Computational Models in Tobacco Control

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Acknowledgment

Many thanks to Dr. David Levy, from Georgetown University for providing slides about the SimSmoke model,
and to Dr. Rafael Meza, from the University of Michigan for providing the slides about the CISNET models.
Why Model?

◆ To fully understand the problem
  • Models provide a coherent framework to analyze a situation and integrate different data sets
◆ To monitor and forecast
◆ To evaluate the consequences of policies
◆ To guide data collection
Example of questions that models can help to address

◆ If current conditions continue, what is the likely trajectory of smoking prevalence?

◆ If we fully implement all the tobacco control measures known to be effective, what is the likely trajectory of the smoking prevalence?
Example of questions that models can help to address

◆ What would be the population health impact of removing menthol cigarettes from the market?

◆ What would be the consequences of increasing the minimum purchasing age for tobacco products?
Example of questions that models can help to address

- What would be the impact of reducing nicotine in combustible tobacco products to non-addictive levels?

- What is the estimated impact of tobacco control policies on avoided mortality?
Michigan Model of Smoking Prevalence and Health Effects
Smokers in the Population

Age 0 to 17 | Age 18 | Age > 18
---|---|---
Never Smoker | Current Smoker | Former Smoker

- Green circles represent Never Smokers.
- Red circles represent Current Smokers.
- Yellow circles represent Former Smokers.
Basic Aggregate Model

- Children
- Smoking at age 18?
- Adult Current Smokers
- Adult Never Smokers
- Cumulative Deaths
- Former Smokers'
  Death Rate
- Current Smokers'
  Death Rate
- Never Smokers'
  Death Rate
- Quit Smoking?
- Smoking Initiation Rate
- Smoking Cessation Rate
- Birth Rate
Building Confidence on the Model

- Fitting the model to observed data
- Comparing predictions with observed data
Observed vs Predicted Smoking Prevalence
All Ages

Year
Prevalence [%]

Forecasted Overall Smoking Prevalence by Different Peak Prevalence at 18
Observed vs. Predicted Adult Smoking Prevalence in the US

Mendez and Warner, *AJPH*, 2004
Adult Smoking Prevalence

<table>
<thead>
<tr>
<th>Year</th>
<th>Observed Prevalence</th>
<th>Predicted Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>23%</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>11%</td>
<td></td>
</tr>
</tbody>
</table>
Including Health Effects

- Relative Risks derived from the Cancer Prevention Study II (CPS II) data
Female relative risk of death, current and former smokers, by age and smoking status

Relative Risk

Age

Never Smokers
Former Smokers
Current Smokers
Male relative risk of death, current and former smokers, by age and smoking status
Compartment Model of Smoking Prevalence, Health Effects and Medical Costs

Inputs

- Policy Set $I_x$, $\lambda_x$, $\mu_x$
- Policy Set $I_0$, $\lambda_0$, $\mu_0$

Dynamics Model

- Age 0-17
- Age 18
- Age >18

Time

Outputs

- Survival Curve under Set $I_x$
- Survival Curve under Set $I_0$
- Comparison

Figure 1. Male relative risk of death, current and former smokers, by age and smoking status.
Example of Model Applications

- Assessing smoking prevalence targets
- Offering smoking cessation programs in managed care organizations
- Evaluating the impact of menthol cigarettes on population’s health
Example of Model Applications

- Evaluating the effectiveness of radon remediation under declining smoking rates

- Evaluating the effect of control policies on global smoking trends
Smoking Prevalence Targets
Even if the initiation rate goes down to zero, cessation rates would still need to increase more than 3-fold to achieve 13% prevalence in 2010.

If the initiation rate drops down to 15% by 2010, cessation rates would need to increase more than 4-fold to achieve a 13% adult prevalence in 2010.
Actual and projected adult cigarette smoking prevalence, United States, 2005 and 2010

<table>
<thead>
<tr>
<th>Source</th>
<th>Model calibrated through</th>
<th>Initial year of projection</th>
<th>2005 (%)</th>
<th>2010 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Health Interview Survey</td>
<td>NA</td>
<td>NA</td>
<td>20.9</td>
<td>19.3</td>
</tr>
<tr>
<td>Mendez and Warner [AJPH 2000], assuming continuation of 30% initiation rate</td>
<td>1995</td>
<td>2000</td>
<td>20.9</td>
<td>19.9</td>
</tr>
<tr>
<td>Mendez and Warner [AJPH 2000], assuming initiation rate declines from 30% to 15% from 2000-2010</td>
<td>1995</td>
<td>2000</td>
<td>20.5</td>
<td>18.4</td>
</tr>
</tbody>
</table>
Status Quo vs. Best Performance

What can the country achieve by emulating best performance?

Mendez & Warner, AJPH, 2008
Projections of U.S. adult smoking prevalence under status quo and California smoking initiation and cessation rates

Under very optimistic conditions, assuming CA initiation and cessation rates, the country will not achieve California’s current prevalence level of 14.7% until after the year 2020.
Impact of Menthol Cigarettes on the Population
## Input Parameters

### General Population

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>TPSAC Estimate</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of Menthol among Initiators</td>
<td>0.35</td>
<td>0.40</td>
<td>0.45</td>
</tr>
<tr>
<td>Proportion of Menthol among Experimenters ($K_4$)</td>
<td>0.38</td>
<td>0.45</td>
<td>0.60</td>
</tr>
<tr>
<td>Ratio of “Proportion of Menthol Experimenters that become Established Smokers” / “….Non-menthol…..” ($K_5$)</td>
<td>1.00</td>
<td>1.68</td>
<td>1.85</td>
</tr>
<tr>
<td>Cessation Rates Ratio (Menthol/Non-menthol)</td>
<td>0.92</td>
<td>0.95</td>
<td>1.10</td>
</tr>
<tr>
<td>Mortality Risk Ratio (Menthol/Non-menthol)</td>
<td>0.80</td>
<td>1.00</td>
<td>1.20</td>
</tr>
<tr>
<td>Switching Rate from Menthol to Non-menthol (among Menthol smokers)</td>
<td>0.9%</td>
<td>1.8%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Switching Rate from Non-menthol to Menthol (among Non-menthol smokers)</td>
<td>0.4%</td>
<td>0.8%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>
## Results for the General Population Model

### TPSAC Estimates

<table>
<thead>
<tr>
<th>General Population</th>
<th>TPSAC Estimates</th>
<th>Counterfactual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiation Age</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Initiation Rate</td>
<td>21.8%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Proportion of Menthol Initiation</td>
<td>40%</td>
<td>---</td>
</tr>
<tr>
<td>Proportion of Menthol Experimentation</td>
<td>45%</td>
<td>---</td>
</tr>
<tr>
<td>Experimentation to Initiation Ratio Menthol/Non-Menthol</td>
<td>1.68</td>
<td>---</td>
</tr>
<tr>
<td>Background Cessation Rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;= 30</td>
<td>0.21%</td>
<td>0.21%</td>
</tr>
<tr>
<td>31-49</td>
<td>2.15%</td>
<td>2.15%</td>
</tr>
<tr>
<td>50+</td>
<td>5.96%</td>
<td>5.96%</td>
</tr>
<tr>
<td>Cessation Ratio Menthol/Non-Menthol</td>
<td>0.95</td>
<td>---</td>
</tr>
<tr>
<td>Menthol Mortality Multiplier</td>
<td>1</td>
<td>---</td>
</tr>
<tr>
<td>Probability of switching to Menthol</td>
<td>0.8%</td>
<td>---</td>
</tr>
<tr>
<td>Probability of switching to Non-Menthol</td>
<td>1.8%</td>
<td>---</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPSAC - Adult Smoking Prevalence - Menthol</td>
<td>6.8%</td>
<td>5.5%</td>
<td>4.9%</td>
<td>4.6%</td>
<td>4.5%</td>
</tr>
<tr>
<td>TPSAC - Adult Smoking Prevalence - Non-Menthol</td>
<td>13.8%</td>
<td>10.5%</td>
<td>8.7%</td>
<td>8.0%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Counterfactual - Overall Adult Smoking Prevalence</td>
<td>20.4%</td>
<td>15.1%</td>
<td>11.9%</td>
<td>10.3%</td>
<td>9.7%</td>
</tr>
<tr>
<td>Cumulative Excess Deaths among Menthol Smokers</td>
<td>172,743</td>
<td>1,601,751</td>
<td>2,777,684</td>
<td>3,804,560</td>
<td>4,696,753</td>
</tr>
<tr>
<td>Cumulative Excess Deaths among Current Smokers</td>
<td>300</td>
<td>44,526</td>
<td>151,132</td>
<td>325,292</td>
<td>587,675</td>
</tr>
<tr>
<td>Cumulative Excess Deaths among Former Smokers</td>
<td>0</td>
<td>-16,797</td>
<td>-48,419</td>
<td>-76,392</td>
<td>-70,064</td>
</tr>
<tr>
<td>Cumulative Excess Deaths among Never Smokers</td>
<td>-300</td>
<td>-10,547</td>
<td>-34,897</td>
<td>-84,310</td>
<td>-190,047</td>
</tr>
<tr>
<td>Total Cumulative Excess Deaths</td>
<td>0</td>
<td>17,182</td>
<td>67,817</td>
<td>164,590</td>
<td>327,565</td>
</tr>
<tr>
<td>Cumulative Excess Smoking Initiation - Menthol</td>
<td>387,845</td>
<td>3,920,549</td>
<td>7,580,884</td>
<td>11,480,562</td>
<td>15,609,338</td>
</tr>
<tr>
<td>Cumulative Excess Smoking Initiation - Non-Menthol</td>
<td>-165,457</td>
<td>-1,632,015</td>
<td>-3,151,558</td>
<td>-4,770,461</td>
<td>-6,484,471</td>
</tr>
<tr>
<td>Total Cumulative Excess Smoking Initiation</td>
<td>222,388</td>
<td>2,288,534</td>
<td>4,429,326</td>
<td>6,710,101</td>
<td>9,124,867</td>
</tr>
</tbody>
</table>
Results from the Menthol Model

- If menthol cigarettes did not exist, an estimated 328,000 premature deaths and 9 million new smokers would be avoided over a 40 year period.
SimSmoke

- SimSmoke simulates the dynamics of smoking rates and smoking-attributed deaths in a State or Nation, and the effects of policies on those outcomes.

- Focus on tobacco control policies
  - Effects vary depending a) on the way the policy is implemented, b) by demographics
  - Dynamic, nonlinear and interactive effects of policies

- Compartmental (macro) model with smokers, ex-smokers and never smokers evolving through time by age and gender.

- Deterministic uni-causal model with sensitivity analysis
Models

Countries:
Albania, Argentina, Bangladesh, Brazil, China, Czech Republic, Egypt, Finland, France, Germany, Great Britain, India, Indonesia, Ireland, Italy, Japan, Korea, Malaysia, Mexico, Netherlands, Pakistan, Poland, Philippines, Taiwan, Russia, Spain, Sweden, Thailand, Turkey, Ukraine, US, Vietnam

States:
Arizona, Calif, Kentucky, Massachusetts, Minnesota, NY, Missouri
Basic Approach

Policy Changes
- Taxes
- Clean air laws
- Media Camp.
- Marketing Bans
- Warning labels
- Cessation Support
- Youth Access

Cigarette Use
- Norms, Attitudes, Opportunities
- Former and current smokers, relative risks

Smoking-Attributable Deaths
Total Mortality and by type:
- Lung cancer
- Other cancers
- Heart disease
- Stroke
- COPD
- MCH Outcomes
Basic Structure of Model

- Population model begins with initial year population (by age and gender) and moves through time (by year) with births and deaths (1st order discrete Markov process)

- Smoking model distinguishes population into never smokers, smokers, and ex-smokers and moves through time with initiation, cessation and relapse (Markov)

- Smoking-attributable deaths depend on death rates, smoking rates and relative risks from CPS-II

- Policy modules for each policy with interdependent effects on smoking rates
Smoking Model: Evolution of Smokers

Population → Not initiate → Never Smoker

Population → Initiation → Ever Smoker*

Ever Smoker* → Not quit → Current Smoker**

Ever Smoker* → Cessation (quit) → Relapse → Ex-Smoker

* Usually as smoked 100 cigarettes lifetime
** usually smoked some or all days
Policies based on FCTC MPOWER

- **Cigarette taxes** - through price
- **Smoke-Free Air Laws**
  - Worksite
  - Restaurant and bars
  - Other public places
- **Tobacco control/media campaigns**
- **Marketing Bans**
- **Health Warnings**
MPOWER policies (cont)

**Cessation Treatment**
- Availability of pharmacotherapy
- Cessation treatment access (hospital etc)
- Quitlines (and web-based treatment)
- Health care provider involvement (not in MPOWER)

**Youth access policies**

includes enforcement, and vending AND self-service bans

*Interactions of Publicity through media campaigns on health warnings and cessation treatment.*
Ireland Male Smoking Prevalence, 1998-2010

data, data, data
U.S. Model Validation: Actual Vs Predicted Per Capita US Consumption Vs Trend Line
Great Britain SimSmoke, Predicted vs Survey, 1999-2009

SimSmoke Male Prevalence 16+
SimSmoke Female Prevalence 16+
Male Prevalence Data ages 16+
Female Survey Data ages 16+
SimSmoke Projections Male and Female Smoking-Attributable Deaths 2010-2040
Status Quo vs. All MPOWER Policies
CISNET is a consortium of NCI-sponsored investigators that use statistical modeling to improve our understanding of cancer control interventions in prevention, screening, and treatment and their effects on population trends in incidence and mortality. These models can be used to guide public health research and priorities.

Learn more about CISNET in the following sections:

**About**
- Funding History & Goals
- Awarded Grants
- CISNET in the NCI Cancer Bulletin
- Organizational Structure
- Looking Towards the Future (PDF)

**Resources**
- Publications
- Publication Support & Modeling Resources

**CISNET Modeling Approach**
- Comparative Modeling
- Multi-cohort Simulation
- Standardized Model Documents

CISNET’s projects focus on the following five cancer sites:

- **Breast Cancer**
  Models include the impact of screening and the role of risk factors on breast cancer trends.

- **Colorectal Cancer**
  Models focus on the natural history of the disease and impact of interventions on mortality.

- **Esophagus Cancer**
  Models focus on the natural history of the disease including precursor states to assess screening and intervention programs.

- **Lung Cancer**
  Models include areas such as tobacco control policies, screening, and genetic susceptibility.

### Highlights

- **Tobacco Control and the Reduction in Smoking-Related Premature Deaths in the United States** (January 2014)
- **Benefits and Harms of Computed Tomography Lung Cancer Screening Strategies** (December 2013)
- **After Negative Colonoscopy, Rescreening with Other Tests May Be Effective** (Nov 2012)
- **Exploring Questions about Lung Cancer Screening** (Nov 2012)
- **Researchers Model Real-Life Benefits of Cancer Screening** (Nov 2012)
Data Sources

- NHIS
- SAMHSA
- NCHS
- CPS-I
- CPS-II
- Berkeley life-tables

Initiation

Cessation

Cigarettes Per Day

Other Cause Death

CPD, OCD

Initiation, Cessation

Simulate an Individual's Life

Create an Individual

Initiation Age, Cessation Age, OCD Age, Smoking History

All Individuals Simulated

Make Prevalence

IOM - Modeling Workshop, April 2015

Theodore R. Holford, Rafael Meza; Kenneth E. Warner, Clare Meernik, Jihyoun Jeon, Suresh H. Moolgavkar, David T. Levy

JAMA. 2014;311(2):164-171
Approach

- Reconstruct smoking experience in the US from 1864-2012
  - By gender, age, birth-cohort

- Simulate counterfactual assuming no reductions in smoking due to tobacco control since 1964

- Model attributed smoking mortality under “actual” and “counterfactual” scenarios
  - Mortality rates by smoking status
Impact of Tobacco Control in the US since 1964

- In 1964-2012, an estimated 17.7 million deaths were related to smoking.

- Tobacco control was estimated to be associated with avoidance of 8 million premature deaths and an estimated extended mean life span of 20 years (two decades of life).

- Although tobacco control represents an important public health achievement, efforts must continue to reduce the effect of smoking on the US’ death toll.
Models in Tobacco Control
Areas for further Development

- Increasing complexity and heterogeneity of the tobacco landscape
- Interaction among individuals is important in determining tobacco use behavior
- Need to develop models that account for the effects of those unique individual interactions.
Thank you