The impact of societal vaccination policies on epidemic dynamics.

Youssef Ait haddou

April 16, 2020

Objective:

The objective of this project is to analyze the impact of societal vaccination policies on epidemic dynamics. The problem can be seen as an optimization problem of costs with respect to benefits. This contribution presented here is more focused on analyzing newborn vaccination in a SIR model with vital dynamics.

Model:

We consider the SIR model with vital dynamics and newborn vaccination. In this model S represents the susceptible individuals, I the infected ones, R the recovered and V the vaccinated. In order to explain the choice of an individual, to whether vaccinate or not and with which probability, we have to compute the probability ϕ of being infected. We consider that all individual are rational and they aim to minimize the expected cost:

$$p_I(t)r_V + (1 - p_I(t))r_I\phi_I^u(t) = p_I(t)r_V - p_I(t)r_I\phi_I^u(t) + r_I\phi_I^u(t).$$

The goal is to prove that our model accepts at least a Nash equilibrium.

The procedure is iterative, we denote by n the iteration counter. For $n = 0$, any $p \in \mathcal{P}$ can be chosen. The minimization problem of the cost of an individual born in t is equivalent to:

$$\min_{p(t)\in[0,1]} p(t)(r_V - r_I\phi_I^{u^n}(t))$$

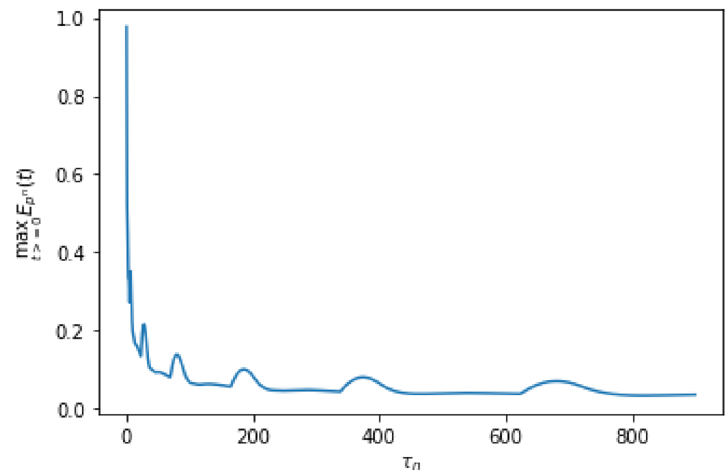
In our procedure we do not take the minimizer in the above term as next iterate. Instead, we want the transition from p_n to p_{n+1} to be smooth; the intuitive interpretation is that the individual wants to minimize their cost but the new vaccination strategy need to be close to the previous one. Hence, we minimize for all t and for a given parameter $\delta_\tau > 0$:

$$\min_{p(t)\in[0,1]} \left\{ \frac{(p(t) - p^n(t))^2}{2\delta_\tau} + p(t)(r_V - r_I\phi_I^{u^n}(t) \right\}$$

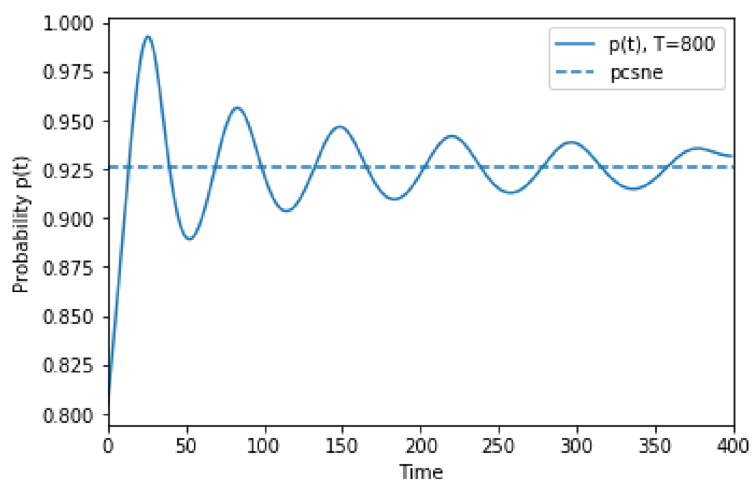
Such that the constant δ_τ plays the role of a pseudo-time; we denote $\tau_n = n\delta_\tau$.

Results:

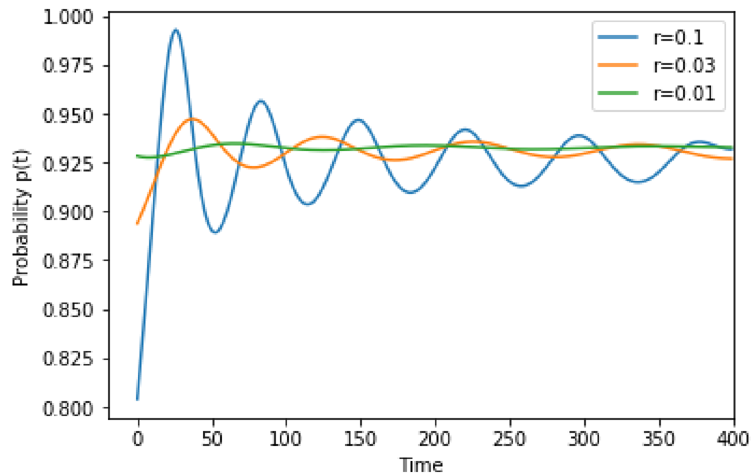
- The maximum mismatch between the current cost and optimal cost decreases by several orders of magnitude and as such one can consider the solution attained.



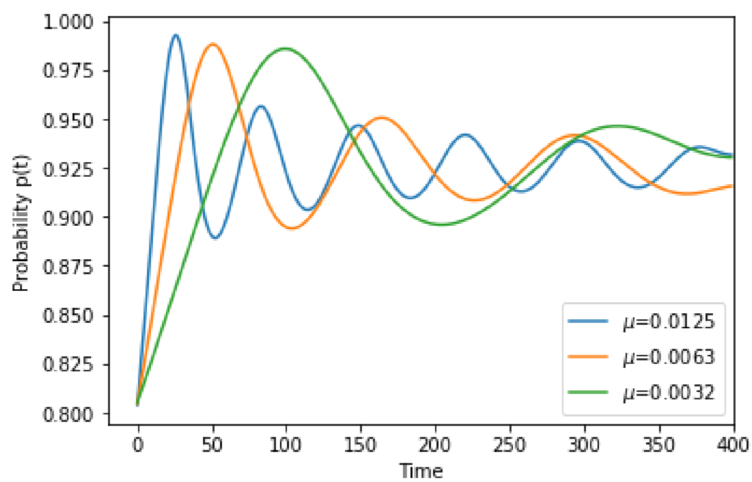
- As a result we get the probability of vaccination $p(t)$, which is the main result of the simulation and which completely characterize the equilibrium.



- When the cost of vaccination is getting higher, there will be a need for a more flexible approach and more alternating between vaccinating more or less people.



- The death / birth rate changes the frequency of the probability $p(t)$, that is a higher rate causes a more frequent change of the population and thus a more frequent vaccination of the population.



- The transmission rate β plays an important role for the choosing of $p(t)$, A higher transmission rate indicate a more infectious disease, which requires a higher vaccination necessity.