Modelling the fake news impact on the spreading of measles in the Italian commuting network

Life Data Epidemiology

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Outline

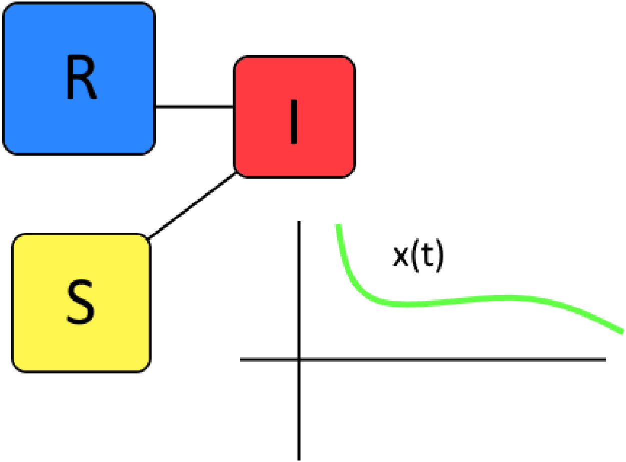
The research question

The starting point of this work are two facts:

- Fake news became a crucial factor into influencing people opinions even for delicate matters such as health.
- The percentage of people immunized for measles dropped in the last few years (Italy 2013-2016 -5% - OECD).

We are gonna build a suitable model to describe the spreading of measles which can take into account the possibility of a varying vaccination propensity.

The model



SIR with vaccination

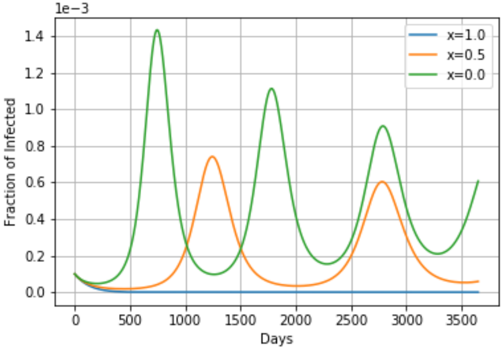
$$
\begin{aligned}
\frac{dS}{dt} &= \lambda(1-x)N - \frac{\beta SI}{N} - \nu S \\
\frac{dI}{dt} &= \frac{\beta SI}{N} - \frac{\nu+\mu}{1-\rho} I \\
\frac{dR}{dt} &= \lambda x N + \frac{\mu}{1-\rho} I - \nu R \\
\frac{dN}{dt} &= (\lambda-\nu)N - \frac{\rho\nu}{1-\rho} I \,.
\end{aligned}
$$

The parameters

- $\nu = (80 \times 365 \text{ days})^{-1}$ death rate
- $\lambda)\nu$ birth rate
- $\mu = (14 \text{ days})^{-1}$ recovery rate
- $x \in [0,1]$ fraction of vaccinated among the newborns
- $R_0 = 18$ basic reproductive ratio
- $\rho = 0.002$ probability of death by disease factors
- $\beta = \frac{R_0(\mu+\nu)}{(1-\rho)} \approx 1.29 \text{ days}^{-1}$ transmissibility

Single patch simulations

Using Euler's method we simulated the differential equations above stated and by varying x (constant in time) we have that the infected number either dies out ($x = 1$) or takes a damped oscillatory behaviour towards the endemic phase:



Epidemic threshold

By varying x we found a family of curves describing the endemic status of the system; as in the basic SIR we have a phase transition between the disease-free and endemic phase however the transition point R_0^* depends on x in the following way:

$$R_0^* = \frac{1}{1-x}$$

Phase diagram

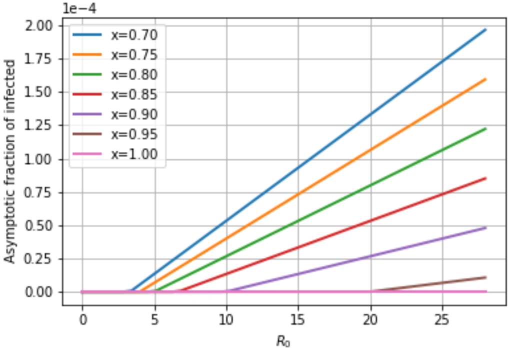


Figure: Portion of the phase diagram for the R_0's we are interested.

Commuting network

- From the single patch SIR we move to a SIR with commuting mobility model.
- The commuting network was taken from ISTAT.
- The network originally described commuting between any two cities however we aggregated the ≈ 8000 cities from the same *provincia* (which are 110) to simplify the simulation.

Commuting network

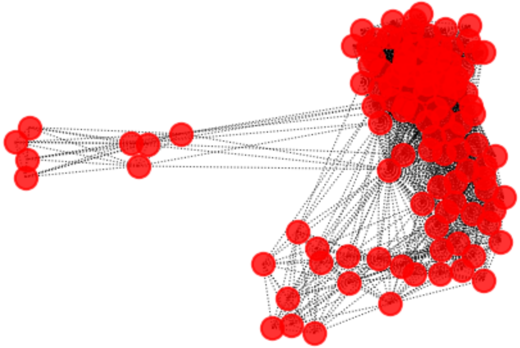


Figure: The italian commuting network; each node is a *provincia*

Commuting network

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Metapopulation equilibrium

$$\sigma_{ij} = \text{leaving rate}$$

$$\gamma = \text{return rate}$$

$$X_{ii} = \frac{X_i}{1 + \sigma_i/\gamma} \quad X_{ij} = \frac{\sigma_{ij} X_i/\gamma}{1 + \sigma_i/\gamma} \quad X_i = S_i, I_i, R_i$$

SIR on commuting network

SIR equations

$$\partial_t I_{ii} = \phi_{ii} S_{ii}(t) - \frac{(\mu+\nu)}{1-\rho} I_{ii}(t)$$

$$\partial_t I_{ij} = \phi_{ij} S_{ij}(t) - \frac{(\mu+\nu)}{1-\rho} I_{ij}(t)$$

$$\phi_{ij} = \frac{\beta_j}{N_j^*}\left[I_{jj} + \sum_l I_{lj} \right] \; \forall i,j$$

Opinion dynamics

- The opinion network is an Erdős-Rényi random network with arbitrary p; we chose p to be either 0.7 or 1.0.
- Each node in the network corresponds to a *provincia*.
- The opinion dynamics are modeled using a modified version of the Deffuant model.
- The Deffuant model is modified by adding a stochastic part that changes randomly the opinion of a random subset of the nodes (*impurities* creation)

Random pairs of neighbour nodes are selected and their opinions updated:

Opinion update rules

$$x_i(t+1) = x_i(t) + f_\mu(x_i(t), x_j(t))$$
$$x_j(t+1) = x_j(t) + f_\mu(x_j(t), x_i(t))$$

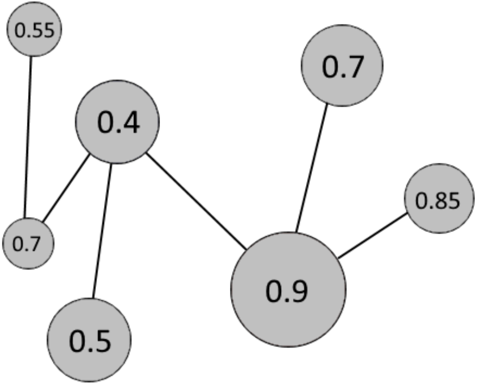
Update policies

$$f_{\mathrm{min}}(x_i, x_j) = \Theta(|x_i - x_j| - \epsilon)\mu_D \left(\min(x_i, x_j) - x_i\right)$$

$$f_{\mathrm{max}}(x_i, x_j) = \Theta(|x_i - x_j| - \epsilon)\mu_D \left(\max(x_i, x_j) - x_i\right)$$

$$f_{\mathrm{mean}}(x_i, x_j) = \Theta(|x_i - x_j| - \epsilon)\mu_D \left(\frac{x_i + x_j}{2} - x_i\right)$$

Min-policy: opinion exchange and a random change:



Simulation

- We fix the initial fraction of infected and recovered for each node (hence the susceptible).
- We distribute the initial population (for each compartment) among nodes according to the commuting network equilibrium equations.
- We fix the initial opinions for each node.
- For the same time period we both evolve the opinions and the epidemics.
- Effectively, the opinions act as an external stochastic time-dependent force on the SIR model.

Simulation

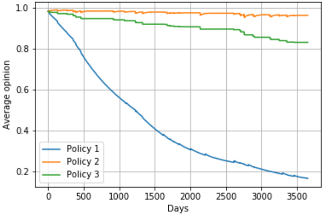
Fixed simulation parameters

ϵ	0.1
μ_D	0.01
x_0	$[0, 10^{-5}]$
r_0	$[0.9, 0.95]$
s_0	$1 - x_0 - r_0$
Infected provinces	110
No-vax provinces	10
Start no-vax provinces opinion	[0.7, 0.9]
Start pro-vax provinces opinion	1
Simulation length	10 y
Simulation time step δ	0.5 days

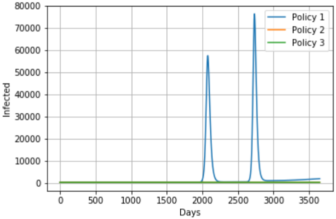
We have two kind of simulations:

1. 5 different parameters configurations; the no-vax nodes are randomly chosen
2. Default parameters configuration with no impurities; the chosen nodes are the one with the highest and lowest degree (*targeted initialization*)

Configuration # 1

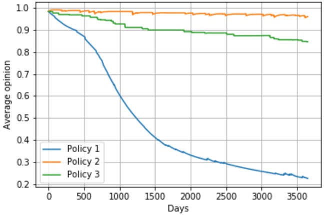


(a) Trend of the opinion for $p = 1$, $p_{imp} = 0.005$, $n_{imp} = 1$.

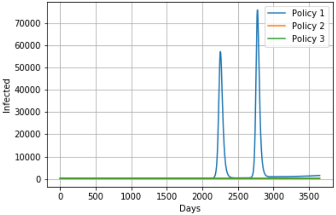


(b) Number of infected for $p = 1$, $p_{imp} = 0.005$, $n_{imp} = 1$.

Configuration # 2

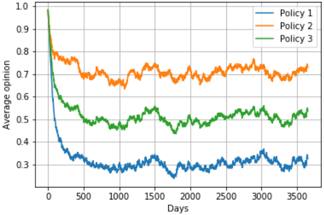


(c) Trend of the opinion for $p = 0.7$, $p_{imp} = 0.005$, $n_{imp} = 1$.

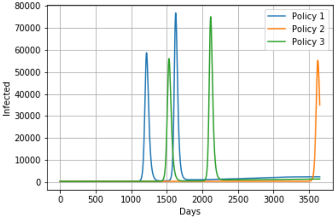


(d) Number of infected for $p = 0.7$, $p_{imp} = 0.005$, $n_{imp} = 1$.

Configuration # 3

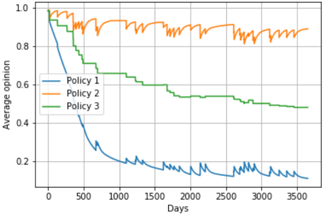


(e) Trend of the opinion for $p = 1$, $p_{imp} = 0.5$, $n_{imp} = 1$.

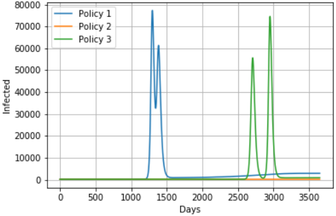


(f) Number of infected for $p = 1$, $p_{imp} = 0.5$, $n_{imp} = 1$.

Configuration # 4

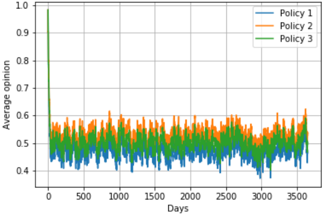


(g) Trend of the opinion for $p = 1$, $p_{imp} = 0.005$, $n_{imp} = 10$.

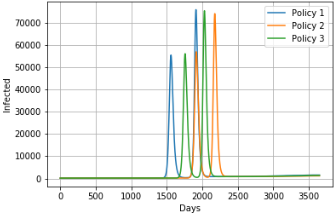


(h) Number of infected for $p = 1$, $p_{imp} = 0.005$, $n_{imp} = 10$.

Configuration # 5

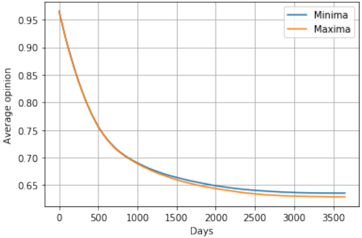


(i) Trend of the opinion for $p = 1$, $p_{imp} = 0.5$, $n_{imp} = 10$.

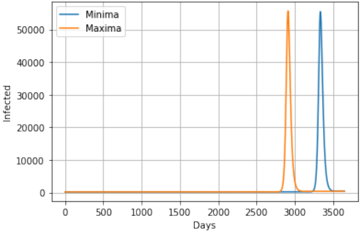


(j) Number of infected for $p = 1$, $p_{imp} = 0.5$, $n_{imp} = 10$.

Targeted initialization



(k) Trend of the opinion; min-policy with no impurities; $p = 0.7$; max and min degrees



(l) Number of infected; min-policy with no impurities; $p = 0.7$; max and min degrees

Conclusions

- The model effectively captures the dependence between the vaccination behaviour (due to fake news spreading) and the epidemic dynamics
- The policy is a very important factor into determining the epidemic state; the policy approach can be extended towards a more complex model where the policy would become time dependent (thus simulating the authorities intervention into the fake news spreading).
- The observed outbreaks are delayed with respect to the opinion dropping: this is meaningful since, after having settled in a small vaccination opinion, one has to wait some time in order to have a sustained number of non-vaccinated newborns.