effect of family and work quarantine of a positive tested individual on the number of deaths and cases (results are provided in the form of upper and lower bounds).



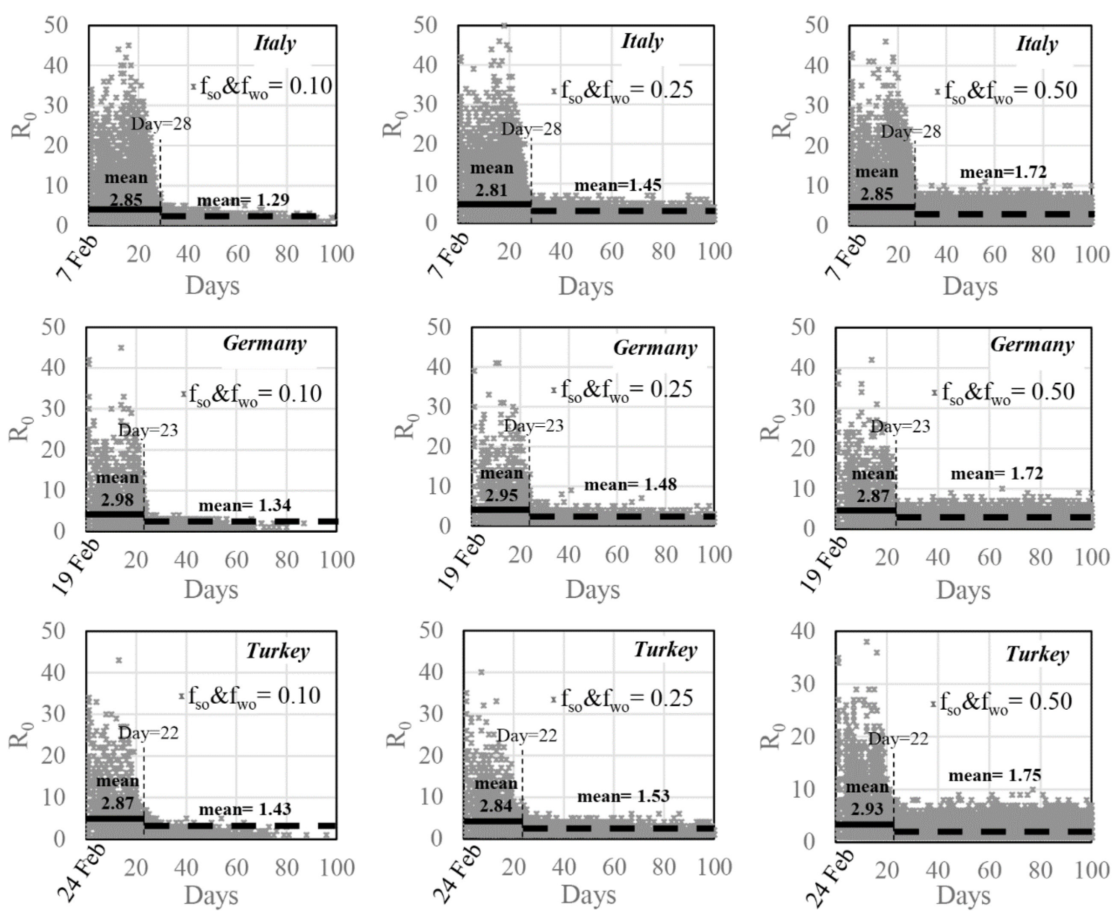
individual were isolated upon positive detection of that individual. In this way, it was possible to reduce the number of fatalities by about 55% (family quarantine), 60% (work quarantine) and 70% (family and work quarantine) on average for Germany and Turkey. None of the three countries appear to apply such a quarantine scheme as the total deaths follow the trend of no quarantine bounds.

Discussion

The simulation results show that Covid-19 is more likely to have initiated in Italy with a larger number of first cases compared to Turkey and Germany resulting in a significantly more severe growth. The number of first cases may not necessarily be the travelers coming to the country but it may also be the health personnel or contacts who might have been rapidly infected and played a vital role in transmitting the disease. Another important remark is on the demography of Turkey, having a smaller elderly population than Germany and Italy, it has an advantage of achieving less number of expected fatalities assuming similar healthcare systems.

In all three countries the estimated total number of cases are much higher than the reported number of cases, with the closest estimate obtained in Germany, possibly due to the high numbers of targeted testing. Non-medical interventions are observed to have great potential to limit the number of fatalities and cases. The social distancing and non-contact working conditions are needed where individuals should reduce the number of non-family contacts by as much as 75-90%. For f_{so} = f_{wo} = 0.25, Italy is likely to have about 30 thousand fatalities, while controlling the fatality growth in about 100 days. On the other hand, Turkey and Germany limit the number of fatalities to 4 to 5 for this scenario. If these strict non-medical interventions were not followed, then the number of fatalities may grow in multiple fold. Since, the estimated number of cases from simulations appear to be much higher than the actual number of reported case, we estimate the average fatality rate to be about 1.5% for the three countries. This calculated fatality rate is obviously significantly lower than the current world wide fatality rate indicating the large number of undetected cases.

Figure 5. Reproduction number of infected individuals before and after non-medical interventions (results are provided for ten simulations).



Random testing appears to result in no significant reduction of spread unless used over 0.5% of the population. Considering the costs and difficulties of such testing, family and work quarantine may be applied as a more viable alternative to reduce the number of fatalities by as much as 50%. The actual reproduction number of Covid-19 still appears to be a mystery according to the authors. The computed R_0 values from individuals in 10 simulations for the three countries are plotted in Figure 5. The mean R_0 prior to the interventions was about 2.8-3.0. It can be observed that super spreaders who have infected more than 40 people are present prior to social distancing. With strict interventions ($f_{so} = f_{wo} = 0.1$ to 0.25) the largest number of spread is limited to about 5 bringing the average R_0 to as low as 1.3-1.5. Even with such strict non-medical interventions it may not be possible to reduce R_0 to below one, and long term social distancing may be needed. Until the discovery of medical interventions, a reduction of 90% in social/work contacts besides family along with school closure should be carried. As reported in a past study [25] the number of contact people on average is found to be around 15. As a rule of thumb, a 90% reduction in social distancing would roughly mean contacting at most 2 people besides family households on a daily basis until the flattening of the Covid-19 case curves.

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