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

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A Changing Landscape

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

- 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
A Conceptual Model

- 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
Input Parameter Groups

- 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

\[
RR \left( \text{age} = a_1, \text{sex} = g_1, \text{tobacco use} = u_1 \right)
= \frac{\prob \left( \text{dying} \mid \text{age} = a_1, \text{sex} = g_1, \text{tobacco use} = u_1 \right)}{\prob \left( \text{dying} \mid \text{age} = a_1, \text{sex} = g_1, \text{tobacco use} = \text{never for all products} \right)}
\]
Tobacco Use Transitions: 1 Product

Never → Current → Former

- Red: Initiation
- Green: Cessation
- Purple: Relapse

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

9 tobacco use combinations & 27 transitions

- Initiation
- Cessation
- Switching
- Relapse
Numerical Implementations: 2 Options

- Standard Markov formulation
  - Explicit representation of stochastic events
  - “Agent-based”/microsimulation formulation
Numerical Implementations: 2 Options

- Dynamical systems: probabilities represent mean rate of transition

\[
\text{Average # of people that transition & don’t die}
\]

\[
pop_{s_j}(t_{k+1}) = \sum_i \text{prob}_{s_i \rightarrow s_j}(t_k) \left[ 1 - \text{prob}(\text{dying}|s_j) \right] \text{pop}_{s_i}(t_k) + m_{s_j}(t_{k+1}) + b_{s_j}(t_{k+1})
\]

- Immigration
- Births
Numerical Implementations: 2 Options

- Dynamical systems: probabilities represent mean rate of transition

\[
Pop(t_{k+1}) = A(t_k) \cdot Pop(t_k) + M(t_{k+1}) + B(t_{k+1})
\]

- Immigration Vector
- State Transition Matrix
- Birth Vector
An Illustrative Analysis

- 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)
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
Overall, smoking prevalence decreases.

New product introduction.
Change in Deaths, ages 35-84 (relative to baseline)
Adult Prevalence: All Product Use

All product use increases by one third, relative to baseline.
Uncertainty

- 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] x cigarette initiation

>40 years, deaths increase for rates >= 0.7x smoking rate

<30 years, deaths decreased for all values considered
### Uncertain Parameters for Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Base Value</th>
<th>Distribution Range*</th>
<th>Variable</th>
<th>Implementation in Model**</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Product Excess Relative Risk (ERR) Factor</td>
<td>0.25</td>
<td>[0.01,0.50]</td>
<td>$\alpha$</td>
<td>Product 2 ERR = $\alpha$*ERR for cigarettes</td>
</tr>
<tr>
<td>Rate of switching from cigarettes to new product</td>
<td>0.03</td>
<td>[0.01,0.05]</td>
<td>$\beta$</td>
<td>$g_{rate} (3) = \beta + 0.02$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$g_{rate} (4^+) = \beta$</td>
</tr>
<tr>
<td>Smoker to dual user transition rate</td>
<td>0.005</td>
<td>[0.001,0.1]</td>
<td>$\phi$</td>
<td>$j_{rate} (3^+) = \phi$</td>
</tr>
<tr>
<td>Fraction of switchers coming from “would-be” quitters</td>
<td>0.5</td>
<td>[0.1]</td>
<td>$\chi$</td>
<td>$f_{rate} (3) = f_{rate} (0) - \chi \times (\beta + 0.02)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$f_{rate} (4^+) = f_{rate} (0) - \chi \times \beta$</td>
</tr>
<tr>
<td>New product initiation rate scaling factor</td>
<td>0.25</td>
<td>[0.0,0.75]</td>
<td>$\delta$</td>
<td>$a_{rate} (3^+) = (1 - \gamma) \times \delta \times b_{rate} (0)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$e_{rate} (3^+) = \gamma \times \delta \times b_{rate} (0)$</td>
</tr>
<tr>
<td>Fraction of new product initiates that are dual users</td>
<td>0</td>
<td>[0.0,0.75]</td>
<td>$\gamma$</td>
<td>$b_{rate} (3^+) = (1 - \varepsilon \times \delta) \times b_{rate} (0)$</td>
</tr>
<tr>
<td>Fraction of new product initiates that would otherwise initiate cigarettes</td>
<td>0.5</td>
<td>[0.1]</td>
<td>$\varepsilon$</td>
<td>$c_{rate} (3^+) = \phi$</td>
</tr>
<tr>
<td>Rate of switching from new product to cigarettes (gateway effect)</td>
<td>0.05</td>
<td>[0.0,0.1]</td>
<td>$\phi$</td>
<td>$c_{rate} (3^+) = \phi$</td>
</tr>
<tr>
<td>New product user to dual user transition rate</td>
<td>0.05</td>
<td>[0.0,0.1]</td>
<td>$\eta$</td>
<td>$i_{rate} (3^+) = \eta$</td>
</tr>
</tbody>
</table>

*All distributions are assumed to be uniform.  
**The notation $\chi_{rate} (y)$ is used to denote the rate for transition $x$ (from Figure 1) in year $y$. 

\[ g_{rate} (3) = \beta + 0.02 \]
\[ g_{rate} (4^+) = \beta \]
\[ j_{rate} (3^+) = \phi \]
\[ f_{rate} (3) = f_{rate} (0) - \chi \times (\beta + 0.02) \]
\[ f_{rate} (4^+) = f_{rate} (0) - \chi \times \beta \]
\[ a_{rate} (3^+) = (1 - \gamma) \times \delta \times b_{rate} (0) \]
\[ e_{rate} (3^+) = \gamma \times \delta \times b_{rate} (0) \]
\[ b_{rate} (3^+) = (1 - \varepsilon \times \delta) \times b_{rate} (0) \]
Change in Deaths, ages 35-84 (relative to baseline): Multivariate Monte Carlo with LHS Design

Mean deaths predicted to increase for multivariate uncertainty analysis!
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