Example: COVID-2019 data for Italian Regions

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The data is taken from official Italian government figures [1]. This mlx. file was proposed by matteo Secli [2] but I did some modifications to it.

[1] https://github.com/pcm-dpc/COVID-19

[2] https://github.com/matteosecli

Initialisation

The parameters are here taken as constant except the death rate and the cure rate.

```
clearvars;close all;clc;

% Download the data from ref [1] and read them with the function
% getDataCOVID_ITA
tableCOVIDItaly = getDataCOVID_ITA();

time = unique(datetime(datestr(datenum(tableCOVIDItaly.Date,'yyyy-mm-DDThh:MM:ss'))));
fprintf(['Most recent update: ',datestr(time(end)),'\n'])
```

```
Most recent update: 28-Jun-2020 17:00:00
```

```

% Add regions and populations here to generate more plots. Eurostat 2018
% data.
Regions     = {'Lombardia', 'Veneto', 'Emilia-Romagna', 'Piemonte'};
Populations = [10.040e6   , 4.905e6 , 4.453e6         , 4.376e6   ];
```

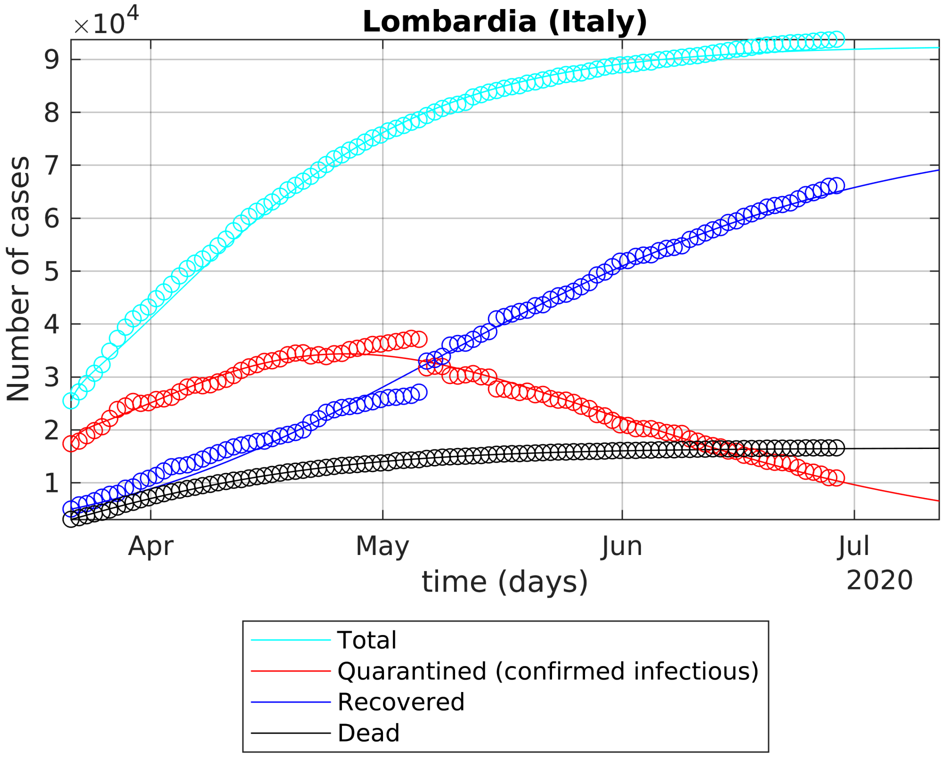
Iterative application of fit_SEIQRDP

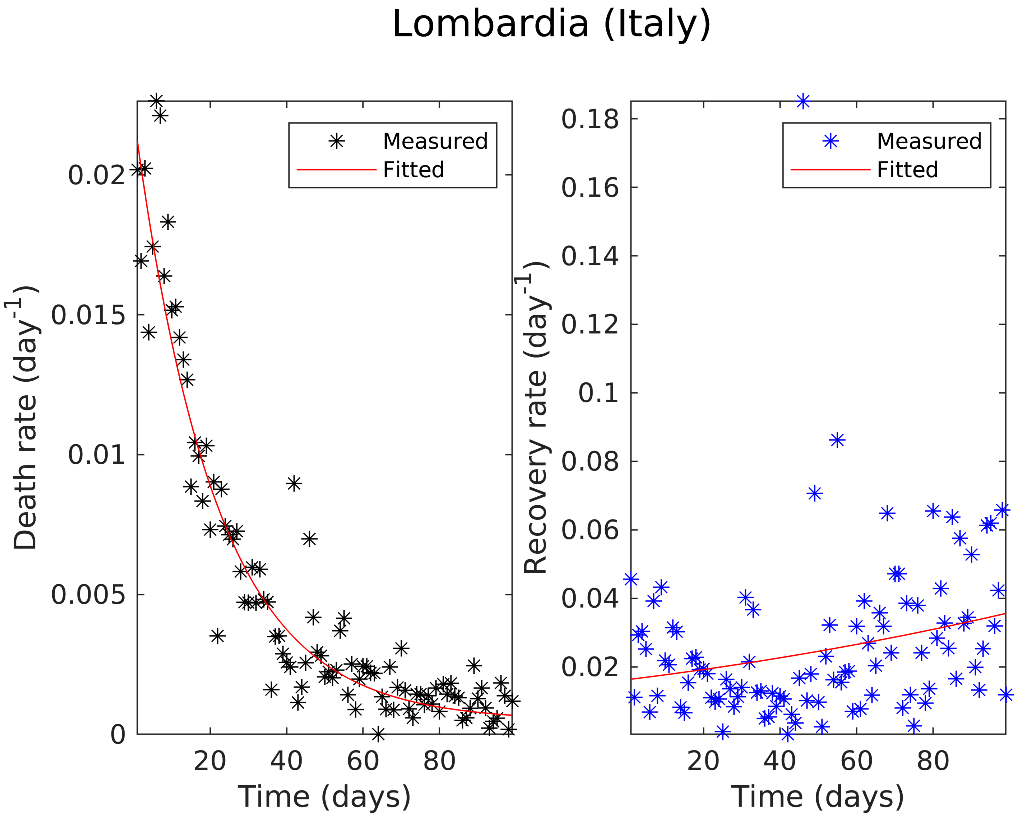
Active cases = Confirmed-Deaths-Recovered (database) = Quarantined (SEIQRDP model)

```
% Definition of the first estimates for the parameters
alpha_guess = 0.06; % protection rate
beta_guess = 1.0; % Infection rate
LT_guess = 5; % latent time in days
Q_guess = 0.5; % rate at which infectious people enter in quarantine
lambda_guess = [0.1,1,10]; % recovery rate
kappa_guess = [0.02,0.05,10]; % death rate
```

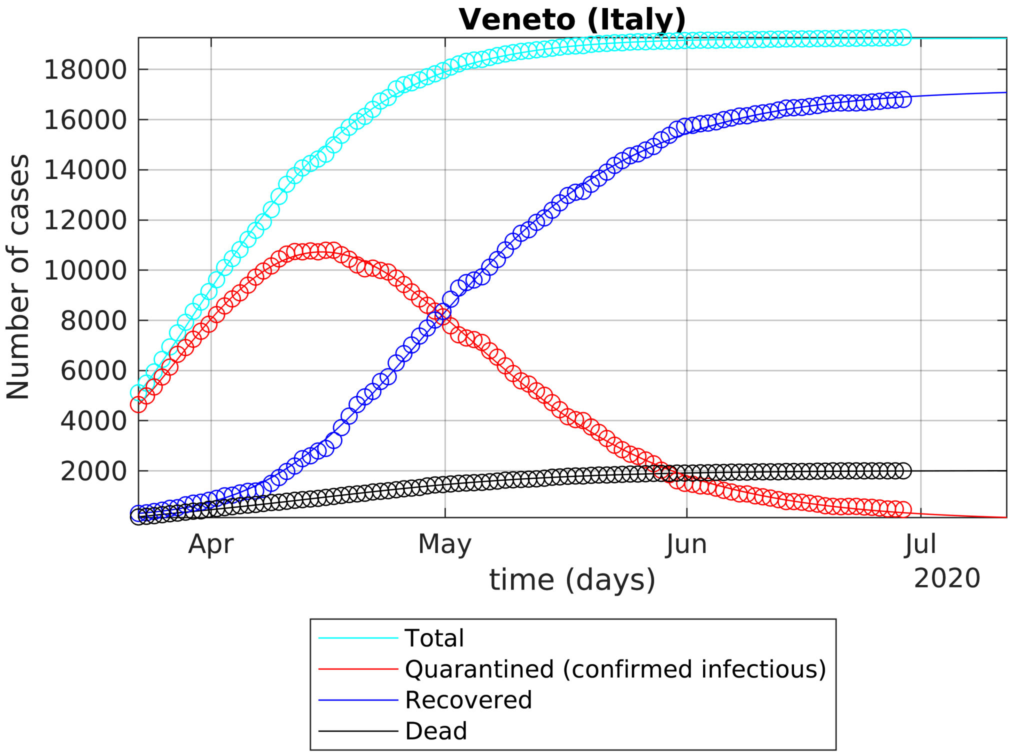
```
guess = [alpha_guess,...
    beta_guess,...
    1/LT_guess,...
    Q_guess,...
    lambda_guess,...
    kappa_guess];


for regionIdx=1:numel(Regions)


    % Region definitions
    regionName = Regions{regionIdx};
    Npop       = Populations(regionIdx); % population

    try
        indLocation = find(contains(tableCOVIDItaly.RegionName,regionName)==1);
    catch exception
        searchLoc = strfind(tableCOVIDItaly.RegionName,regionName);
        indLocation = find(~cellfun(@isempty,searchLoc)) ;
    end

    % Remove the ";" at the end of the line below to show regional data
    tableCOVIDItaly(indLocation,[1,7:end]);

    Recovered   = tableCOVIDItaly.Recovered  (indLocation)';
    Deaths      = tableCOVIDItaly.Deaths     (indLocation)';
    Confirmed   = tableCOVIDItaly.Confirmed  (indLocation)';
    Quarantined = tableCOVIDItaly.Quarantined(indLocation)';
    time        = tableCOVIDItaly.Date       (indLocation)';
    time = unique(datetime(datestr(datenum(tableCOVIDItaly.Date,'yyyy-mm-DDThh:MM:ss'))



    % If the number of confirmed Confirmed cases is small, it is difficult to know whet
    % the quarantine has been rigorously applied or not. In addition, this
    % suggests that the number of infectious is much larger than the number of
    % confirmed cases
    minNum= round(0.25*max(Confirmed));

    indRemoved = unique([find(Confirmed<=minNum),find(isnan(Confirmed))]);
    Recovered(indRemoved)=[];
    Deaths(indRemoved)=[];
    time(indRemoved)= [];
    Quarantined(indRemoved)=[];
    Confirmed(indRemoved)=[];

    %% To simulate the cases after fitting
    dt = 1/24; % time step
    time1 = time(1):dt:datetime(datestr(floor(datenum(now))+datenum(14)));
    N = numel(time1);
    t = [0:N-1].*dt;
    % Initial conditions
    Q0 = Confirmed(1)-Recovered(1)-Deaths(1);
    I0 = 0.2*Q0; % Initial number of infectious cases. Unknown but unlikely to be zero.
    E0 = Q0; % Initial number of exposed cases. Unknown but unlikely to be zero.
    R0 = Recovered(1);
    D0 = Deaths(1);

    [alpha1,beta1,gamma1,delta1,Lambda1,Kappa1,lambdaFun,kappaFun] = ...
        fit_SEIQRDP(Quarantined,Recovered,Deaths,Npop,E0,I0,time,guess,'Display','off',

    %     disp(lambdaFun);
    disp(kappaFun);

    % Simulate the epidemy outbreak based on the fitted parameters
    [~,~,~,Q,R,D,~] = SEIQRDP(alpha1,beta1,gamma1,delta1,Lambda1,Kappa1,...
        Npop,E0,I0,Q0,R0,D0,t,lambdaFun,kappaFun);

    % Comparison of the fitted and real data
    figure
    semilogy(time1,Q+R+D,'c',time1,Q,'r',time1,R,'b',time1,D,'k');
    hold on
    set(gca,'ColorOrderIndex',1);
    semilogy(time,Confirmed,'co',time,Quarantined,'ro',time,Recovered,'bo',time,Deaths,
    % ylim([0,1.1*Npop])
    ylabel('Number of cases')
    xlabel('time (days)')
    title([regionName,' (Italy)']);
    % leg = {'susceptible','exposed','infectious','quarantined','recovered','Dead','ins
    leg = {'Total','Quarantined (confirmed infectious)','Recovered','Dead'};
    legend(leg{:},'location','southoutside')
    set(gcf,'color','w')
    grid on
    axis tight
    % ylim([1,8e4])
    set(gca,'yscale','lin')

    checkRates(time,Quarantined,Recovered,Deaths,kappaFun,lambdaFun,Kappa1,Lambda1);
    try suptitle([regionName,' (Italy)']);end
end
```

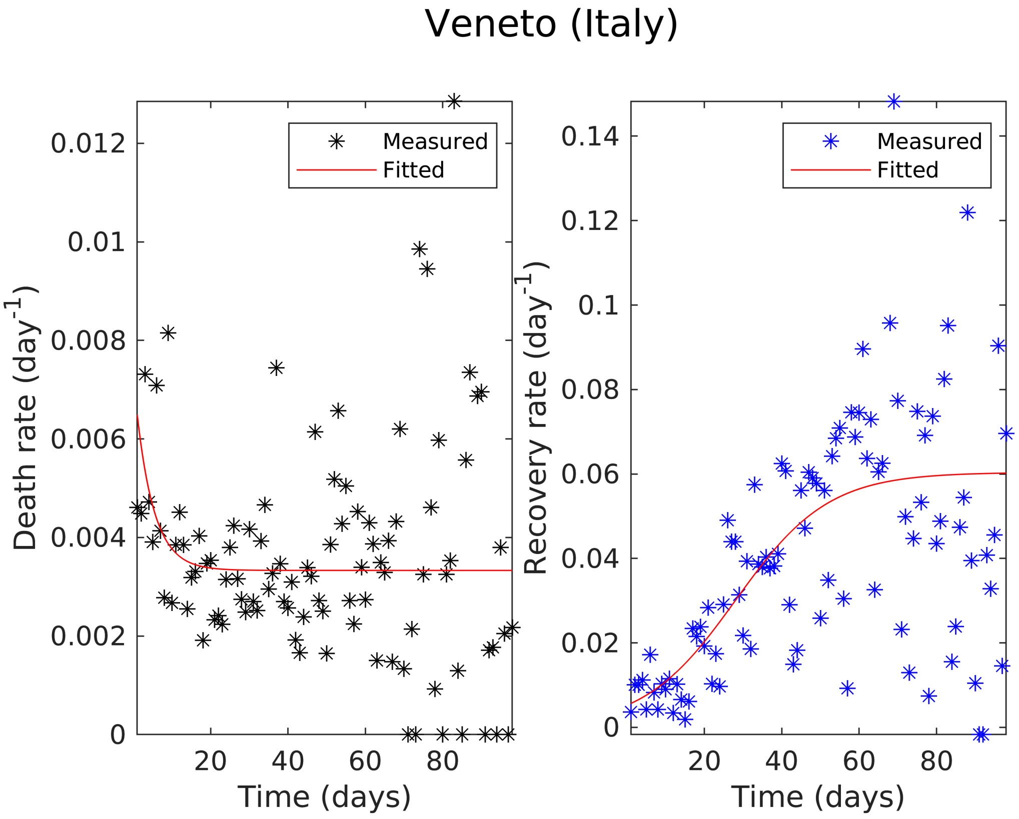
```
@(a,t)a(1)+exp(-a(2)*(t+a(3)))
```



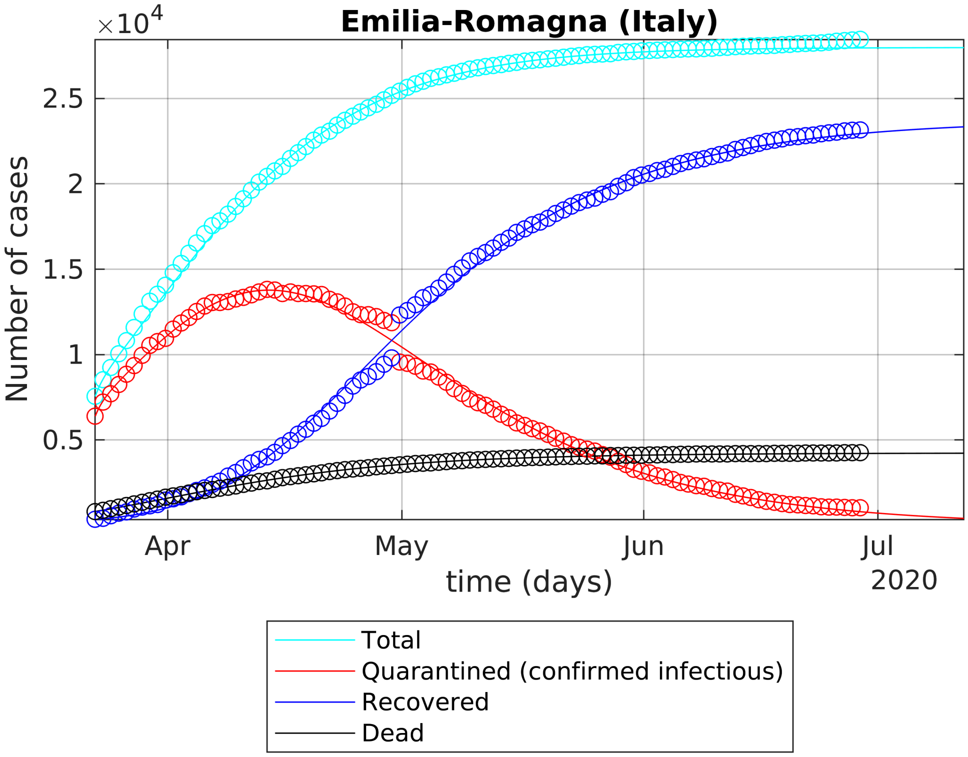


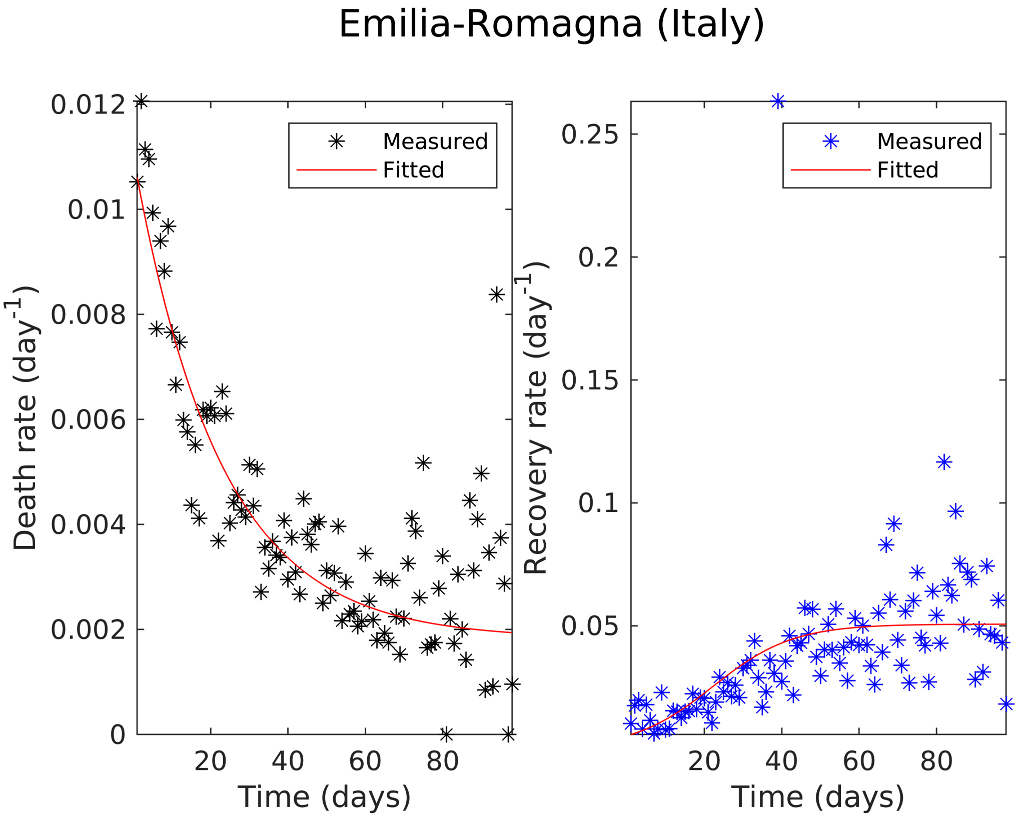
```
@(a,t)a(1)+exp(-a(2)*(t+a(3)))
```



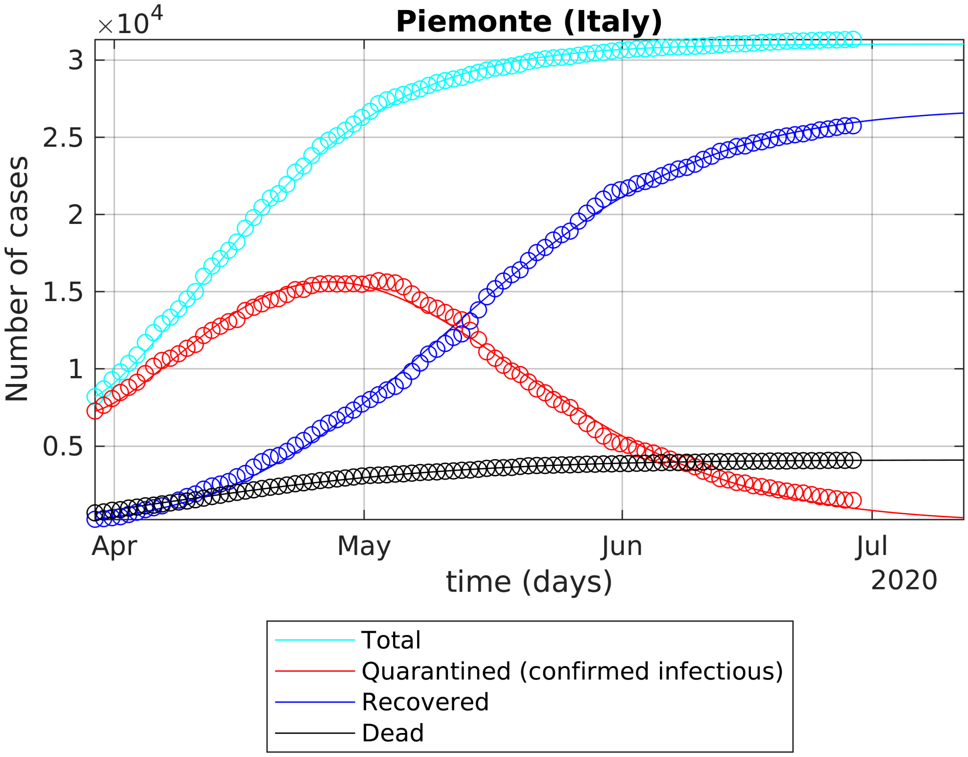


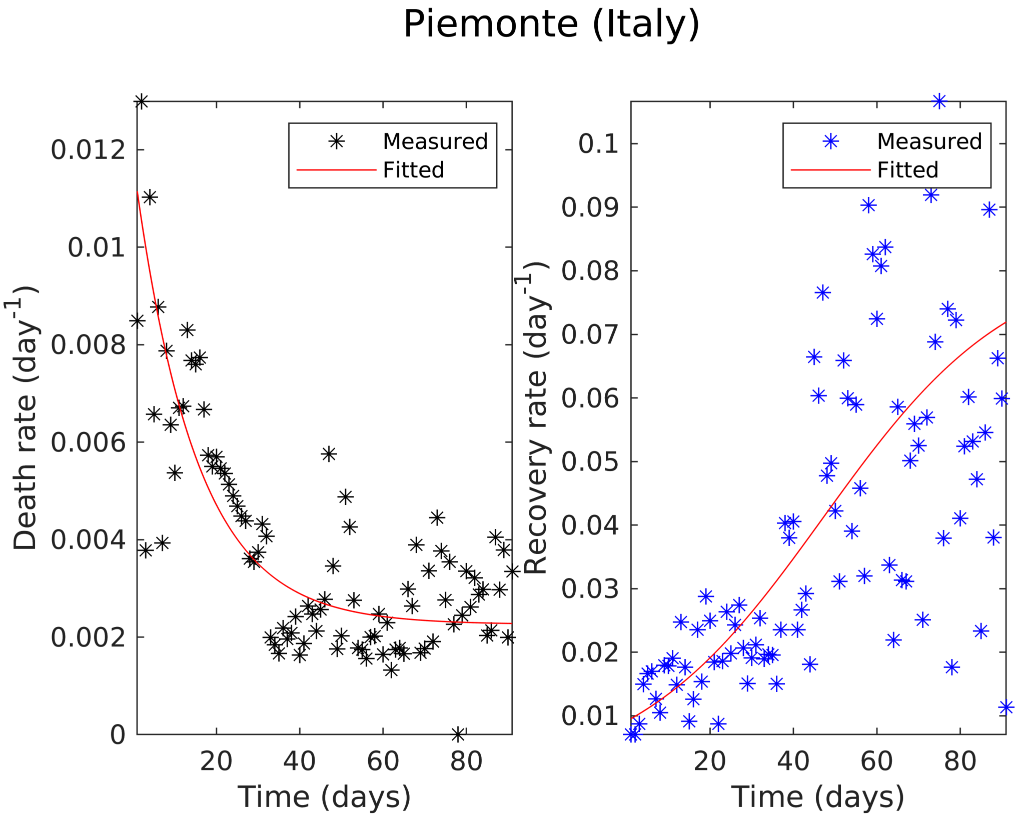
```
@(a,t)a(1)+exp(-a(2)*(t+a(3)))
```





```
@(a,t)a(1)+exp(-a(2)*(t+a(3)))
```





Cumulative data

Perform nation-wide statistics by summing the data of all the regions.

```
% Merge regional data for each day
tableCOVIDItaly_Tot = varfun(@sum,tableCOVIDItaly, ...
    'InputVariables',tableCOVIDItaly.Properties.VariableNames(7:end), ...
    'GroupingVariables','Date');
% Remove the 'GroupCount' variable, should total to the number of Italian regions (19 +
tableCOVIDItaly_Tot = removevars(tableCOVIDItaly_Tot,'GroupCount');
% Rename the accumulated variables with the original variable names
tableCOVIDItaly_Tot.Properties.VariableNames=[tableCOVIDItaly.Properties.VariableNames


Npop = 60.48e6; % population

Recovered   = tableCOVIDItaly_Tot.Recovered'  ;
Deaths      = tableCOVIDItaly_Tot.Deaths'     ;
Confirmed   = tableCOVIDItaly_Tot.Confirmed'  ;
Quarantined = tableCOVIDItaly_Tot.Quarantined';
time        = tableCOVIDItaly_Tot.Date'       ;
time = unique(datetime(datestr(datenum(tableCOVIDItaly.Date,'yyyy-mm-DDThh:MM:ss'))));

disp(kappaFun);
```

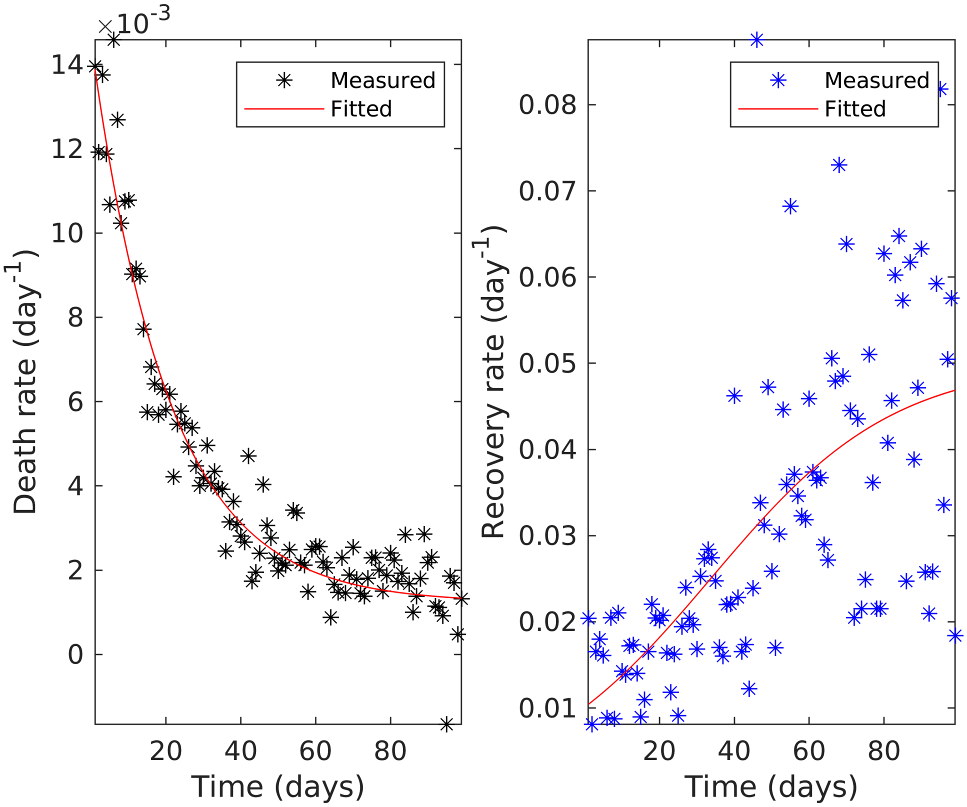
```
@(a,t)a(1)+exp(-a(2)*(t+a(3)))
```

```


% If the number of confirmed Confirmed cases is small, it is difficult to know whether
% the quarantine has been rigorously applied or not. In addition, this
% suggests that the number of infectious is much larger than the number of
% confirmed cases
minNum= round(0.22*max(Confirmed));
indRemoved = unique([find(Confirmed<=minNum),find(isnan(Confirmed))]);
Recovered(indRemoved)=[];
Deaths(indRemoved)=[];
time(indRemoved)= [];
Quarantined(indRemoved)=[];
Confirmed(indRemoved)=[];


% To simulate the cases after fitting
dt = 1/24; % time step
time1 = datetime(time(1)):dt:datetime(datestr(floor(datenum(now))+datenum(7)));
N = numel(time1);
t = [0:N-1].*dt;

% Initial conditions
Q0 = Confirmed(1)-Recovered(1)-Deaths(1);
I0 = 0.2*Q0; % Initial number of infectious cases. Unknown but unlikely to be zero.
E0 = Q0; % Initial number of exposed cases. Unknown but unlikely to be zero.
R0 = Recovered(1);
D0 = Deaths(1);

[alpha1,beta1,gamma1,delta1,Lambda1,Kappa1,lambdaFun,kappaFun] = ...
```

```
    fit_SEIQRDP(Quarantined,Recovered,Deaths,Npop,E0,I0,time,guess,'Display','off');



[S,E,I,Q,R,D,P] = ...
    SEIQRDP(alpha1,beta1,gamma1,delta1,Lambda1,Kappa1,Npop,E0,I0,Q0,R0,D0,t,lambdaFun,k
```

Display the fitted and measured death and recovery rates

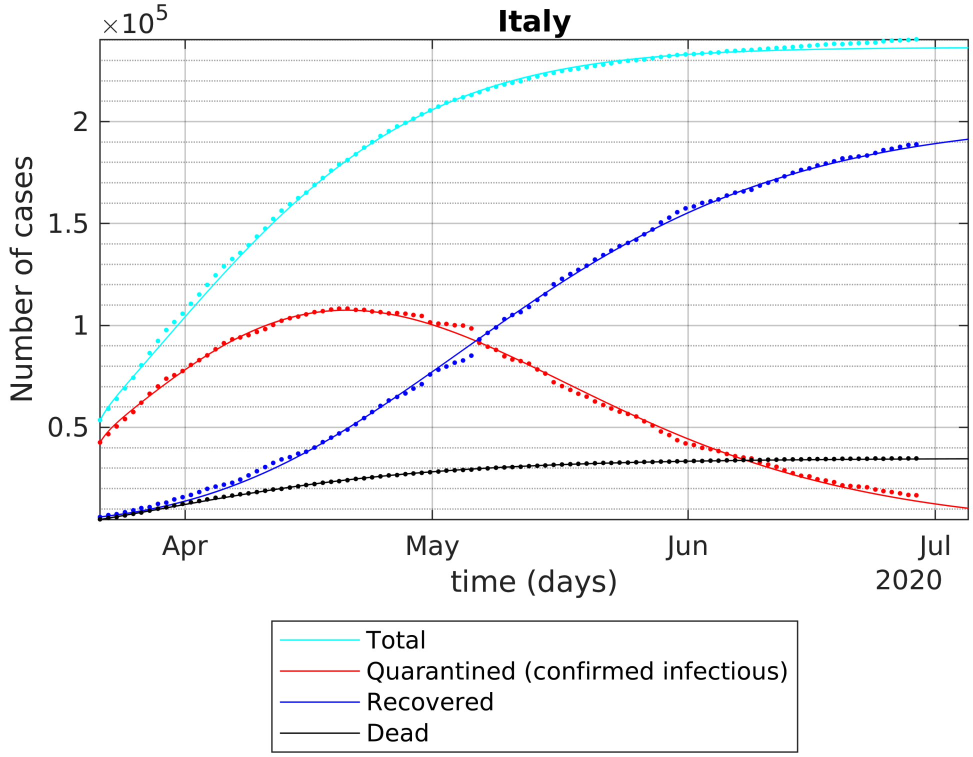
```
checkRates(time,Quarantined,Recovered,Deaths,kappaFun,lambdaFun,Kappa1,Lambda1);
```



Comparison of the fitted and real data

```
figure
semilogy(time1,Q+R+D,'c',time1,Q,'r',time1,R,'b',time1,D,'k');
hold on
set(gca,'ColorOrderIndex',1);
semilogy(time,Confirmed,'c.',time,Quarantined,'r.',time,Recovered,'b.',time,Deaths,'k.'
ylabel('Number of cases')
xlabel('time (days)')
title('Italy');
leg = {'Total','Quarantined (confirmed infectious)','Recovered','Dead'};
legend(leg{:},'location','southoutside')
set(gcf,'color','w')
grid on
grid minor
axis tight
```

```
set(gca,'yscale','lin')
```


Italy
×10^5
Number of cases
Apr
May
Jun
Jul
time (days)
Total
Quarantined (confirmed infectious)
Recovered
Dead