Dynamic Population Health Modeling for Multi-Product Tobacco Environment

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Outline

- Motivation
- Model Description
- Single Product Simulation
- Hypothetical Two Product Simulation
- Summary
A Changing Landscape

New products, changing demographics and policies necessitate new health models

- Electronic cigarettes
- Traditional cigarettes
- Smokeless tobacco
- Ban on flavored cigarettes
- Graphic warning labels

Family Smoking Prevention and Tobacco Control Act

WARNING: Cigarettes cause fatal lung disease.
Modeling Needs

- Multiple tobacco products
- Expand transition behaviors: switching, poly-use, etc.
- Flexibility to represent different products and risk models
- Temporal dynamics
  - Impacts may take time to be realized
  - Conclusions can vary depending on analysis time period
Model Framework

- Population consists of individuals that vary by state attributes
  - Age
  - Sex
  - Tobacco product use state for each product: never/current/former

- Markov model of state transition and death
  - Tobacco use transition and death are Markov processes
  - Probability of transition depends only upon current state

- Population size varies due to births, deaths, and net international migration

- Total population model can be represented as a time-variant, linear system of equations

\[
\text{Pop}(t_{k+1}) = A(t_k) \text{Pop}(t_k) + M(t_{k+1}) + B(t_{k+1})
\]
Key Model Input and Output Groups

**Inputs:**

- Initial population: distribution across states at time 0
- Net international migration, birth and never user death rates
- All-cause mortality risks, relative to never use
- Transition probabilities:
  - Initiation
  - Cessation
  - Switching
  - Relapse

**Outputs:**

- Prevalence
- Mortality
- Life years lived

By demographic and product use subgroups

- Sex, age and multi-product use state

Input parameters are specified by

- Sex, age and multi-product use state
Intended Model Use

- **Single scenario analysis** – project changes to population over time
  - Status quo baseline
    - Project changes in population where there is no change in model parameters from the start
  - Project possible “what if” futures

- **Multiple scenario analysis** – compare target scenario(s) projection(s) to baseline scenario
  - Side-by-side output comparison
  - Difference between scenario and baseline
    - Changes in mortality
Tobacco Use Transitions: 1 Product

3 tobacco use states & 3 transitions
Tobacco Use Transitions: 2 Products

9 tobacco use combinations & 27 transitions
Single Product Model Inputs

Demographic:
- Initial population by sex, age, and smoking status - (U.S. Census, NHIS)
- Birth rate - (U.S. Census)
- Net international migration rate - (U.S. Census)
- Immigrant smoking prevalence - (NHIS)

Smoking Initiation and Cessation Rates:
- Sex- and age-specific initiation and cessation rates based on reconstructions of cohort smoking histories from NHIS
  - Generated by NCI-funded Cancer Intervention and Surveillance Modeling Network (CISNET) Lung Working Group.
  - See Feuer et al (2012) for detail on methodology

Death Rates and Relative Risks:
- Never smoker death rates
  - Based on data from U.S. Vital Statistics (under age 35) and NHIS-Linked Mortality Files (ages 35+)
  - Projected future decline in age-specific death rates based on Lee-Carter mortality projection
- Relative risk by sex, age, smoking status, and age at cessation based on NHIS-LMF
Single-Product Model Validation: Comparison with Observed Data

Adult Cigarette Smoking Prevalence

Prevalence

Time

Model

CDC 2000-2012
An Illustrative Two-Product Scenario Analysis

- Initial population uses 2000 U.S. demographics with cigarettes only
- Introduction of a lower risk, hypothetical new tobacco product in Year 3
  - Hypothetical new product has excess relative risk (ERR) = 0.25 x cigarette ERR
  - Hypothetical new product initiation*
    - Never smokers may take up alternative (0.5 x smoking initiation rate)
    - Hypothetical new product users may switch to cigarettes or become poly-users (0.05 annual rate)
      *Only allowed for individuals under age 30.
  - Smokers taking up hypothetical new product (0.03 annual rate)
    - Half switch completely
    - Half become dual users

*These scenarios were created using hypothetical values to demonstrate the functionality of the model. No policy purpose or outcome should be inferred.
Adult Cigarette Smoking Prevalence

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Adult Prevalence: Total Product Use

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Scenario Legend

- **Baseline**
  - No new tobacco product

- **Multi-Product Scenario**
  - 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
Annual Change in Deaths due to Alternative Product Use

Note: trend is changing due to initiation among never smokers

New product introduction

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Annual Change in Deaths due to Alternative Product Use

Overall impact initially decreases due to switching but eventually exceeds baseline level due to new product initiation.

New product introduction

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Uncertainty

- We do not know exact parameters for future products
  - Previous results have not accounted for parameter uncertainty

- Including uncertainty
  - Single parameter sweep
  - Multiple variables (Latin hypercube design)
Sensitivity Analysis

Analyze effect of one or more uncertain inputs on output values*

Change one or more inputs at once

How does output change when one or more inputs change?

Plot shows effect of simultaneous change in many inputs on one output

Model

*All other parameters are held at fixed values.
Uncertainty Analysis Process

1. Design experiment
2. Start multi-run scenario
3. Repeat many times:
   - Generate set of input parameters
   - Use identical initial population
   - Project population change in time
   - Write results to output file
4. End multi-run scenario
5. Analyze data file
6. Interpret results
Change in Deaths: Cigarette-to-New Product Annual Switching Rate

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Change in Deaths: 
New Product Excess Relative Risk

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## Hypothetical Parameter Values and Ranges for Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Parameter Description*</th>
<th>Base Value</th>
<th>Distribution Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Health Risk of the New Product</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New product excess relative risk (RR-1) factor - $E_{RR_factor}$</td>
<td>0.25</td>
<td>(0.01, 0.5)</td>
</tr>
<tr>
<td><strong>Impact on Current Smokers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual proportion switching from cigarettes to new product</td>
<td>0.015</td>
<td>(0, 0.03)</td>
</tr>
<tr>
<td>Annual proportion transitioning from cigarettes only to dual use</td>
<td>0.015</td>
<td>(0, 0.03)</td>
</tr>
<tr>
<td>Proportion of switchers and new dual users who would have otherwise quit smoking that year</td>
<td>0.25</td>
<td>(0, 0.5)</td>
</tr>
<tr>
<td><strong>Impact on Never Smokers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New product initiation rate scaling factor</td>
<td>0.5</td>
<td>(0.25, 0.75)</td>
</tr>
<tr>
<td>Proportion of new product initiates that would have otherwise initiated cigarettes</td>
<td>0.5</td>
<td>(0.25, 0.75)</td>
</tr>
<tr>
<td>Annual proportion switching from new product to cigarettes</td>
<td>0.05</td>
<td>(0, 0.1)</td>
</tr>
<tr>
<td>Annual proportion transitioning from new product to dual use</td>
<td>0.05</td>
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Change in Deaths: Multivariate Monte Carlo with LHS Design

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Summary

- Multi-product models are needed to assess a changing marketplace
- Previous cigarette-centric models provide an effective technical foundation for multi-product model development
- Our approach provides a flexible framework for multi-product analysis
- Future challenges
  - Need to shift focus to multi-product analyses – reflecting current market conditions
  - Data challenges: data needs increase exponentially
    - Multi-product transitions
    - Cause-specific mortality
    - Morbidity
Questions