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Dynamic, Multi-Product Population Health Modeling for Tobacco Policy Analysis

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A Changing Landscape

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electronic cigarettes

dissolvable tobacco

traditional cigarettes

ban of flavored cigarettes

graphic warning labels

New products, changing demographics, and policies necessitate new population health models

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Modeling Needs

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- Multiple products
- Expand possible transition behaviors: switching, poly-use, etc.
- Flexibility:
  - Different products
  - Different risk interactions
  - Single or multi-cohort
- Dynamics
  - Impacts may take time to be realized
  - Conclusions may vary, depending on analysis time period

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A Conceptual Model

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- Population consists of individuals that vary by state attributes
  - Age
  - Sex
  - Tobacco product use: never/current/former user status for each product considered
- Markov model of state transition and death
  - Tobacco use transition and death are stochastic processes
  - Probability of transition depends only upon current state
- Population size varies due to births, deaths, and migration
- Some basic assumptions
  - State can change once per year
  - Current and former users cannot transition to never

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Input Parameter Groups

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- Initial population
  - State distribution at time 0
- Transition probabilities
  - Initiation, cessation, switching, and relapse
  - Depend upon state
  - Need to think about transition in terms of multiple products
- Relative risks (RR) vary by state
  - All cause or cause-specific

$$RR\left(age = a_1, sex = g_1, tobacco\ use = u_1\right) = \frac{prob\left(dying \mid age = a_1, sex = g_1, tobacco\ use = u_1\right)}{prob\left(dying \mid age = a_1, sex = g_1, tobacco\ use = never\ for\ all\ products\right)}$$

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Tobacco Use Transitions: 1 Product

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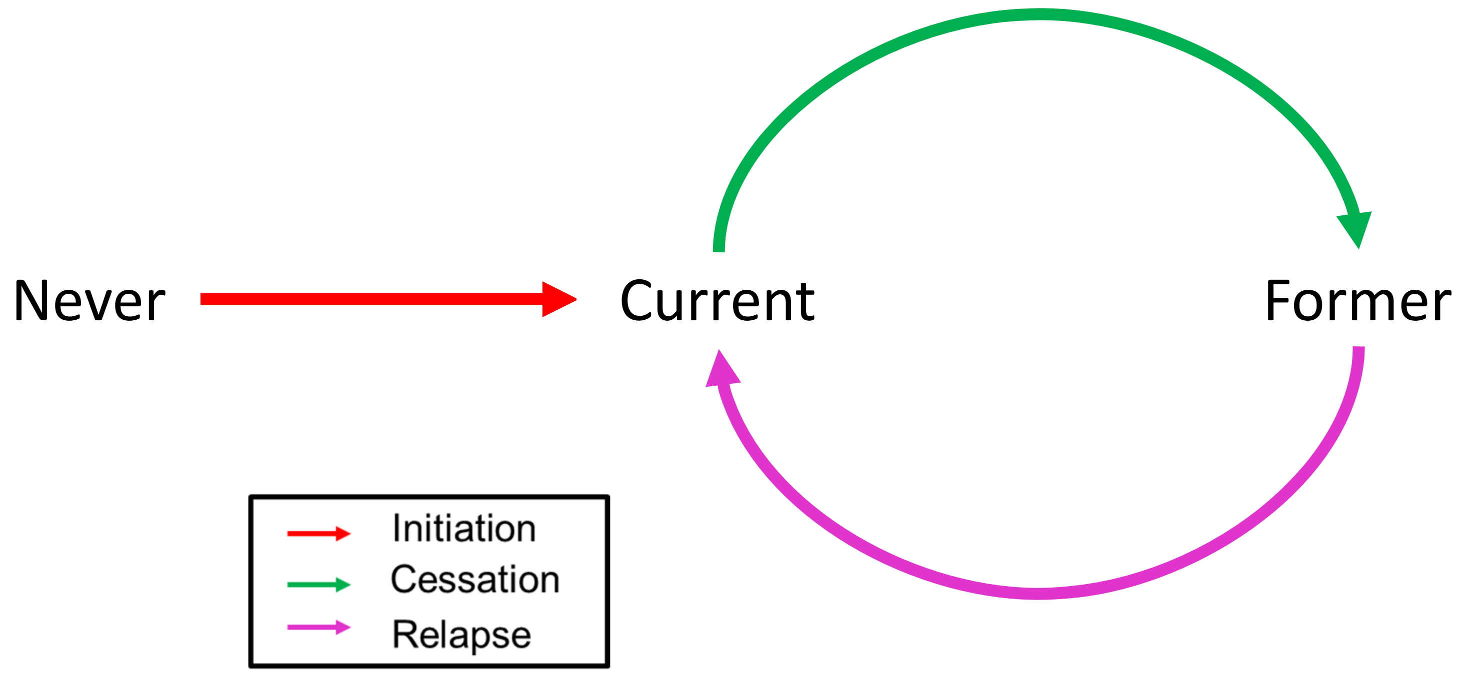

3 tobacco use statuses & 3 transitions

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Tobacco Use Transitions: 2 Products

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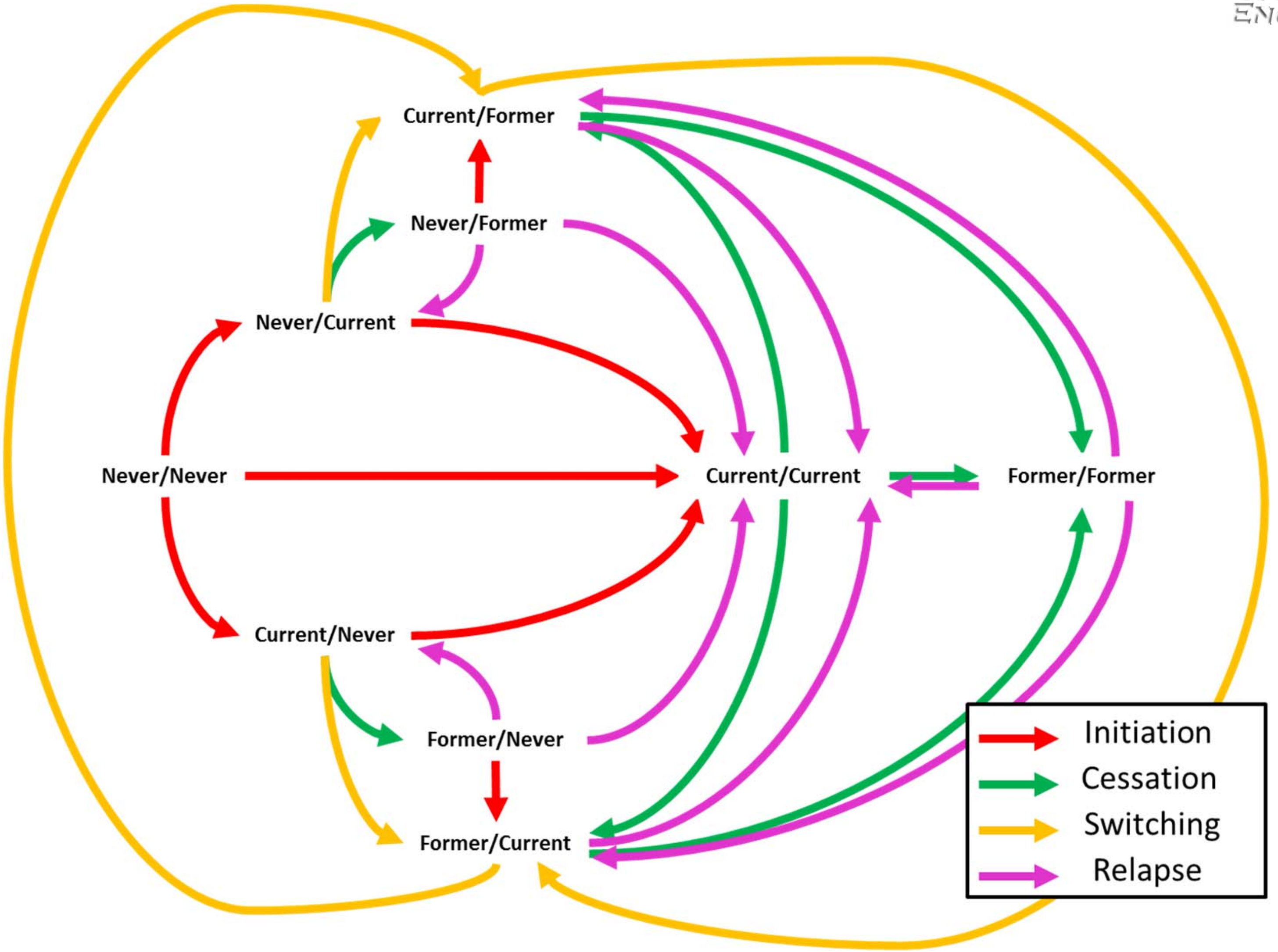

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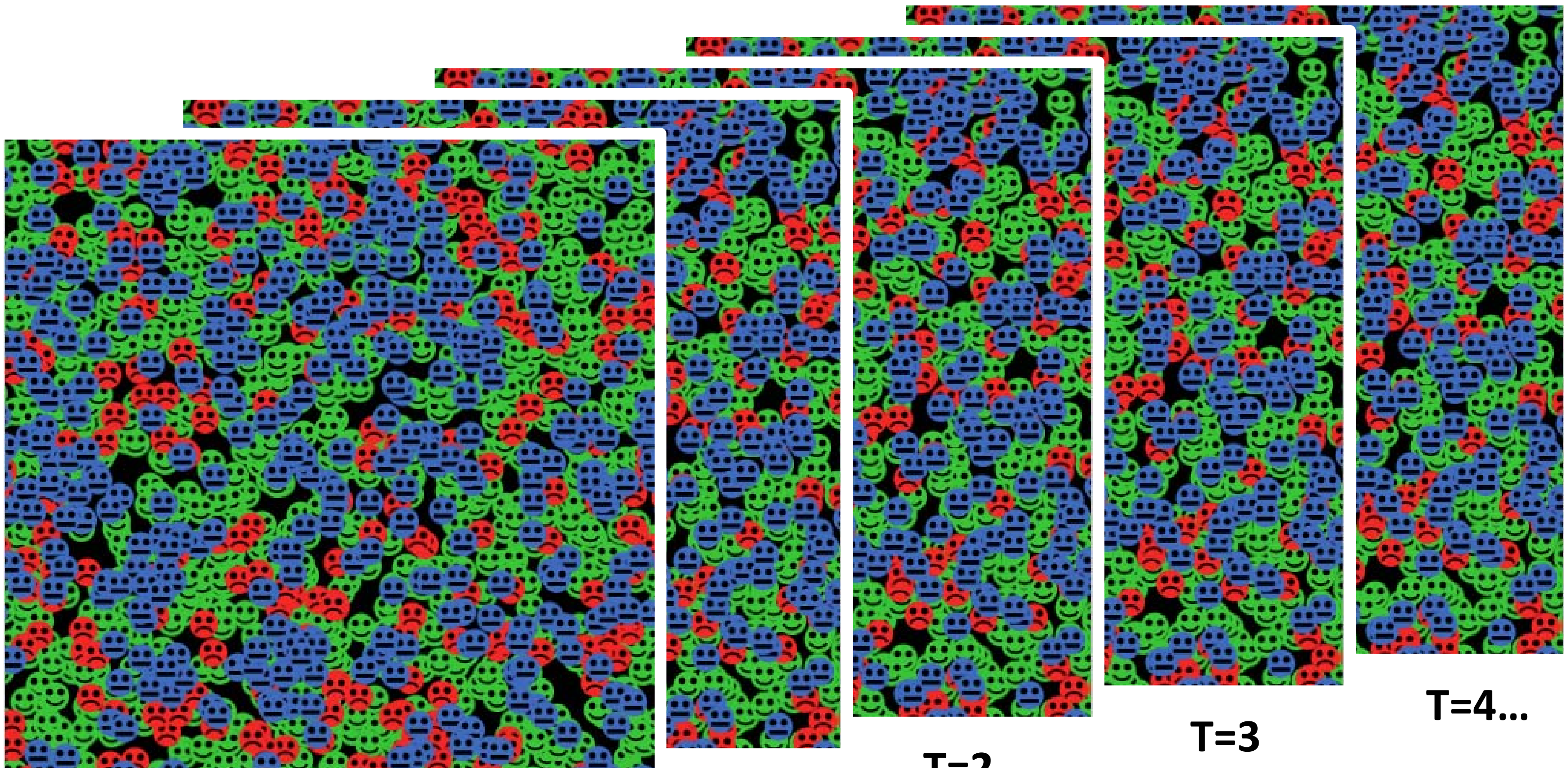
9 tobacco use combinations & 27 transitions

Numerical Implementations: 2 Options

- Standard Markov formulation
  - Explicit representation of stochastic events
  - "Agent-based"/microsimulation formulation



Numerical Implementations: 2 Options

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- Dynamical systems: probabilities represent mean rate of transition

Average # of people that transition & don't die

$$pop_{s_j}(t_{k+1}) = \sum_i prob_{s_i \to s_j}(t_k)\left[1 - prob\left(dying \middle| s_j\right)\right] pop_{s_i}(t_k)$$

$$+ m_{s_j}(t_{k+1}) + b_{s_j}(t_{k+1})$$

Immigration

Births

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Numerical Implementations: 2 Options

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- Dynamical systems: probabilities represent mean rate of transition

Immigration Vector

$$Pop\left(t_{k+1}\right) = A\left(t_k\right) Pop\left(t_k\right) + M\left(t_{k+1}\right) + B\left(t_{k+1}\right)$$

State Transition Matrix

Birth Vector

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An Illustrative Analysis

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- Initial population designed to represent U.S. 2000 demographics (age, sex, cigarette usage)
- Year 3: introduction of a lower risk, hypothetical new tobacco product
  - Excess relative risk (ERR)=0.25 x cigarette ERR)
- Switching and poly-use
  - Switching (0.03-0.05 annual proportion of current smokers)
  - Poly-use transition (smoking to smoking + new product; 0.005 annually)
- Alternative product initiation
  - Non-smokers may take up alternative (0.25x smoking initiation rate)
  - Alternative users may switch to cigarettes or become poly-users (0.05 annual rate)

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Four Scenarios

- Baseline
  - No new tobacco product
- Impacts to current smokers
  - Allow current smokers to switch or become poly-users
  - No new product initiation among never smokers
- Impacts to never smokers ○○○
  - Never smokers may initiate and switch to smoking or become poly-users
  - No switching or poly-use from current smokers
- Overall Impact ◊◊◊
  - All impacts included

Adult Smoking Prevalence

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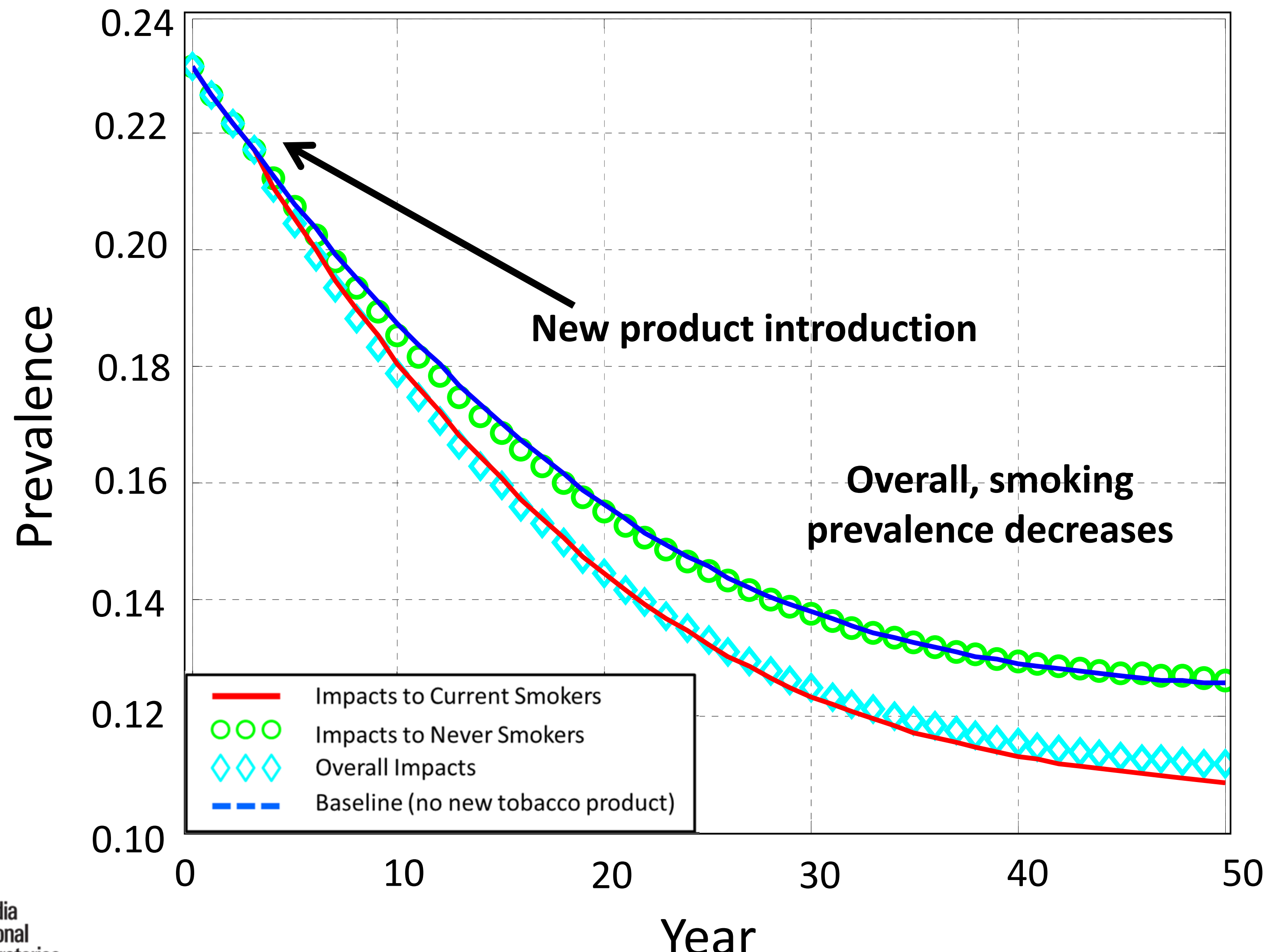

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Change in Deaths, ages 35-84 (relative to baseline)

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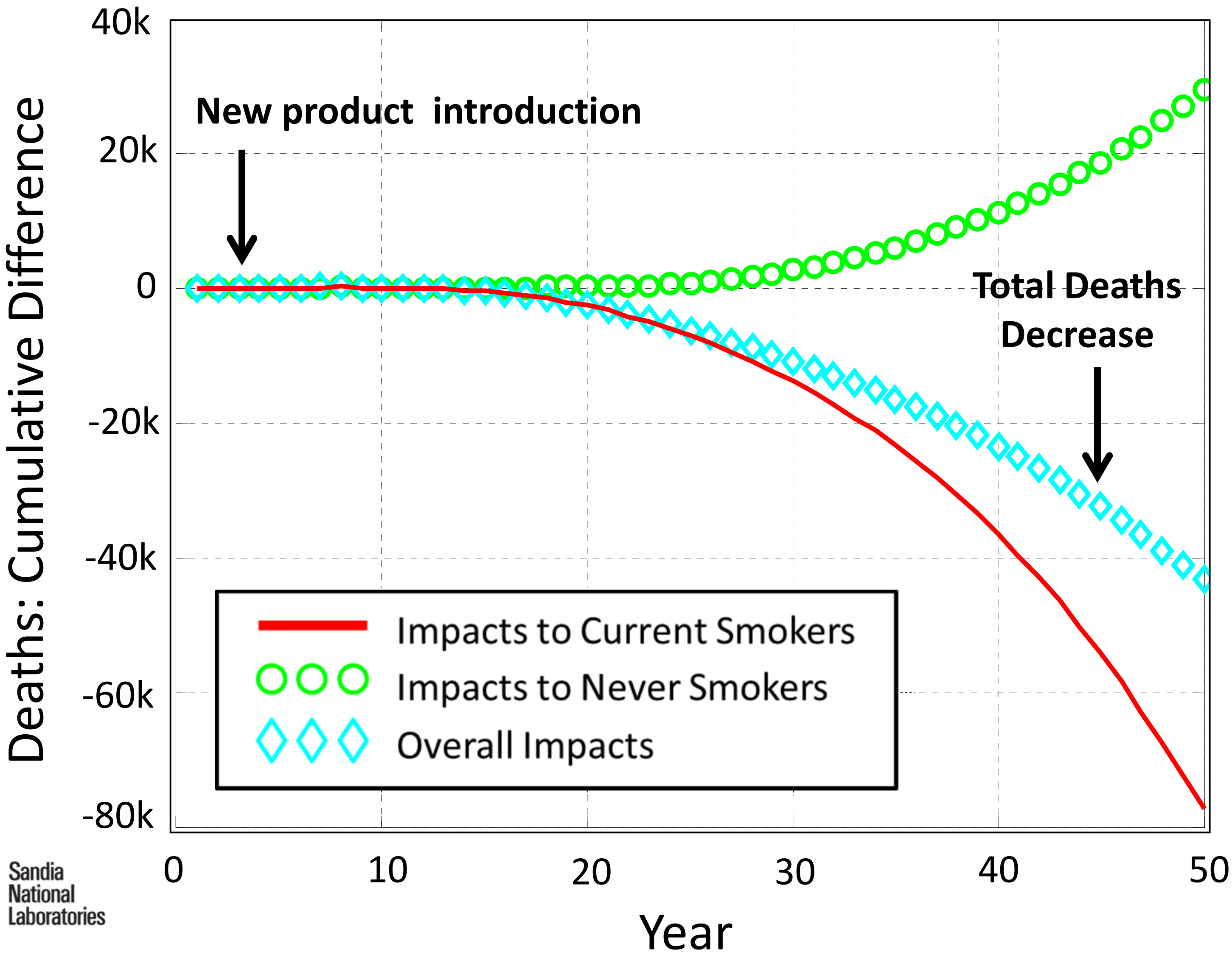

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Adult Prevalence: All Product Use

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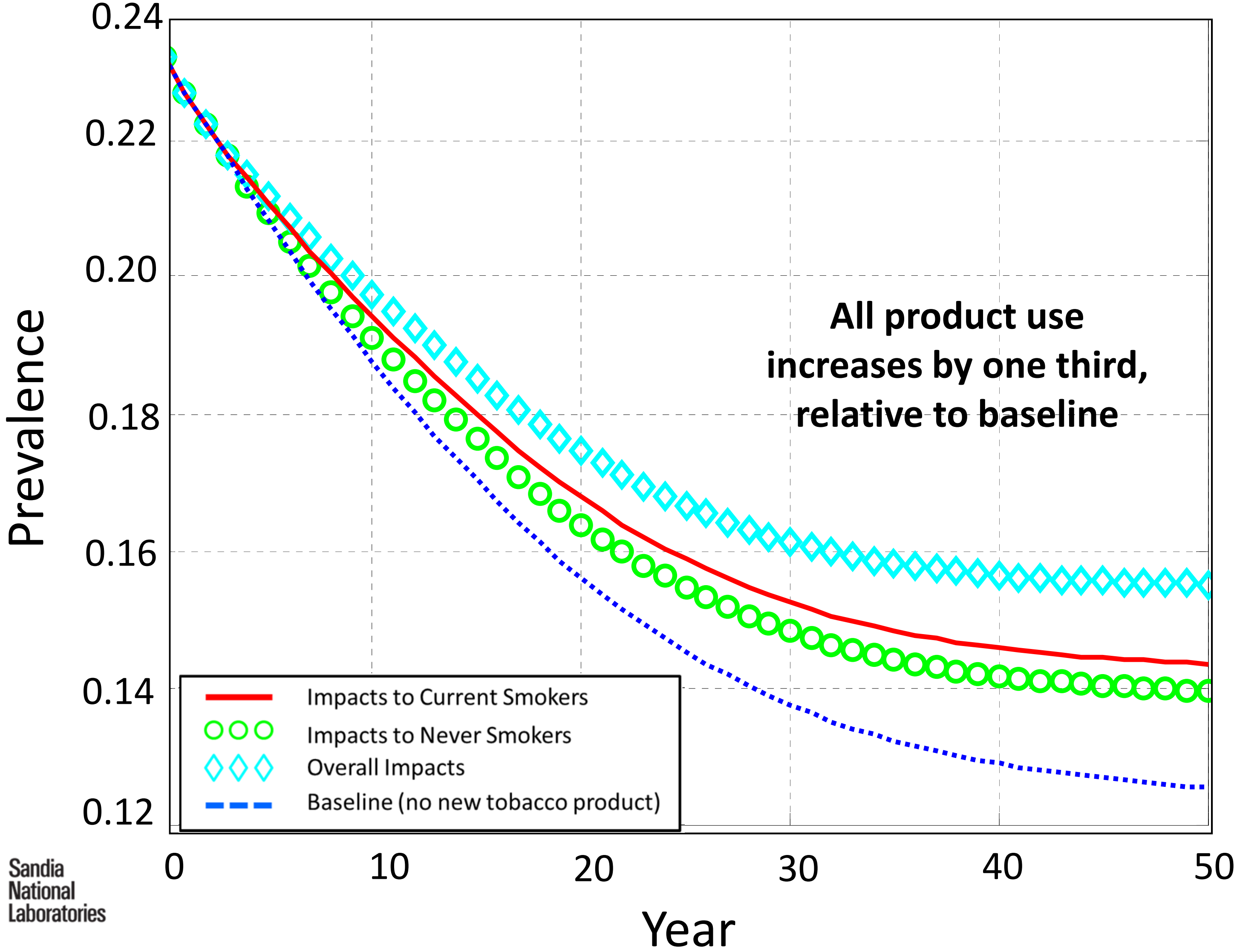

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Uncertainty

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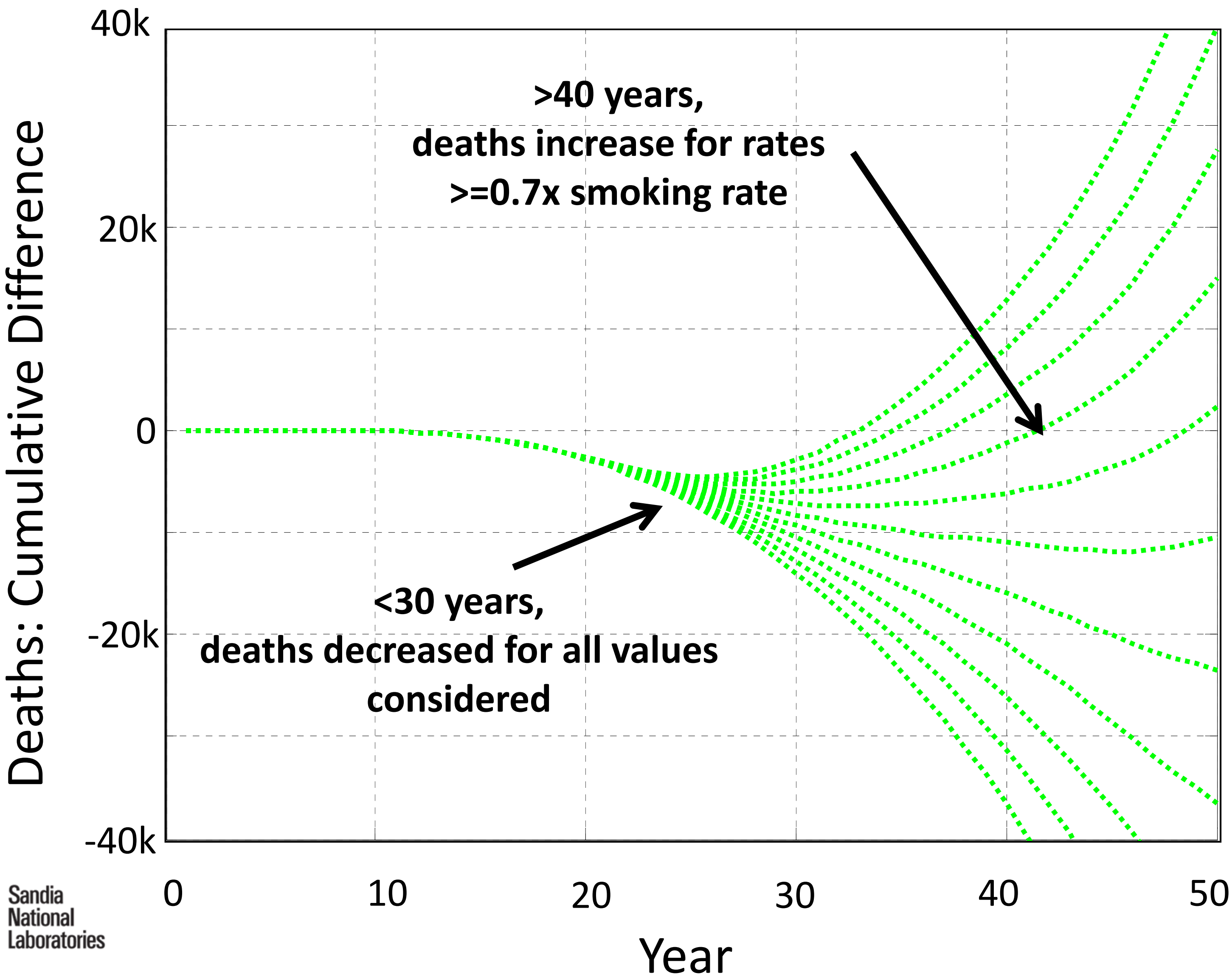
- We do not really know exact parameters for future products
  - Previous results have not accounted for parameter uncertainty
- Including uncertainty
  - Single parameter sweep
  - Multiple variables (Latin hypercube design)

Change in Deaths, ages 35-84 (relative to baseline): New Product initiation rate= [0,1] xcigarette initiation



Uncertain Parameters for Monte Carlo Simulation

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Parameter Description	**Base Value**	**Distribution Range***	**Variable**	**Implementation in Model****
New Product Excess Relative Risk (ERR) Factor	0.25	[0.01,0.50]	α	Product 2 ERR = α*ERR for cigarettes
Rate of switching from cigarettes to new product	0.03	[0.01,0.05]	β	$g_{rate}(3) = \beta + 0.02$ $g_{rate}(4^+) = \beta$
Smoker to dual user transition rate	0.005	[0.001,0.1]	φ	$j_{rate}(3^+) = \varphi$
Fraction of switchers coming from "would-be" quitters	0.5	[0,1]	χ	$f_{rate}(3) = f_{rate}(0) - \chi \times (\beta + 0.02)$ $f_{rate}(4^+) = f_{rate}(0) - \chi \times \beta$
New product initiation rate scaling factor	0.25	[0,0.75]	δ	$a_{rate}(3^+) = (1-\gamma) \times \delta \times b_{rate}(0)$ $e_{rate}(3^+) = \gamma \times \delta \times b_{rate}(0)$
Fraction of new product initiates that are dual users	0	[0,0.75]	γ	
Fraction of new product initiates that would otherwise initiate cigarettes	0.5	[0,1]	ε	$b_{rate}(3^+) = (1 - \varepsilon \times \delta) \times b_{rate}(0)$
Rate of switching from new product to cigarettes (gateway effect)	0.05	[0,0.1]	ϕ	$c_{rate}(3^+) = \phi$
New product user to dual user transition rate	0.05	[0,0.1]	η	$i_{rate}(3^+) = \eta$

*All distributions are assumed to be uniform.

**The notation $x_{rate}(y)$ is used to denote the rate for transition *x* (from Figure 1) in year *y*.

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Change in Deaths, ages 35-84 (relative to baseline): Multivariate Monte Carlo with LHS Design

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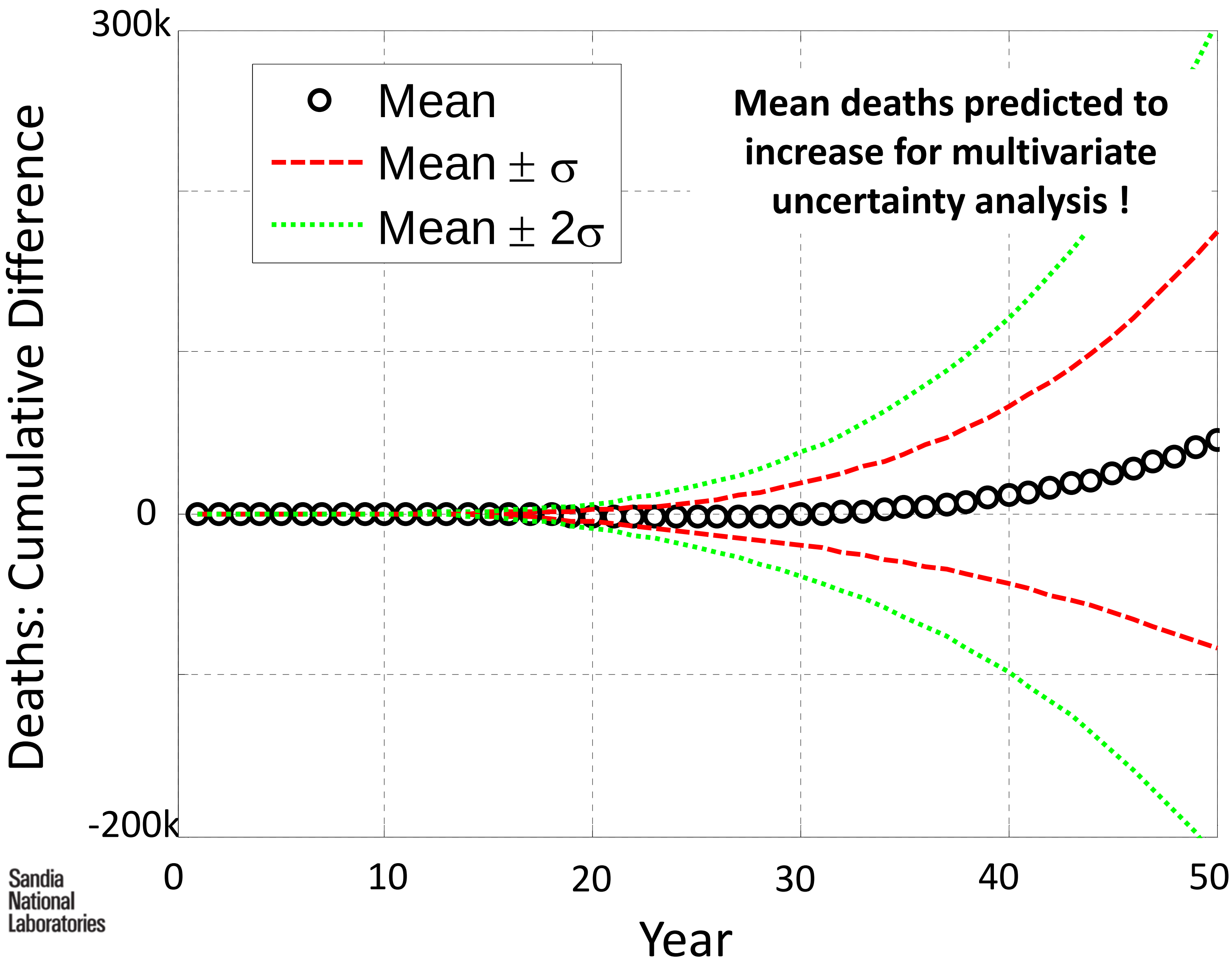

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Summary and Next Steps

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- Multi-product models are needed to assess policy in a changing marketplace
- Previous cigarette-centric models provide a nice "springboard" for multi-product model development
- The approach presented provides a flexible framework for multi-product analysis
- Future challenges
  - Need a "multi-product mindset"
  - Data challenges

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