Modeling Peer-Influenced Smoking Initiation Using Agent-Based Simulation with Calibration

Qinyao Yu, Chenlan Wang, Thuy Le, David Mendez

School of Public Health, University of Michigan, Ann Arbor

TCORS Center for the Assessment of Tobacco Regulations [CAsToR]

This research was funded by the NCI/FDA grant U54CA229974			
Off-label medication uses discussed: No			
Please add "yes" or "no" to each table cell. If "yes", please turn cell background color to yellow.	Tobacco Industry	Non-Pharma Nicotine Product Industry	Pharma Industry
The work being presented has received funding or other means of support from any of the following sources:	no	no	no
Any of the authors have received funding (including consultancy) from any of the following sources in the past 5 years:	no	no	no

Introduction

Background

- Smoking addiction in youth often spreads through peer influence within social networks.
- Traditional Ordinary differential equation (ODE) models ignore individual-level interactions.

Objectives

- Develop a gender-stratified agent-based model (ABM) to simulate smoking initiation as a two-stage process involving self initiation and peer imitation.
- Estimate gender-specific peer imitation and provide theoretical analysis.

Methods

Smoking Transition Mechanism

Two-stage update rule per time step

Step 1: Self-initiation

- Non-smokers may initiate smoking independently at each time step.

Step 2: Peer influence

- Otherwise, non-smokers sequentially contact each peer once per time step.
- Only smoking peers exert influence, each with a fixed peer imitation probability (κ).
- Adoption occurs at the first successful influence, or the individual remains unchanged after all peers are visited.

Cessation

- Smokers may quit independently at each time step.

Peer imitation probability κ

- Definition: Probability that such contact leads the nonsmoker to start smoking.

Data

- National Survey on Drug Use and Health (NSDUH)
- Parameter inputs Datasets: National Survey from reference [1]

Table 1 Parameter Details

cohort	$s_m(0)$	$s_f(0)$	α_m	α_f	μ_m	μ_f
2001	0.008	0.004	0.012	0.064	0.468	0.340
2004	0.006	0.003	0.008	0.041	0.492	0.447
2008	0.001	0.006	0.018	0.027	0.512	0.650
2011	0.002	0.003	0.001	0.019	0.719	0.679
2013	0.001	0.001	0.001	0.013	0.864	0.737

[1] Simon, C., & Mendez, D. (2021). The importance of peer imitation on smoking initiation over time: a dynamical systems approach. Health Care Management Science 2021 25:2.

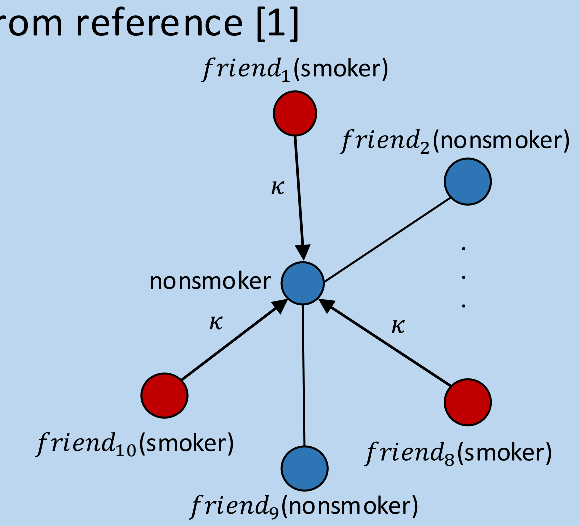

Figure 1 Individual-Level Peer Influence

Methods(cont.)

Agent-based Model (ABM)

Simulation setup

- Population: 500 males, 500 females
- Initial prevalence and α, μ from referenced ODE model [1]
- Network: 10 fixed companions (6 same-gender + 4 other)
- Time step: Δt = 1/120 year, total T = 5 years (600 ticks)

Behavioral rules

- Self-initiation：start smoking with probability α_m, α_f
- Peer imitation：start smoking with probability κ_m, κ_f
- Cessation rate: quit smoking with probability μ_m, μ_f

Calibration

- Objective: minimize average total error
- Search: random search

Random Search Procedure for Estimating Optimal κ

Repeat the process for N=1000 iterations:

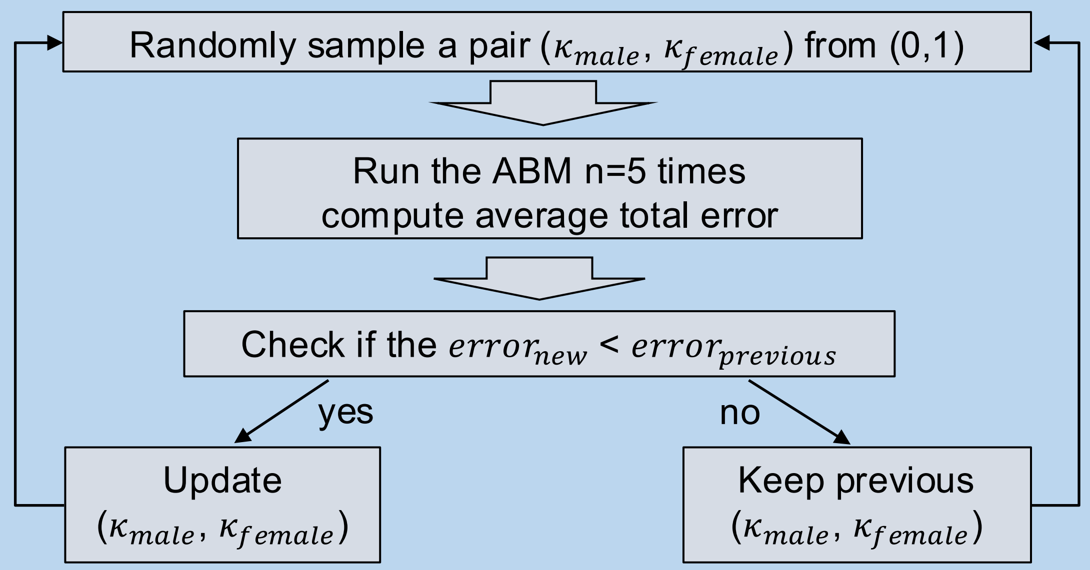

Figure 2 Individual-Level Peer Influence

Where average total error is:

$$error(\kappa) = \sum_{t=1}^{5}[s_{true}^{female} - s_{sim}^{female}(t)]^2 + \sum_{t=1}^{5}[s_{true}^{male} - s_{sim}^{male}(t)]^2$$

Results

- Male imitation probability consistently higher than female.
- Estimates are relatively stable over time, suggesting persistent gender differences in peer contagion strength.

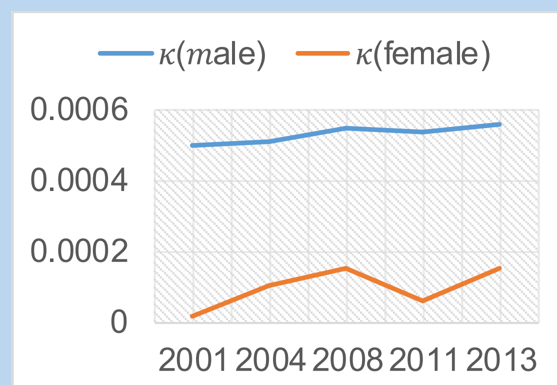

Figure 3 Estimated κ by Gender

Calibration Theory

Considering the average total error, we focus on on the male term for simplicity:

$$error_{male}(\kappa) = \sum_{t=1}^{5}[s_{true}^{male} - s_{sim}^{male}(t)]^2$$

We analyze the deterministic mean-field trajectory, i.e.

$$s(t) = \lim_{N\to\infty} \mathbb{E}[s_{sim}(t)]$$

Taking the first derivative of error with respect to κ:

$$\frac{\partial\, error_{male}}{\partial\kappa} = -2\sum_{t=1}^{5}[s_{true} - s(t)] \cdot \frac{\partial\, s(t)}{\partial\kappa}$$

Recursive Formula for s(t):

$$s(t+1) = s(t) + [\alpha + \kappa \cdot f_t] \cdot (1 - s(t)) \cdot \Delta t - \mu \cdot s(t) \cdot \Delta t$$

Where f_t represent the number of smokers in companions, $0 < f_t < 10$.

Taking the first derivative with respect to κ:

$$s'(t+1) = A_t s'(t) + f_t(1 - s(t))\Delta t + \kappa(1 - s(t))\Delta t \cdot \sum_{j=0}^{t}\frac{\partial\, f_t}{\partial s(j)} \cdot \frac{\partial\, s(j)}{\partial\kappa}$$

Where $A_t = 1 - (\alpha + \kappa f_t)\Delta t - \mu\Delta t$, $A_t > 0$ for small κ. $\frac{\partial\, f_t}{\partial s(j)} > 0$.

Since $s'(0) = 0$, $s'(1) > 0$, we have $s'(t) > 0$ by induction.

Taking the second derivative with respect to κ:

$$\frac{\partial^2 error_{male}}{\partial^2\kappa} = 2\sum_{t=1}^{T}[(s'(t))^2 - (s_{true} - s(t)) \cdot s''(t)]$$

Under the iterative calibration scheme, the objective function is minimized. Hence, in a neighborhood of the optimal κ, the residuals are small:

$$s_{true} - s(t) \approx 0 \quad small$$

i.e.

$$\sum_{t=1}^{T}((s'(t))^2) > \sum_{t=1}^{T}((s_{true} - s(t)) \cdot s''(t)$$

Hence,

$$\frac{\partial^2 error_{male}}{\partial^2\kappa} > 0$$

implying that the objective function is locally strictly convex in κ, and therefore the optimal parameter is locally unique.

Contribution

- Translate aggregate peer effects into an individual-level network mechanism.
- Provides theoretical guarantees for parameter optimality while preserving mathematical tractability in ABM.
- Provide a foundation for studying heterogeneous network effects in peer-driven behaviors.