

SI Model Stability

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1 Simplified SI Model

The SI (Susceptible-Infected) model is a discrete-time, deterministic model.

$$\begin{aligned}\frac{dS}{dt} &= -\frac{\alpha}{N}SI \\ \frac{dI}{dt} &= \frac{\alpha}{N}SI\end{aligned}$$

- α : the contact rate, i.e. the average number of individuals successfully infected

SI is the number of potential contacts with an infected individual. Then $\frac{\alpha}{N}SI$ is the average number of successful infections per population times the number of potentially successful contacts.

Initial conditions:

$$\begin{aligned}S_0 + I_0 &= N \\ S_0 > 0, I_0 > 0\end{aligned}$$

1. The total population size, N , remains constant: $N = S_n + I_n$.
2. Each individual is equally likely to contract the disease.

1.1 Stability Analysis

Reduce to one equation. Since $S = N - I$:

$$\frac{dI}{dt} = \frac{\alpha}{N}(N - I)I$$

The equilibria / fixed points are when $\frac{dI}{dt} = 0$.

$$I^* = 0, I^* = N$$

Corresponding to $S^* = N$ and $S^* = 0$, respectively.

This gives two (S, I) pairs: the DFE pair $(N, 0)$ and the endemic equilibrium pair $(0, N)$.

The Jacobian for $x = \frac{dS}{dt}$ and $y = \frac{dI}{dt}$ is

$$J = \begin{vmatrix} \frac{\partial x}{\partial S} & \frac{\partial x}{\partial I} \\ \frac{\partial y}{\partial S} & \frac{\partial y}{\partial I} \end{vmatrix} = \begin{vmatrix} -\frac{\alpha}{N}I & -\frac{\alpha}{N}S \\ \frac{\alpha}{N}I & \frac{\alpha}{N}S \end{vmatrix} = \frac{\alpha}{N} \begin{vmatrix} -I & -S \\ I & S \end{vmatrix}$$

1.2 Disease-Free Equilibrium (DFE)

DFE: $(S, I) = (N, 0)$

Evaluate the Jacobian.

$$J = \begin{vmatrix} 0 & -\alpha \\ 0 & \alpha \end{vmatrix}$$

Evaluate the characteristic polynomial:

$$J - \lambda I = \begin{vmatrix} 0 & -\alpha \\ 0 & \alpha \end{vmatrix} - \begin{vmatrix} \lambda & 0 \\ 0 & \lambda \end{vmatrix} = \begin{vmatrix} -\lambda & -\alpha \\ 0 & \alpha - \lambda \end{vmatrix}$$

Evaluate the determinant:

$$\det = -\lambda(\alpha - \lambda) - 0(-\alpha) = -\lambda(\alpha - \lambda)$$

Eigenvalues: $\lambda_1 = 0$, $\lambda_2 = \alpha > 0$

1.3 Endemic Equilibrium

Endemic equilibrium: $(S, I) = (0, N)$

Evaluate the Jacobian.

$$J = \begin{vmatrix} -\alpha & 0 \\ \alpha & 0 \end{vmatrix}$$

Evaluate the characteristic polynomial:

$$J - \lambda I = \begin{vmatrix} -\alpha & 0 \\ \alpha & 0 \end{vmatrix} - \begin{vmatrix} \lambda & 0 \\ 0 & \lambda \end{vmatrix} = \begin{vmatrix} -\alpha - \lambda & 0 \\ \alpha & -\lambda \end{vmatrix}$$

Evaluate the determinant:

$$\det = -\lambda(-\alpha - \lambda) - 0(\alpha) = \lambda(\alpha + \lambda)$$

Eigenvalues: $\lambda_1 = 0$, $\lambda_2 = -\alpha < 0$.

References

- [1] Allen, L.J.S. (1994). Some discrete-time SI, SIR, and SIS epidemic models. *Mathematical Biosciences* 124(1), 83-105. [https://doi.org/10.1016/0025-5564\(94\)90025-6](https://doi.org/10.1016/0025-5564(94)90025-6)
- [2] Jacquez, J.A. & Simon, C.P. (1993). The stochastic SI model with recruitment and deaths I. comparison with the closed SIS model. *Mathematical Biosciences*, 117(1-2), 77-125. [https://doi.org/10.1016/0025-5564\(93\)90018-6](https://doi.org/10.1016/0025-5564(93)90018-6)