Complex Bifurcations Generated by Waning and Boosting of Immunity in Infectious Disease Dynamics

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Abstract

We investigate a class of epidemiological models that incorporates waning of immunity at the individual level and boosting of the immune system upon re-exposure to the pathogen. When immunity is fully restored upon boosting, the system can be expressed as an SIRS-type model with discrete and distributed delays. We conduct a numerical bifurcation analysis varying the boosting force and the maximum period of immunity (in the absence of boosting), while keeping other parameters fixed at values representative of a highly infectious disease like pertussis. The stability switches of the endemic equilibrium, identified numerically, are validated using an established analytical approach, confirming that the equilibrium is unstable in a bounded parameter region, and stable outside this region. Using recently developed continuation methods for models with discrete and distributed delays, we explore periodic solutions and their bifurcations. Our analysis significantly extends previous findings and reveals a rich dynamical landscape, including catastrophic bifurcations of limit cycles, torus bifurcations, and bistability regions where two stable periodic solutions coexist, differing in amplitude and period. These complex bifurcations have critical public health implications: perturbations—such as non-pharmaceutical interventions—can shift the system between attractors, leading to long-term consequences on infectious disease dynamics from short-term measures.

Joint work with Francesca Scarabel, Mónika Polner, Daniel Wylde, Maria Vittoria Barbarossa.

References

[1] Scarabel, F., Polner, M., Wylde, D., Barbarossa M.V., Röst G., Bistability and complex bifurcation diagrams generated by waning and boosting of immunity. J. Math. Biol. 91, 30 (2025). https://doi.org/10.1007/s00285-025-02264-3

[2] Barbarossa MV, Polner M, Röst G (2017) Stability switches induced by immune system boosting in an SIRS model with discrete and distributed delays. SIAM J Appl Math 77(3):905–923

[3] Barbarossa MV, Polner M, Röst G (2018) Temporal evolution of immunity distributions in a population with waning and boosting. Complexity 2018(1):9264743

[4] Barbarossa MV, Röst G (2015) Immuno-epidemiology of a population structured by immune status: a mathematical study of waning immunity and immune system boosting. J Math Biol 71:1737–1770