Unveiling Epidemic Management: Understanding Individual Responses to Interventions through Integrated Modeling and Optimal Control Theory

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Title:　Unveiling Epidemic Management: Understanding Individual Responses to Interventions through Integrated Modeling and Optimal Control Theory (流行管理の解明: 統合モデリングと最適制御理論を通じて介入に対する個人の反応を理解する)

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論 文 内 容 の 要 旨

Thesis Summary

In this thesis, we extensively explore epidemic models, behavior models, and optimal control theory to understand the complexities of managing infectious diseases. Our overarching goal has been to gain insights into how individuals respond to interventions and uncover the social dilemmas inherent in epidemic situations. Throughout our investigation, we have examined various epidemic scenarios, focusing on the nuanced examination of individual behaviors facilitated by mathematical modeling.

In Chapter 1, we introduced the study's background, outlined the thesis structure, and provided fundamental preliminary information essential for this research.

Chapter 2 delves into an epidemiological model rooted in SEIR dynamics, where self-quarantine and forced quarantine interventions intertwine with human behavior dynamics. We find that the decision to self-quarantine is intricately linked to individual choices driven by personal costs, while authorities can enforce quarantine through incentives, constrained by budget limitations. These interventions, derived from behavioral modeling, emerge as pivotal strategies in curtailing infection peaks and addressing the social efficiency deficit.

Chapter 3 introduces a two-strain epidemic model, highlighting the delayed emergence of a new strain and exploring pre-infection and post-infection vaccination strategies. Our exploration reveals that human behavior in committing to vaccination dynamically responds to prevailing circumstances, intensifying as infection rates rise or highly transmissible variants emerge. Delaying the second strain not only reduces infection peaks but also alleviates the social dilemma associated with vaccination decisions.

Chapter 4 delves deeper into vaccination decision-making, examining the social dilemma by featuring both provaccination and antivaccination susceptible groups. We meticulously analyze the impact of waning

immunity on individuals' willingness to undergo revaccination, underscoring the significance of boosting vaccination rates to mitigate the social dilemma despite challenges posed by higher rates of waning immunity.

Chapter 5 addresses the complexity posed by multi-strain diseases and multiple vaccination options, emphasizing the importance of achieving equilibrium in vaccine adoption. Our analysis uncovers a nuanced interplay between waning immunity, vaccine efficacy, and the presence of highly transmissible strains.

Chapter 6 pioneers a novel methodology using optimal control theory to evaluate the Social Optimum of a vaccination game, considering variables such as cost, availability, and distribution policies. Our research yields valuable insights into optimizing vaccination strategies within complex societal dynamics, emphasizing the need to account for variables such as waning immunity and vaccination costs.

In conclusion, this thesis provides a comprehensive understanding of epidemic dynamics, shedding light on the complexities of individual decision-making and the social dilemmas inherent in epidemic scenarios. Our findings have profound implications for policy-making and public health efforts, offering a roadmap for navigating the challenges posed by infectious diseases and optimizing intervention strategies in a dynamic and evolving landscape.