Development of Smoking Behavior in Adolescence: the Case of North Dakota

by
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“*There will come a time, I am convinced, when tobacco will no longer be widely smoked, and people will marvel at this odd obsession of the past. And historians will puzzle over how and why nicotine captured as many people as it did, and for so long*.”

“Golden Holocaust”, Dr. Robert N. Proctor,
University of California, 2011

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Abstract

This thesis describes a modeling project, performed by Oleksandr Ivanov, a student enrolled in European Master Program in System Dynamics, in cooperation with assistant professor Arielle Selya (University of North Dakota) and under the supervision of associate professor I. David Wheat (University of Bergen).

The fieldwork was conducted in Grand Fork, North Dakota, the USA in April-June 2015.

The main problem is devoted to the prevalence in smoking cigarettes among adolescents (middle school and high school students) in North Dakota. Despite the comprehensive anti-tobacco policies implemented since 1998, more than 20% of high school students are still exposed to a smoking habit. Among the reasons for this are high nicotine dependence level and the low state excise tax for tobacco products.

The thesis provides an overview of main driving forces and feedbacks within the system of smoking development, pointing out peer and parental pressure, nicotine dependence and other ambient factors (cigarette availability, exposure to second-hand smoking, etc.). Additionally, the research explores potential consequences of the boom in the market of e-cigarettes under different scenarios.

Particular focus is made on the policy analysis and implementation, testing tax, informational, compliance and ban on flavors policies towards meeting Healthy People 2020 objectives. It was found that the increase in the state tobacco excise tax by 1.56 usd is the most promising policy. If implemented in 2016, it would benefit the society by 1381 lives saved from the premature death and total saved costs of 1204 billion usd by 2032.

The thesis is structured as follows. Chapter 1 provides an introduction to the problem, observes current trends in smoking, formulates research objectives and research questions, and discusses the research methodology. Chapter 2 describes the model structure in stock-and-flow and causal loop perspectives. Chapter 3 tests the initial hypothesis by model simulations. Chapter 4 is devoted to the process of model validation. Chapter 5 suggests policy options, analyses their cost-effectiveness, and provides a detailed action plan.

Key words: smoking development, adolescents, nicotine dependence level, anti-tobacco policy, e-cigarettes, system dynamics

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List of Acronyms

BNC	blood nicotine concentration
CDC	Centers for Disease Control and Prevention www.cdc.gov
CLD	causal loop diagram
DHHS	U.S. Department of Health and Human Services www.hhs.gov
FDA	U.S. Food and Drug Administration www.fda.gov
FTQ	Fagerström Tolerance Questionnaire
GYTS	Global Youth Tobacco Survey www.who.int/tobacco/surveillance/gyts/en/
HP	Healthy People Program
IOM	Institute of Medicine www.iom.edu
MTF	Monitoring the Future www.monitoringthefuture.org
NCI	National Cancer Institute www.cancer.gov
ND	North Dakota
NDL	nicotine dependence level
NDSS	Nicotine Dependence Syndrome Scale
NRT	nicotine replacement treatment
NSDUH	National Survey on Drug Use and Health www.nsduhweb.rti.org
NYTS	National Youth Tobacco Survey www.cdc.gov/tobacco/data_statistics/surveys/nyts/
PAF	population-attributable fraction
PHAPI	Problem, Hypothesis, Analysis, Policy Design and Implementation
RR	relative risk for all-cause mortality
SAMMEC	Smoking-Attributable Mortality, Morbidity, and Economic Costs
SAM	Smoking-Attributable Mortality
SD	system dynamics
SECASP	Social and Emotional Contexts of Adolescent Smoking Patterns Study
SFD	stock and flow diagram
SR	Surgeon Report
TFND	Tobacco Free North Dakota
QALY	quality-adjusted life year
UND	University of North Dakota www.und.edu
UiB	University of Bergen www.uib.no
WHO	World Health Organization www.who.int
YRBS	Youth Risk Behavior Survey
YRBSS	Youth Risk Behavior Surveillance System www.cdc.gov/healthyyouth/data/yrbs
YTS	Youth Tobacco Survey www.cdc.gov/tobacco/data_statistics/surveys/yts/

Chapter 1. Introduction

1.1. About this Project

The thesis project described below is written in accordance with the requirements of European Master in System Dynamics, representing modeling and analytical skills gained by me during my involvement into the study program in 2013-2015 years.

The project opportunity has been realized in terms of a wider collaboration between the University of Bergen in Norway (UiB) and the University of North Dakota (UND) in the United States (an associate member of EMSD Consortium) established in March 2013. The research initiative was supported by a funding assistance of the Norwegian Center for International Cooperation in Education (SIU).

The research topic was suggested by Arielle Selya, assistant professor at School of Medicine and Health Sciences, and Scott Johnson, principal advisor at the Institute for Energy Studies, who jointly teach a system dynamics (SD) course at UND. The motivation for the project originates foremost in the research activities of professor Selya, who has been working on the Social and Emotional Contexts of Adolescent Smoking Patterns (SECASP) Study since 2011. She provided supervision on the substantive aspect of my research while I was in Grand Forks, ND, during the period of April-July, 2015. My UiB thesis supervisor, associate professor David Wheat, provided SD modeling assistance.

Among stakeholders in the field, Eric Johnson, the head of Tobacco Free North Dakota (TFND), provided his expertise on the substantial interrelations within the model and up-to-date insights on current smoking trends. He has taken part in validating the modeling results as well.

The thesis is organized in a logical sequence, introducing the problem definition, research hypothesis, methodology used, literature review, model structure, simulation results, validation tests, policy analysis and conclusions. The thesis also includes a policy brief.

1.2 The Phenomenon of Smoking

Cigarette smoking is recognized as a popular practice of inhaling the tobacco mixture of aerosol particles and gasses for the purpose of recreation and relaxation. The smoke consists mainly of the pharmacologically active alkaloid nicotine and other substances that are absorbed into the bloodstream through the lungs. They affect the brain, providing a positive sensation effect. Traditionally the smoke is produced as a result of burning dried tobacco leaves in cigarettes, hookahs or other devices. Among alternative products for smoking are marijuana, flavored liquids and vaporized opium with the similar principle of use and effects.

According to its origin, first of all, smoking is considered a social phenomenon. Thus, among the main factors that cause the initiation of smoking is peer pressure (Schaefer, 2012), in which social interaction, desire to be attached to the community, and status motivate one to start and keep smoking. This causality has a reinforcing nature. There are other factors such as environmental, cognitive, and genetic influences (Reyes-Gibby, 2015) (SR, 2012) connected to second-hand and parental smoking; socio-demographic and behavioral factors that make people susceptible to this habit.

The development of smoking behavior is a dynamic process (SR, 2012). It combines several stages from initiation to progression to active smoking with different levels of intensity.

Smoking tobacco products has long historical roots, beginning long before the negative health consequences were identified by the researchers and have become more widely known. After the European exploration and conquest of the Americas, tobacco smoking spread around the world, gaining great popularity. In the USA, the peak of smoking epidemic was reached at the beginning of 1960s, when more than 50% of the adult male population were classified as current smokers (SR, 2012), and per capita consumption was 4166 cigarettes . At the same time, due to the improved methods of medical research, the Surgeon General's Report on Smoking and Health (1964) stressed the scientific evidence of negative health consequences of smoking and emphasized the necessity of immediate regulation. Since 1965, smoking has become a national public health issue and has been the focus of the scientific and policy making community.

Health consequences

Smoking is considered one of the “leading causes of preventable death globally” .

Firstly, the cigarette smoke consists of different tars that cause lung cancer (Doll, 1950), heart attacks, chronic obstructive pulmonary disease, erectile dysfunction and cardio vascular diseases (WHO, 2015), leading to a reduced life expectancy (appendix 1).

Secondly, the medical research identified nicotine as highly addictive. Regularity of smoking cigarettes forms a habit and stimulates the nicotine dependence that makes its impact on the organism. The main symptoms of nicotine dependence include withdrawal, tolerance and craving for tobacco. It is a complex and multidimensional characteristic that is measured by level of smoking, future relapses, and unsuccessful cessation (SR, 2012), and is represented by different scales (FTQ, HONK, CDS, NDSS (Sato, 2012)).

“The pharmacologic and behavioral processes that determine tobacco addiction are similar to those that determine addiction to drugs such as heroin and cocaine” (SR, 2012). Because of their addictive properties, tobacco products are regulated by the U.S. Food and Drug Administration (FDA) as recreational drugs.

Thirdly, secondhand smokers, people who breathe in the smoke exhaled by others, are in the same risk group as regular smokers. “More than 10% of all smoking-related deaths are the result of non-smokers being exposed to second-hand smoke” (WHO, 2015).

Finally, these general health effects of smoking contribute to “increased absenteeism, loss of well-being, and have implications for health care and its costs” (SR, 2012).

Anti-tobacco policies

Since the 1960s, the federal and state governments have designed and implemented a set of anti-tobacco policies intended to regulate the dramatic increase in smoking among the population. Mainly the policies were focused on increasing the federal, state and local excise taxes on cigarettes, assistance in quitting, health-related information campaigns, warning pictures on cigarette packs, clean indoor air laws, bans on tobacco advertisement, etc. The ongoing policy implementation process within the states is monitored and analyzed (NDSP, 2015).

There is also known nicotine replacement treatment (NRT) (patches and nicotine gum) that helps to cut down the quantity of cigarettes and quit smoking. Some researchers (SR, 2014) also consider smokeless tobacco as a potentially preferable alternative to conventional cigarettes.

Since the mid 1990s, attention to smoking in adolescence has increased, because that is the period when 95% of smokers initiate the habit (NDSP, 2015). For the purpose of preventing the tobacco use among teenagers, the Tobacco Master Settlement Agreement (1998) with the biggest tobacco companies was signed and the Family Smoking Prevention and Tobacco Control Act (2009) passed the US Congress. It helped to raise additional funds for anti-tobacco programs and restrict the tobacco advertisement. “Many states also have passed laws against selling tobacco products to minors (establishing a smoking age)” .

In the field of tobacco regulation the national objectives are set by FDA. Healthy People (2010, 2020), the nation’s disease prevention and health promotion plan, provides “science-based, 10-year national objectives for improving the health of Americans”, highlighting tobacco use as one of the nation’s “Leading Health Indicators” (SR, 2012).

The effectiveness of anti-smoking regulations is limited by significant policy resistance. This can be partly explained by the strong lobby of tobacco companies, the activity of smokers’ communities and the general bureaucratic nature of policy implementation mechanisms.

Tobacco market

“Cigarettes are primarily industrially manufactured from loose tobacco and rolling paper” . The most famous brands of cigarettes include Marlboro, Newport, and Camel (2011-2013), that are owned by large tobacco companies that operate in the US market, such as Phillip Morris, Reynolds American, Lorillard (85% of market share in total), etc.

Tobacco companies promote, produce and supply cigarettes to the market. The overall consumption of tobacco products reached 264 billion cigarettes in 2014 (CDC, 2014) that brought multibillion dollar revenues for the producers. This makes tobacco business very attractive for investors and intensifies the development of the new tobacco/ nicotine products.

The tobacco companies are also among the largest corporate taxpayers in several states. The overall tobacco tax (federal, state and local) paid in 2014 is 32.9 billion usd (Orzechowski, 2014). "Taxes on tobacco provide revenue to governments at a relatively low administrative cost" making these taxes especially appealing (SR, 2014).

Measures of Tobacco Use

Monitoring programs track the tobacco epidemic and suggest how to improve existing policies. The main indicators of tobacco use include a variety of epidemiologic measures, such as frequency and quantity of smoking, current prevalence of cigarette smoking, trends in cigarette smoking over time, disparities in cigarette smoking and other tobacco use (SR, 2012), attempts to quit smoking, concentration of nicotine in the air, the age when cigarette smoking begins, etc. This kind of information is usually obtained by accomplishing the recurring national/regional surveys (National Survey on Drug Use and Health (NSDUH), National Youth Tobacco Survey (NYTS), Youth Risk Behavior Surveillance System (YRBSS), Monitoring the Future (MTF)) and from other surveillance systems. Statistics on the dynamics of smoking behavior are widely reported by specialized research institutions, national reporting initiatives, NGOs (Tobacco Free Kids), health departments, and media.

Smoking in the USA

Despite the medical evidence concerning harmful health consequences, smoking is practiced by over 1 billion people worldwide in the majority of human societies. Meanwhile each year, about 4.9 million people worldwide die as a result of it (WHO, 2015), especially in Eastern European and Asian countries. At the same time the USA has demonstrated significant progress in tobacco control, by more than halving smoking rates since 1964 (from 43% to 18%) (Johnston, 2014). As a result of anti-tobacco policies per capita tobacco consumption is decreasing over time (Figure 1.1).

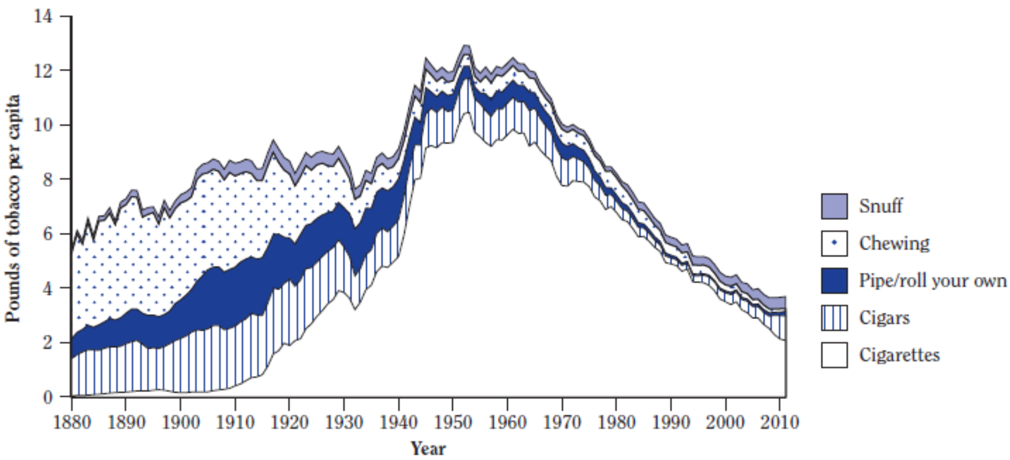


Figure 1.1 Per capita consumption of different forms of tobacco in the USA, 1880-2011 (SR, 2012)

The vast majority of smokers initiate smoking by the age of 16 (Johnston, 2015). This manifests the importance of studying this age group to prevent individuals “that are in the greatest risk of lifetime chronic smoking” (Selya, 2013) from developing smoking habit at its earlier stage. According to the statistics (SR, 2014), “every adult who dies early because of smoking is replaced by two new young smokers in the USA”.

In the USA the trend in the prevalence of ever cigarettes smoking shows a relative decline since 1976 with a slight increase in 1998 (Figure 1.2.). Among adolescent groups, cigarette smoking is more inherent to males of White and American Indian race, low-educated, living in the Midwest and the South, and adolescents from low-income families (SR, 2014).

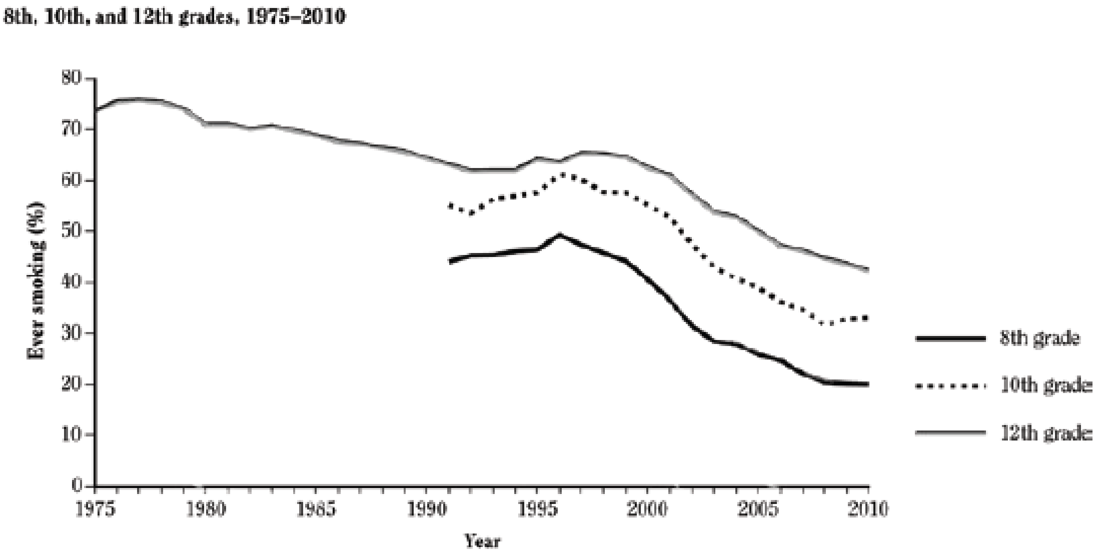


Figure 1.2 Trends in prevalence (%) of ever smoking among young people over time, by grade level; MTF, 1975-2010; the USA (Johnston, 2015)

It was interesting to find out that the prevalence in smoking among adults strongly correlates with smoking among adolescents (Figure 1.3.). This underlines the argument that “serious diseases in adulthood have their roots in adolescence” (SR, 2012), and encourages certain interventions.

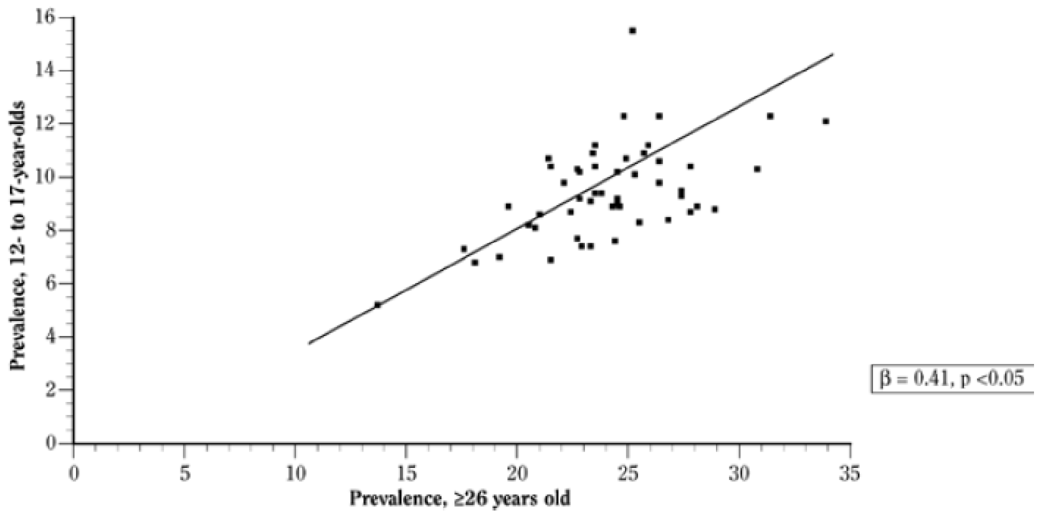


Figure 1.3 Prevalence of current cigarette smoking among 12- to 17-year-olds and those 26 years of age and older, by state; NSDUH 2008-2010; the USA

Future trends and threats: ***E-cigarettes***

There has been a decrease in the prevalence of use of conventional cigarettes since 1964, but there many other tobacco-related challenges facing the society.

For instance, increased taxation and regulation encourage tobacco companies to intensify their innovation process and diversify their products as an alternative way of approaching consumers. There is certainly a new smoking revolution approaching, offering a range of alternative nicotine products such as e-cigarettes, smokeless tobacco, etc. All of them give birth to new product cycles. At the same time, new complex behavioral pathways are emerging in smoking such as diversification or dual use of multiple tobacco products. Despite the prohibition of cigarettes sales to minors in a majority of states, adolescents are still the most sensitive group to product innovations, among which new flavors, images, and style. The dynamics of market innovations fosters the changes in the system and makes the complexity of smoking development much greater.

During the last five years, the US market has experienced a boom in e-cigarettes (electronic nicotine delivery systems) consumption (HP, 2015), increasing from 0 to 15% prevalence. The new product is available in many flavors and design packages. It is actively advertised in media and weakly regulated by governments.

There is an active public debate about the problem of product classification: whether to consider e-cigarettes as a tobacco product or not, as they use nicotine liquid (not tobacco leaves). This raises a question of whether anti-tobacco policies, including taxation, should be extended to e-cigarettes. In its latest report the Center for Disease Control and Prevention (CDC) (2014) recommends the state and local governments to consider e-cigarettes as a tobacco product. But so far only 10 states have recognized it.

There are various opinions regarding health consequences of e-cigarettes. Supporters of the product argue that they are less harmful in general than tobacco cigarettes, as they don’t contain tars found in the cigarette smoke , and there is an option of nicotine-free e-cigarettes available at the shops. However, nicotine-free vaporizing is preferred by less than 3% of consumers (SR, 2014). According to the supporters, e-cigarettes will help current smokers of conventional cigarettes quit smoking. Although by 2015 e-cigarettes haven’t been approved as a smoking cessation device by any government in the world . Opponents emphasize nicotine consumption by e-smokers, the potential nicotine overdose in case of dual use, and other unintended health hazards. Thus, users of e-cigarettes are less likely to quit than those smokers who never tried e-cigarettes. Additional research is required to justify those opinions.

Because of the uncertainty of health consequences, e-cigarettes are treated differently within the world and the USA – from the absolute ban (Australia) to free purchase even for minors (Massachusetts, the USA) . Moreover, the variety of flavors and specific design make the e-cigarettes popular among adolescents, even those who have never tried conventional cigarettes. This potentially serves as a gateway to later cigarette use (SR, 1994).

1.3 Smoking in North Dakota

Smoking patterns in North Dakota reflect the overall trends in the USA with their own particularities over time.

First of all, the geography of the region, rural vs urban, density of population, weather condition, etc. define the specifics of human interactions and susceptibility to smoking. Secondly, cultural features like religiosity (Christianity/ American Indian beliefs) have an impact on the social norms (SR, 2012) and smoking behavior, and limit or reinforce the initiation of smoking.

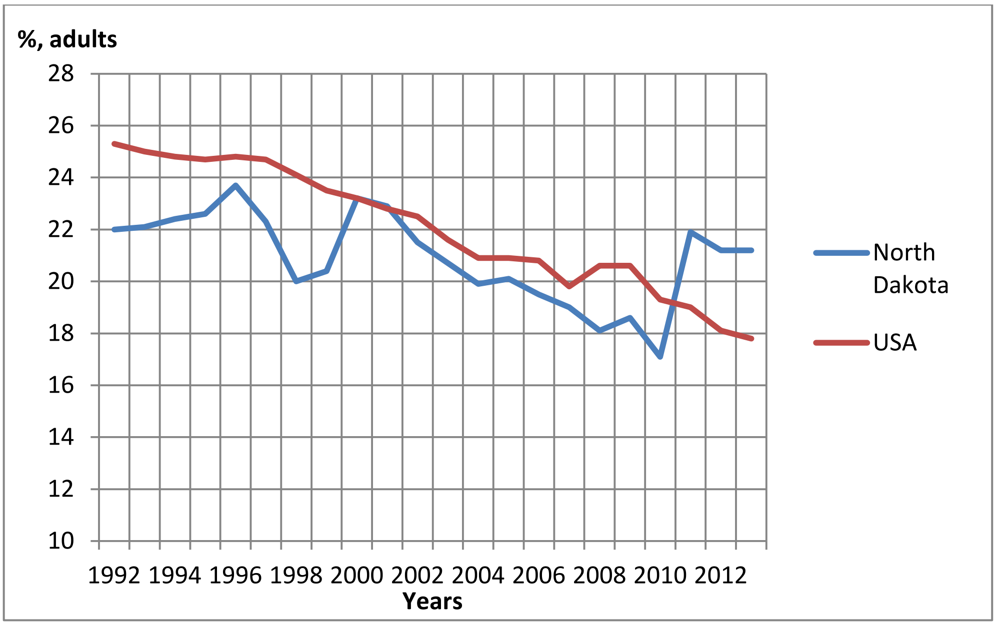


Figure 1.4 Prevalence of current cigarette smoking (%) among adults in North Dakota and the USA, 1992-2013 (SR, 2014)

The trend in current cigarette smoking among adults in the USA depicted on Figure 1.4. shows a steady decline over time with a slight increase in 2008. The similar trend in ND fluctuates with increases in 1996 and 2001, a drop in 1998, and a decline after 2001. The increase in 2011 is caused by changing the methodology for data collection (ND Report Card, 2014). In general, adults in ND smoke less than average in the USA.

The average retail price per pack of cigarettes in ND is lower than the US average because the state has one of the lowest tobacco excise taxes (0.44 usd/pack), and it hasn't been changed for 20 years . This significantly increases accessibility to tobacco.

On the other hand, ND is one of the fewest states that provides a funding assistance of anti-tobacco programs in accordance with CDC recommendations (CDC, 2014), fulfilling 97% of the norm with 9,8 million usd per year.

ND laws related to smoking issues include the Century Code (§§12.1-31-03, 23-12-9 to 23-12-11, 44-04-06, 51-32-01, 57-36-06), the Smoke-Free Law, the Tobacco Products Tax Law. There is also State Strategic Plan to Prevent and Reduce Tobacco Use 2009-2014 issued by the Health Department of ND (2007).

ND's legislative policy makers are divided into House of Representatives and Senate in a state legislature that meets on a biennial basis. In the executive branch of power the ND Government's Tobacco Prevention and Control Advisory Committee has jurisdiction over tobacco-control bills and the Health Department of ND implements the new regulations and monitors the overall smoking dynamics. There are a few interest groups such as TFND and Breathe ND that support to regulatory initiatives and communicate them to the society.

The 2015 legislative session displayed a quite conservative position concerning changes in the tax policy, defeating two bills that would have increased the excise tax from 0.44 to 2 usd per pack. At the same time, deputies didn't recognize the e-cigarettes as a tobacco product, what keeps them out of taxation and makes them more available for consumers.

1.4 Problem Description

Although tobacco use in adolescents has declined over the past 2 decades in ND, it remains a significant determinant of current and future health outcomes. The rapid decline in tobacco use in the early twenty-first century has not continued at the same pace. Tobacco use among youth remains unacceptably high, and national surveys show that "declines in rates of current smoking have been slower and more sporadic in recent years" (SR, 2014).

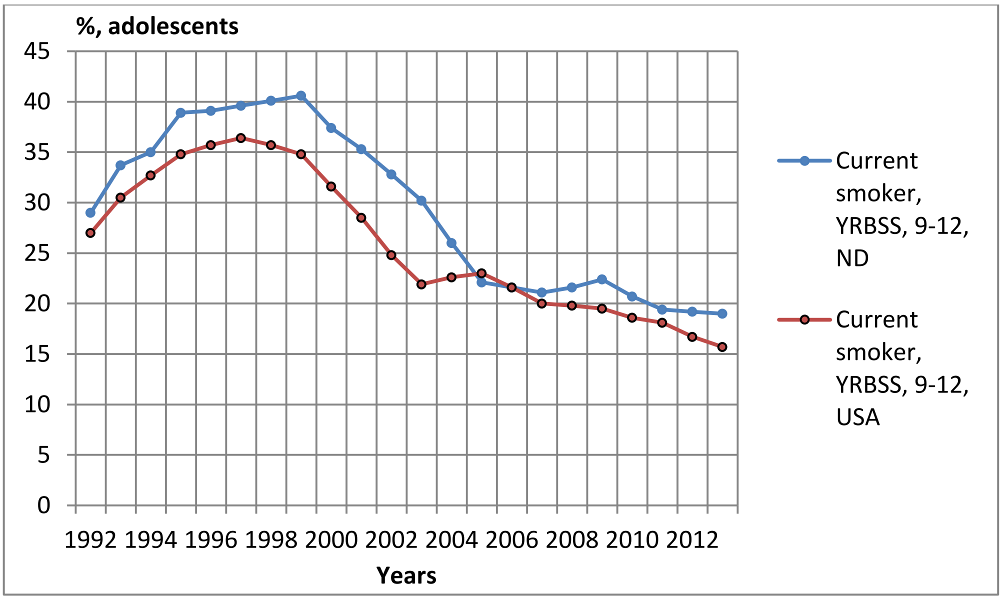


Figure 1.5 Percentage (%) of middle school and high school students who were current smokers of conventional cigarettes, North Dakota, 1992-2013, Youth Tobacco Survey (2013)

Unlike adults (Figure 1.4), adolescents in ND are more likely to smoke than adolescents nationwide (Figure 1.5).

After years of steady progress, "declines in the use of tobacco by youth and young adults have stalled for smokeless and alternative tobacco use" (SR, 2012). Thus, the recent surveys (Johnston, 2014) monitoring trends in tobacco use indicate that the percentage of US middle and high school students who use new tobacco products (e-cigarettes, snuff) tripled between 2011 and 2013 (from 3.3% to 9.8%). The unregulated boom in distribution and promotion of the e-cigarettes raises concerns about the future of smoking behavior.

Moreover, the goals set in the field of smoking regulation on the federal and state levels have been hard to achieve. For example, the Healthy People objectives 2010 (16% in high school students) , and North Dakota's Strategic Plan in Preventing Tobacco 2008-2013 (15%) (2007) haven't been fulfilled. All of this requires more detailed system research.

1.5 Research Objectives and Research Questions

According to the issues described in section 1.4, the research objectives can be formulated as follows. First, to develop a general understanding of smoking dynamics among adolescents, including development of nicotine dependence, in North Dakota since 1992. Second, to test existing anti-tobacco policies by experimenting with the applications of SD to gain new insights related to new alternative tobacco products. Third, to explore the impact of e-cigarettes on the system of smoking development.

These objectives were specified in the research questions. The first set of questions is related to the factors affecting smoking and their influence on the system:

1. What are the **main driving forces** influencing the development of smoking behavior in adolescence? How does the initial level of nicotine dependence affect the system?
2. What is the **effect of parental smoking** on the initial nicotine dependence level (genetic vs environmental contributions)?

The second set of questions is focused mainly on the existing policies and alternative tobacco products (e-cigarettes) that are booming in North Dakota and the USA:

3. Is it possible to achieve the **Healthy People goal** by 2020? What is the possibility of a smoking-free society?
4. What are the potential unintended consequences of the **boom in e-cigarettes**?
5. What are the **most effective policies** in dealing with semi-regulated market of e-cigarettes?

1.6. Research in the Field: Model-Based Analysis

Smoking as a social phenomenon is a focus of multi-disciplinary research in different scientific fields from medicine to sociology. As a complex system, smoking involves “layered social and environmental contexts” (SR, 2012), different factors and driving forces (mentioned in section 1.2). The plurality of scientific methods was implied to study smoking behavior, including modeling. The models of smoking development are classified according to the scope, the principle of construction, software used, etc.

Theoretical models that consider these multiple levels of neurobiological, sociocontextual, and environmental influence can be labeled “integrated biopsychosocial-ecological models” (Sussman, 2008). In these models, intrapersonal predictors of tobacco use are grounded within larger social and environmental structures. The main theoretical concepts are well-described in the editions of Surgeon General Report’s 1994, 2012, 2014.

The stage model is a useful heuristic device (SR, 1994) and, as “is true with other integrative models, helps to stimulate new research and guide efforts in prevention”. As newer data analytic techniques have become available, researchers have been able to empirically identify “developmental trajectories of tobacco use that more clearly capture this heterogeneity” (Mayhew, 2000) (Chassin, 2000) (Bernat, 2009). Several studies have identified three to six discrete smoking trajectories (Bernat, 2009) in such models: four stages of smoking acquisition (Pallone, 2008), escalating stages (Colder, 2001), susceptibility model (Pierce, 1998), the stage of noncurrent experimenters (Gilpin, 1999), clusters of smokers (Soldz, 2002), etc. However, these stages are still based mostly on theory (Flay, 1993), with limited empirical evidence to validate them.

Other quantitative modeling approaches were reflected in many deterministic models by S. Boker, J. Graham (1998) - linear models of drinking and smoking, D. Schaefer (2012) and J. Lospinoso (2010) - models of smoking and friendship formation, M. Turbin (2000) - normative transgression, A. Selya (2013) - structural equation and hierarchical linear models of risk factors. But all existing models fragmentally describe the main causes and effects related to smoking, showing correlations to other pernicious habits or conceptual representation of the existing theories. All mentioned approaches are event-oriented (Morecroft, 2007; Sterman, 2000) without providing a broader picture on the issue of smoking in adults and adolescents.

The growing complexity of the issue requires additional observation and empirical evidence interpreted with a systemic prospective. Moreover, a pluralism of human behavior within the social system creates the non-linearity that has to be discovered with alternative methods than linear modeling. Thus, multilevel modeling techniques (Figure 1.6) are commonly used to examine how factors such as intrapersonal characteristics, families, peer groups, schools, and communities, interact together to jointly influence adolescent tobacco outcomes (SR, 2012).

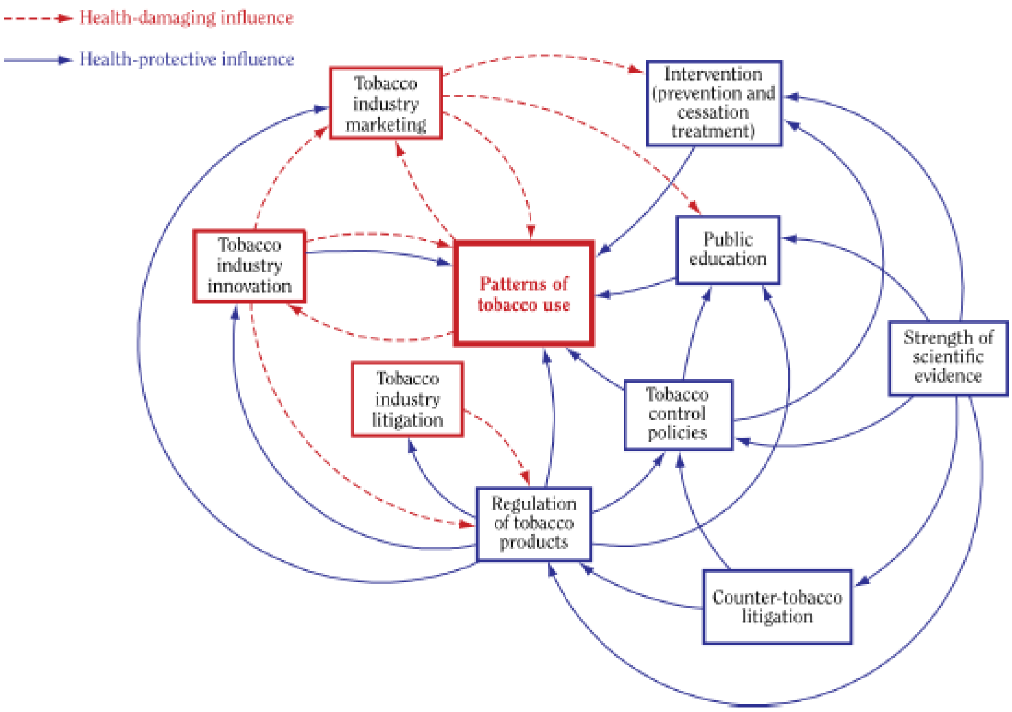


Figure 1.6 Simplified dynamic model of protobacco and antitobacco forces on patterns of tobacco use; created by A. Villanti (SR, 2014)

In considering how to accelerate the end of the tobacco epidemic, models also serve as “an essential tool for projecting the potential consequences of tobacco control strategies” (SR, 2014). For instance, Levy’s model of cessation treatments (Levy, 2010) explored the effects of implementing a comprehensive tobacco control strategy with four components directed at reducing the prevalence of smoking in the population: “(1) price increases including those that result from cigarette tax increases, (2) smoke-free indoor air laws, (3) mass media/educational policies, and (4) evidence-based and promising new cessation treatment policies”. Thus, “systems-level modeling will remain a needed tool for continually revising tobacco control strategies, reflecting the dynamic nature of the tobacco epidemic and its drivers” (SR, 2014).

There are a few smoking research projects conducted in the field of SD, focusing mainly on the issues of smoking in the USA, New Zealand, and Indonesia. The overview of these projects highlights the main conceptual (Ahmad, 2007) and quantitative models (Richardson, 2007). In general they represent dynamics of the main reinforcing feedback loops ("social pressure") and counteracting loops (restrictions in selling cigarettes, quitting programs) in smoking development. However they focused on the general population. The lack of consideration of smoking behavior during adolescence, when the nicotine dependence and smoking pathways occur constitutes a gap in the knowledge and requires further SD research devoted to this particular age group.

1.7 Methodology Choice and Research Strategy

Methodology

Researchers in the field of smoking behavior use different research strategies to achieve their research goals. In most cases clinical experiments (Turbin, 2000), surveys, and statistical analysis (Selya, 2013) are widely used to elicit information and test the hypothesis.

Taking into account a practice-oriented focus of this research, the research strategy for this thesis can be characterized as a combination of grounded theory, and SD modeling and experimentation. Moreover, other tools will be used such as regression analysis for quantification of interrelations within the model.

The overall methodology used in the thesis embraces the logical sequence of the stages of problem definition, hypothesis formulation, analysis, policy design and implementation. It is widely applied in the field of SD projects (Moxnes, 2009a).

Thus, the first part of the research is devoted to exploration of the main historical patterns of smoking dynamics during adolescence, requiring the analysis of secondary data (previous reports and surveys) and elicitation of information from the mental models (Luna-Reyes, 2003) through interviews. Basing on those procedures, it was possible to describe the influence structure (Vennix, 1996) and develop appropriate understanding of how the system works.

The second part is focused on the quantitative SD modeling and simulation based analysis of the dynamics of the system and testing different anti-tobacco policies. The tests are organized in the form of iterative simulations and experiments within the quantitative stock and flow SD model (built beforehand on the basis of assumptions formulated in the first part of the research). It enabled the understanding of the main structure of the development process (smoking initiation, progression, cessation, and relapse processes), identifying "leverage points" (the most sensitive elements of the model) (Sterman, 2000), visualizing the results of the simulation on the graphs and fostering the discussion around the possible future scenarios.

The core of the model is represented as a diffusion model (Richardson, 2007), characterizing transition of potential smokers into the current smokers (who have smoked at least 100 cigarettes in their life). This process includes transition stocks of smokers in between with different symptoms and levels of addiction. The flow equations are in the focus of the research, capturing main driving forces (for example, social smoking concept or new cigarette products) and helping to understand the dynamics of smoking prevalence (Richardson, 2014).

Data collection and analysis

Decisions related to the implementation of the described strategies required different kinds of information for analysis: both primary data (elicited from the interviews and simulation results) and secondary data (previous researches and surveys analysis). Moreover, qualitative data was needed to build the cognitive maps and quantify the non-liner relationships within the model (for instance, peer influence) to set up the stock and flow (SFD) structure and run the SD model. A set of interviews was conducted with G. Richardson (2014) and E. Johnson (2015).

Among sources of quantitative data in this case it is necessary to highlight: statistical time-series data and graphs (health care reports), specific reports, a set of existing SD models (equations part), and assumptions made in the similar smoking behavior models (case study).

All the data collected creates several types of "collaborative knowledge" (Saunders, 2012): explanatory (which factors influence the smoking behavior), evaluative (what is the effectiveness of existing anti-tobacco policies) and prescriptive (what kind of policies would amplify anti-tobacco effect in dealing with identified factors).

1.8 Research process

The preliminary planning of research activities and the research proposal were delivered during the course of Research Methodology taken at Radboud University in Nijmegen, the Netherlands in September-January, 2014. Preliminary literature overview related to the main problem was carried out during the same period.

The conceptualization stage included modeling a causal structure of the issue within tight model boundaries, identification of main stocks, flows, and parameters, and analysis of feedback loops. The first draft of the preliminary model was tested in terms of different on-going anti-tobacco policies. The model was delivered at the end of GEO-SD308 "Policy design and implementation" course at UiB in February, 2015.

Another part of the modeling process was accomplished at UND during April-July, 2015. It was mainly based on the issue of NDL, quantitative estimation of parameters and simulations. The sensitivity analysis of driving forces was combined with identifying leverage points.

Finally, the most challenging part of the research was the comprehensive analysis of model behavior and model validation tests (structural and behavioral). Particularly challenging was producing credible results and conclusions concerning the hypothesis.

The research process was aligned with interim reporting to the supervisors, following discussions with the main stakeholder.

This chapter provided an overview of the phenomenon of smoking in the USA and North Dakota particularly, pointing out the distinctive features of smoking development and current trends among adults and adolescents. In section 1.4 the main problem was identified. Sections 1.5-1.9 described research objectives and research questions, a comprehensive overview of the modeling initiatives and methodology chosen for the current research.

Chapter 2. Model Description

2.1 Model Overview

This part provides a highly aggregated overview of the stock-and-flow model.

Smoking is “a multidetermined behavior” (SR, 2012) with a plurality of pathways. It is determined by “the interrelations of various risk and protective factors” (SR, 2014). According to Forrester (1961), smoking development can be characterized as a multiloop, multistate, and nonlinear feedback system. All of this makes the development of smoking behavior very complex.

The SD modeling approach can be beneficial in this case. It provides a methodology that helps to formulate a dynamic hypothesis, portray it within the causal structure, and identify the driving forces in terms of major feedback loops.

The general view of the SD models described in section 1.6 includes the basic developmental epidemic structure. Usually it consists of several stages that represent different levels of the person’s involvement in smoking behavior. Thus, the core of the current SD structure contains such a stage model (SR, 1994) provided in Figure 2.1. Having analyzed the existing variants of the stage model, I chose the one suggested in (CDC, 2002) that is better suited for testing initial assumptions. Moreover, I extended the structure to the additional stage of former experimenters according to Gilpin (Gilpin, 1999).

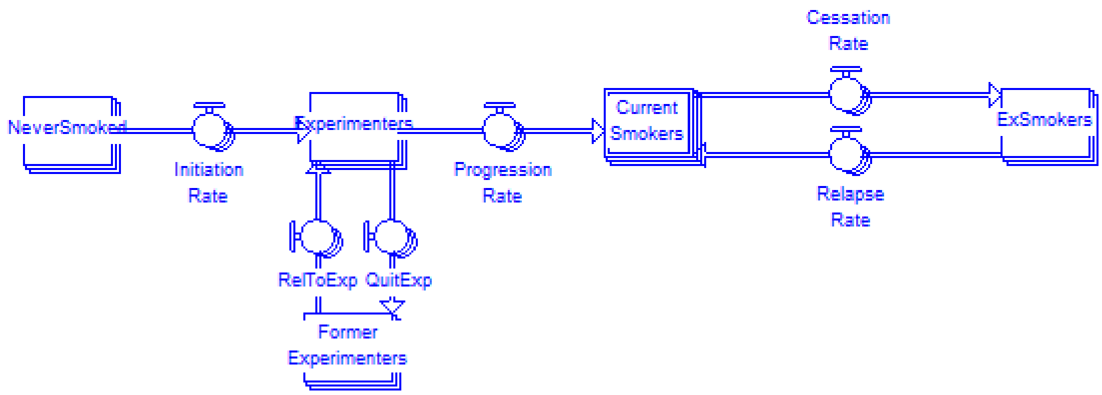


Figure 2.1 The stage model of smoking development

The target group that has been observed in this thesis includes adolescents, aged 11-18, split into two sub-groups of middle school (5^{th} -8^{th} grade) and high school (9^{th} -12^{th} grade) students. These two focus sub-groups are organized within an array in the model. They comprise the stocks representing different smoking modes. The transitions between them are modeled as flow rates (initiation (IR), progression (PR), cessation (CR), and relapse (RR)) that need to be controlled. The auxiliary variables (factors) described in section 1.2 affect certain flows. They are represented either separately or grouped into modules (smoking in adults, second-hand smoking, risk perception, NDL, alternative tobacco, marketing) with a certain level of detail.

As it is stated in section 1.2., the target variables in this case include the prevalence of smoking (the fraction of current smokers), the appropriate values of the stocks, the level of perception of health consequences, and parental smoking. Moreover the target model elements include NDL. All of these variables are endogenous within the model structure.

The scope of the model is focused on the existing data in North Dakota. However the universal language of SD will easily allow reformulating the model to any similar cases in other regions within the USA if necessary.

The time scale for simulation is 1992-2014 (replication of reference mode) and 2015-2032 (forecasting) years. The time horizon allows exploring the overshoot and collapse behavior in 1992-2001 years, and the perspective for reaching the Healthy People objectives (HP, 2020).

The core tobacco behavior is related to smoking of conventional cigarettes, but the research also provides insights regarding the alternative tobacco patterns.

2.2 Model Assumptions

The model hypothesis is based on the set of assumptions grounded in theory and practice. It determines the structure of the model, its boundaries and all interrelations between the variables. This section provides a more detailed discussion of the fundamental ideas, on which the research is based as well as arguments supporting them, and potential consequences of their use in the model.

The main sources of knowledge for conceptualization include a comprehensive literature overview, reports, interviews and benchmarking among similar SD models.

2.2.1 The Stage Model

The stage model (Figure 2.1) captures potential pathways of smoking development. It starts from non-smokers and goes along the chain, progressing in smoking experience. The first puff determines the initiation and brings the person to experimenters (smoked during last 30 days, but without an experience of 100 cigarettes in lifetime). At this stage an adolescent can progress to current smokers (with an experience of more than 100 cigarettes) or stop experimenting, and move to former experimenters. Smokers are able to quit smoking although not easily; similarly ex-smokers can relapse to regular use of cigarettes. It is not possible to move back from smokers to non-smokers or experimenters as this represents cumulative smoking experience (shown as uniflows within the structure).

The initial values for the stocks are calculated based on the epidemiologic measures for middle school and high school students in North Dakota in 1992. The sum of all the stages determines the total population of adolescents. The fraction of smokers is calculated as follows:

Current_Smokers/TotAdoPop

"Adolescence represents a time of heightened vulnerability for both the initiation of tobacco use and the development of nicotine dependence" (SR, 2012). According to section 1.2 the susceptibility ratio and social factors are assumed to be the determinants of IR. Perception of health risks, second-hand smoking, quitting attempts, price and NDL affect PR, CR and RR.

2.2.2 Maturing Dynamics

The number of people within the stocks is influenced by maturing processes. There are a few places within the model capturing these dynamics:

- *From primary school to middle school students:*

  The graduates of primary schools are assumed to be an input to non-smokers among middle school students as they have not had smoking experience yet. The number of people entering the stock of non-smokers is calculated as a replacement of students who matured to high school and relative growth in this cohort during the year;

- *From middle school to high school students*

  It is assumed that in 4 years the cohort of middle school students becomes high school students. So, there is a transition from middle school to high school students within the array at all stages respectively (for instance, the outflow from middle school non-smokers is equal to the inflow to high school non-smokers, as it is shown on Figure 2.2);

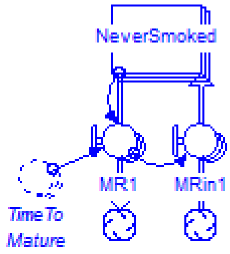


Figure 2.2 An example of the maturing structure

- *From high school students to adults*

  Similarly to middle school students, it is assumed that in 4 years the cohort of high school students becomes adults, providing the input from the stage model to the certain module of Smoking in Adults.

The death rate was eliminated from the boundaries as it is not significant as in adults. The net change in adolescent population is calculated basing on the growth rate that is kept exogenous.

2.2.3 Smoking-Related Mortality in Adults

The health consequences of smoking described in section 1.2 lead to premature death. The surveillance system of Smoking-Attributable Mortality, Morbidity, and Economic Costs (SAMMEC) provides certain evidence on the potential mortality risks related to smoking.

It was found that the experience gained in smoking increases the death rate for smokers compared to non-smokers by the relative coefficient (relative risk). In case of current smokers, the value of this coefficient depends on the intensity of smoking. In case of former smokers, the coefficient is correlated with the age of quitting smoking (Figure 2.3).

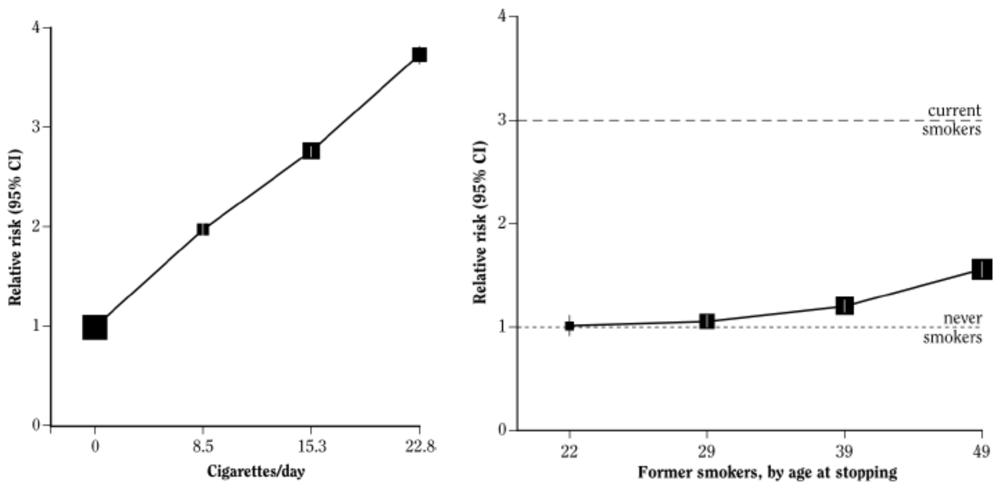


Figure 2.3 Relative coefficient for all-cause mortality among current smokers (left graph) and former smokers (right graph) versus non-smokers, adapted from the 2014 Surgeon Report

I assume the relative coefficient for current smokers is 2.7 (the median in Figure 2.3); for former smokers – 1.2.

2.2.4 Social Factors

As it is stated above there are different social factors that affect the flow rates. Understanding that they "either reinforce or interrupt progress along the smoking trajectory" is crucial for intervention into smoking behavior (SR, 2012). Those factors can be classified according to Sussman (2008) as ultimate (pro-smoking culture), distal (social and physical environments), or proximal domains (perception of health risks).

It is assumed that ultimate and distal domains form the social pressure within the model and affect IR and PR. The social pressure combines three substantial influences from peer community, families, and media that artificially amplify the pro-smoking culture. The social pressure represents the variable with range from 0 to 1 (absolute pro-smoking culture).

The evidence is sufficient to conclude that there is "a causal relationship between peer group social influences and the initiation" (SR, 2012) as it was discussed in section 1.2. For instance, studies comparing schools with high versus low smoking rates have found that "attending a school with a relatively high smoking rate increases susceptibility to smoking among nonsmoking students" (Leatherdale, 2006). Thus, the fraction of smokers is connected to social pressure.

Smokers among parents also have a social impact on their children, representing the smoking as a norm within a family. "Parental smoking has been consistently associated with smoking initiation in offspring, progression and nicotine dependence" (Selya, 2012) through direct (permissiveness towards smoking) and indirect (positive attitudes towards smoking) influences. The parental smoking variable represents the probability that at least one parent within the family is a current smoker. The formula for calculations is based on the Bayes' theorem.

At the same time, studies (SR, 1994) find that parental smoking is less influential compared to peer pressure. In terms of relative coefficients it can be represented as 1 (parental smoking influence) to 2 (peer pressure influence).

The other component of social pressure is related to promotion of the smoking habit in media, movies, and other entertainment. The use of cigarettes is tied to "glamour, wealth, sex appeal, popularity, power, and good health" (SR, 1994). The evidence is sufficient to conclude that there is "a causal relationship between depictions of smoking in the movies and the initiation of smoking among young people" (SR, 2012). This eventually amplifies a pro-smoking environment. It was found that one-third of experimentation with smoking by adolescents is attributable to tobacco advertising . Thus, the tobacco in media amplifier was conceptualized as a value of 1.5.

Social factors are likely to be "more influential in low-level or early tobacco use, while intrapersonal factors tend to be strong predictors of later and higher levels of use, when addiction to nicotine is more strongly involved" (Sussman, 2008).

2.2.5 Second-Hand Smoking

Exposure to environmental tobacco smoke that has been exhaled by the smoker is known as second-hand smoking. There is enough evidence to assume the causal relationship between second-hand smoking and negative health consequences (SR, 2012) such as respiratory effects and nicotine addiction. Around 40% of non-smokers are exposed to these adverse effects (SR, 2014).

Usually second-hand smoking occurs in a family when parents or other members smoke, in the peer community or accidently in public places. In all cases the percentage of second-hand smokers among non-smokers depends on the contact rate with smokers.

According to the survey (SHS, 2014), it is assumed that 40% of families where at least one parent smokes produce exposure to the second-hand smoking. At the same time the contact rate for the peer interaction changed in 2009-2010 after the implementation of clean air laws by a majority of states within the USA. In 2011 it was assumed to be at the level of 0.8 (compared to 1 before 2009). Moreover, it was found that the percentage of young people who don't mind being around people who smoke is approximately 35% (Johnston, 2015).

Exposure to second-hand smoking affects directly the NDL and susceptibility ratio.

2.2.6 Perception of health consequences

One of the factors that motivates adolescents to progression in smoking is related to the perception of negative health consequences. The level of awareness known as proximal domain (Sussman, 2008) affects the susceptibility to smoke. In general, the delay between smoking patterns and occurrence of smoking-related diseases makes adolescents less likely than adults to care about their lives. This is manifested in low levels of perceived health risks.

On the one hand, information campaigns and educational programs at schools and families help to raise awareness of smoking issues, thus increasing the perception by adolescents. There is adjusting time to perceive the new information that is assumed as 6 months. The level of perception ranges from 0 (no one is aware) to 1 (everyone is aware).

On the other hand, the perception can be decreased as a result of forgetting. For instance, new generations of adolescents are growing up, and they have to be informed and educated. In 8 years the current adolescents will be completely replaced by others. If any of the tobacco awareness programs stop or receive less funding for that period of time, the new cohort would become much more susceptible to smoking. This feature is known as a "cohort effect" (Johnston, 2014), characterizing the process of "generational forgetting" (Johnston, 2015).

This concept of perception was used by A. Zagonel to explain the societal lifecycle of cigarette smoking in the period of 1900-2100 in the USA. The SD model was developed for this particular purpose. The analysis indicated that "the society is now in the beginning of a very long and gradual phase of losing awareness" (Zagonel, 2012).

Contrary to those findings, the MTF report shows a steady increase in the level of awareness among high school students since 1975 (Figure 2.4). But the risks of a potential decline in the future hypothesized by A. Zagonel are growing as well.

According to the survey (Johnston, 2015), the perception of health consequences was on the level of 85% for high school students and 60% for middle school students in 2014. But is it hypothetically possible to reach 100% of awareness in the future, investing the same amount of money into the information and educational programs? There is always a resistance effect. Thus, people who do not perceive health risks will become more resistant to information delivered. That's why the policy makers should either find more sophisticated ways to approach this category of adolescents or invest additional funds into anti-tobacco campaigns.

The dynamics of perception affects the susceptibility ratio, CR, and RR.

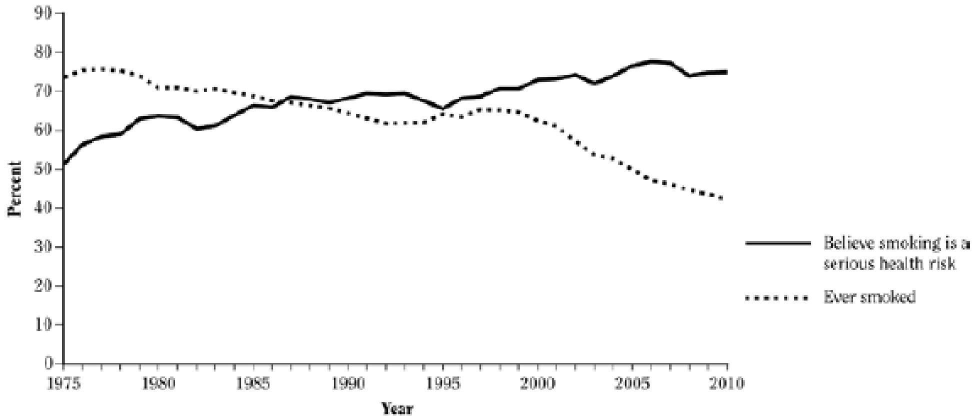


Figure 2.4 Trends in the percentage of high school students who believe that smoking represents serious health risks, and the percentage of high school students who have ever smoked; MTF 1975-2010; the USA (Johnston, 2015)

2.2.7 Marketing

Tobacco business uses different marketing techniques to increase sales and gain market share. It has consistently denied that its efforts affect smoking behavior of adolescents. At the same time evidence (NDSCPPRT, 2008) demonstrates that over the last decade the industry's marketing activities have been "a key factor in leading young people to take up tobacco, keeping some users from quitting, and achieving greater consumption among users".

According to the Tobacco Master Settlement Agreement (1998) the direct advertisement of tobacco products is not allowed, but the companies still actively approach the potential customers, including adolescents by influence their biology (or personality), social situation, and cultural environment (appendix 3) (SR, 2012). In this case, the availability of cigarettes (perceptional and physical) is considered as the environmental factor affecting smoking behavior.

Youth remain influenced by advertising and promotional efforts that can be considered under 4 "Ps": Product, Price, Promotion, and Placement (Cummings, 2002). If the features of Product have been already discussed in section 1.2, there are more details related to Price and Promotion.

Price effect

The cigarettes price is a significant determinant of tobacco supply and demand. It comprises of the wholesale price, federal, state and local excise taxes, and sales tax. The tax rates are the subject of the tax regulation (section 1.2).

The US market for tobacco products was considered highly concentrated, with little price competition. But in recent years, the price-discounting has become a key marketing strategy in the tobacco industry as an intention to compensate the increasing pressure of taxes .

Some researchers believed (SR, 2014) that because of the addictive properties of nicotine, tobacco demand might be inelastic to the price. Contrary to this, numerous econometric studies have confirmed that an inverse relationship indeed exists between the prices of cigarettes and their consumption (SR, 2012). For instance, Chaloupka (1999) states that a 10% increase in the cigarette price will result in a 3–5% reduction in consumption. At the same time, Katzman (2007) argues that the total price elasticity for cigarette demand among adolescents ranges from -0.556 to -0.857; DeCicca (2008) found that it can be measured from -0.59 to -0.79. It is suggested that the actual price elasticity is characterized with the non-linear relationship depending on the prevalence in smoking, and ranges from -0.5 to -0.8.

Several recent studies also examined the impact of price on the initiation and cessation of smoking among adolescents. For example, Cawley (2004) found that the price elasticity of initiation can be represented as -1.12. At the same time Ross (2005) estimated the price elasticity of cessation as a range from 0.3 to 0.9. These values are taken for the SD model as well.

As a justification for the findings related to the price elasticity, it is possible to compare how the average price of cigarettes has changed over the last two decades with the similar patterns of prevalence in smoking among adolescents in the USA (Figure 2.5).

At the same time Figure 2.5 shows how the prevalence of smoking has continued to decline between 2002 and 2007, despite the steady development of cigarette prices during that period. Moreover, the significant increase in the federal tax in 2009 doesn't seem to make an appropriate effect on the smoking behavior. This requires observing additional factors as well.

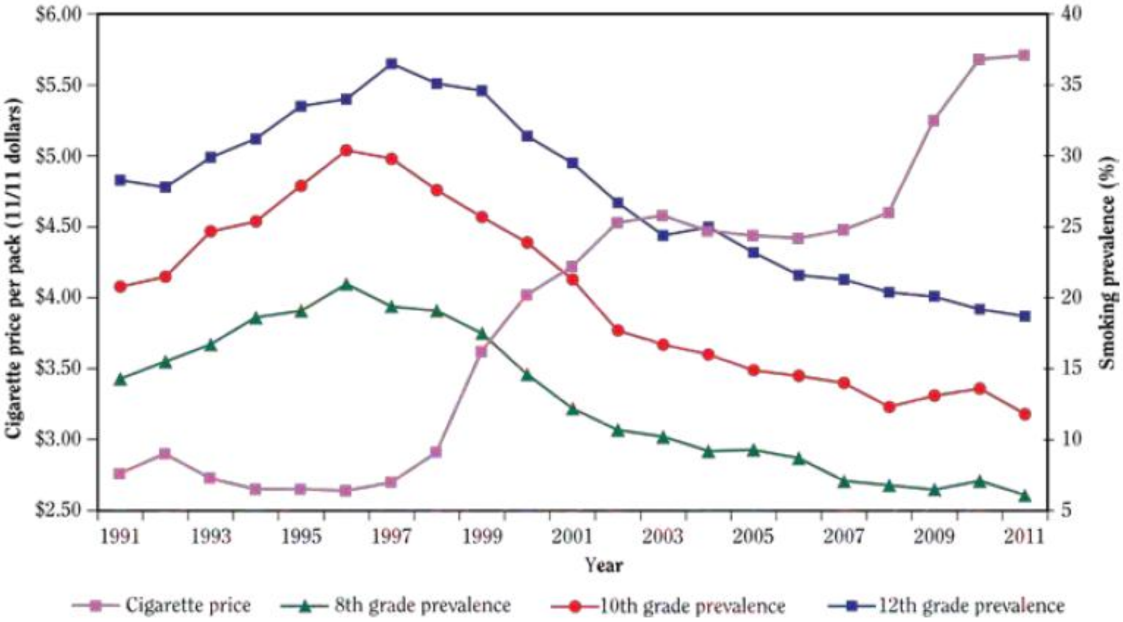


Figure 2.5 Average cigarette prices and prevalence among adolescents by grade, the USA, 1991-2011 (Orzechowski, 2011)

It was found that the increase in cigarette prices affects not only the consumption, but also the average number of cigarettes smoked by smokers and the regularity of smoking with an average elasticity of -0.52 (Tauras, 2005). At some point the continuous decrease in cigarettes availability can also make an adverse effect, as adolescents are considered as risk-taking. A desire to obtain the "forbidden fruit" can be a motivation for them to keep experimenting with smoking.

There is some evidence that the cigarette industry uses its pricing promotion strategies to respond to tobacco control efforts other than tax increases. For example, in states with stronger state and local tobacco control policies, "the increased advertising partially offsets the effects of the higher prices, increasing cigarette consumption by 2.7 to 4.7%, and hence blunting the effects of the price increase by 33–57%" (Keeler, 2002). Similar characteristic is observed in North Dakota.

Promotion and distribution

The evidence is sufficient to conclude that there is "a causal relationship between advertising and promotional efforts of the tobacco companies and the initiation and progression of tobacco use among adolescents" (SR, 2012). The actual effects of tobacco advertising on tobacco use have been described in reports of the Surgeon General (SR, 2014) and NCI monograph (2008). The advertising influence on adolescents is complex and dynamic. It was conceptualized according to existing theories of health behavior (appendix 3).

Almost 30% of the tobacco companies' revenue is spent on marketing efforts. In 2008, tobacco companies spent $9.94 billion on marketing of cigarettes which is 48% higher than in 1998, the year the Master Settlement Agreement was signed (SR, 2012).

Expenditures on price discounts accounted for nearly three-fourths of total expenditures compared to traditional marketing with less than 2% of total spending (SR, 2014). They mainly cover price discounts, coupons, bonus cigarettes, public entertainment (for adults).

Advertising, promotion, and smoking in movies (described in section 2.2.4) all directly influence distal-level factors (SR, 2014), such as exposure to other smokers, peer attitudes, cultural practices, and beliefs about smoking consequences. Thus, susceptibility can be increased as "a function of receptivity to promotional items" (SR, 2012). Pierce (1998) estimated that, 34% of experimentation with smoking by adolescents can be attributed to tobacco marketing.

The retail sales of cigarettes are prohibited to minors by the federal law (Family Act, 2009). But in fact, the compliance to this restriction is reported at the level of 70%. Moreover, the surveys (TRBHSS, 2011) show that shops (usually the gas stations) remain one of the main sources of cigarettes for adolescents.

2.2.8 Nicotine Dependence Level

Empirical evidence demonstrates that there is "a causal relationship between smoking and addiction to nicotine" (SR, 2012) Trials, experimentation, and conversion to regular smoking, develops nicotine tolerance. At the same time, as it is stated in section 1.2, NDL is one of the factors that reinforce the use of tobacco products.

NDL is affected by the desired blood nicotine concentration (BNC), the level of depression and second-hand smoking. NDL varies at all stages of smoking development. Even non-smokers can be initially addicted because of parental influence and other environmental factors. NDL is measured by NDSS scale ranging from 1 to 4.

Usually BNC is perceived by smokers differently compared to its actual level in blood (similar to alcohol models (Moxnes, 2009b)), because of the delays within an organism. Nicotine is supplied immediately to the bloodstream after the first puff (intake), and is eliminated during metabolism processes, which introduces a delay. The time necessary to metabolize nicotine differs among tobacco products and NRT (appendix 4), but for the purpose of this research it is assumed to have a half-life of 2 hours (Benowitz, 2009).

The average cigarette in the USA contains 1mg of nicotine (DiFranza, 2005) that actually enters the body. A concentration in the body from 50mg/kg to 100mg/kg is considered an overdose for a human organism that can lead to death (SR, 2014). Therefore, this certain limit is incorporated within the model, restricting the adverse effects of this factor.

The continuous increase in BNC updates the desired level of BNC, which changes the smoking behavior and influences the frequency (number of days in a month) and the intensity (number of cigarettes per day) of smoking. It affects the overall nicotine intake. In case of quitting smoking, for instance, with the Cold Turkey method (SR, 2014), it is assumed that in 1-3 months the ex-smoker can significantly decrease NDL (DiFranza, 2005) and recover from the addiction.

Smoking frequency can also be affected by the perception of cigarette availability, the contact rate with a peer community, available tobacco flavors (especially in case of adolescents), and NDL. According to the latest findings of A. Selya (2013) it is hypothesized that the quantity of smoking "is a stronger predictor of increased regularity" at the stage of experimentation, while NDL dominates when smoking is more regular (Figure 2.6). This idea is reflected in the non-linear functions within the model.

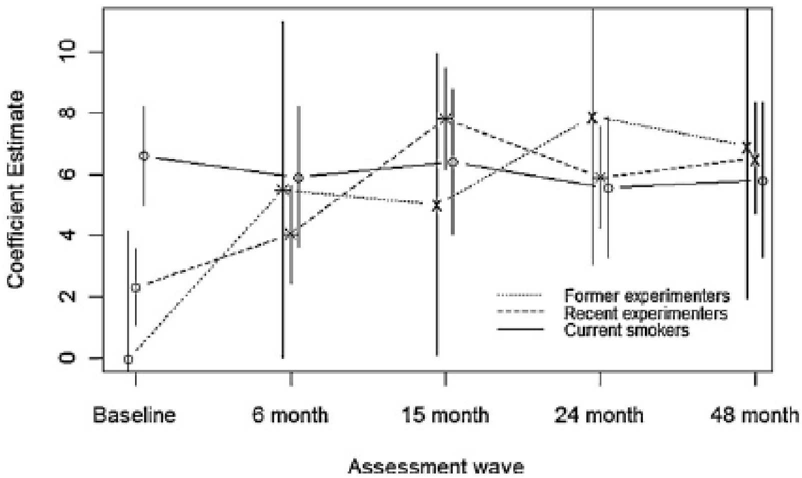


Figure 2.6 Time-varying effect of NDSS on adolescent smoking regularity, A. Selya, 2013

Thus, NDL correlates with frequency of smoking as it is shown on Figure 2.8.

	Percentage by category % (95% CI)	Smoke >15 cigarettes per day[a] % (95% CI)	First cigarette within 30 minutes of waking % (95% CI)	Nicotine Dependence Syndrome Scale Mean % (95% CI)
Overall	100.0	5.5 (4.9–6.1)	29.7 (28.4–31.1)	2.29 (2.27–2.30)
Number of days smoked in past month				
<10	47.1 (45.7–48.4)	1.0 (0.7–1.5)	12.1 (10.7–13.6)	1.95 (1.94–1.97)
10–19	14.6 (13.6–15.6)	2.1 (1.3–3.3)	18.4 (15.9–21.3)	2.17 (2.13–2.20)
20–29	14.7 (13.7–15.7)	3.1 (2.2–4.4)	30.4 (27.4–33.7)	2.44 (2.40–2.47)
30	23.7 (22.6–24.8)	18.0 (15.9–20.2)	65.2 (62.6–67.7)	2.92 (2.89–2.95)

Figure 2.7 Indicators of cigarette smoking and NDL among 12- to 17-years-olds current smokers; NSDUH, 2007-2010 ; the USA

At the same time smoking frequency has an effect on smoking intensity, increasing the number of cigarettes smoked per day (Figure 2.8).

Number of days	<1 cigarette smoked per day % (95% CI)	1 cigarette smoked per day % (95% CI)	2–5 cigarettes smoked per day % (95% CI)	6–10 cigarettes smoked per day % (95% CI)	11–20 cigarettes smoked per day % (95% CI)	>20 cigarettes smoked per day % (95% CI)
1–2	52.2 (48.2–56.2)	31.9 (28.5–35.5)	14.4 (12.0–17.2)	1.3 (0.5–2.9)	0.0	0.3 (0.1–1.0)
3–5	22.6 (17.7-28.5)	33.8 (27.1–41.4)	40.5 (35.2–46.0)	2.3 (1.1–5.0)	0.4 (0.1–2.1)	0.3 (0.0–2.4)
6–9	17.6 (12.0–25.2)	23.3 (17.8–29.8)	52.2 (43.9–60.4)	6.0 (3.2-11.0)	0.8 (0.1–4.8)	0.1 (0.0–0.4)
10–19	6.8 (4.5–10.2)	21.4 (16.3–27.5)	62.8 (55.6–69.5)	7.8 (5.1–11.7)	1.2 (0.5–3.1)	0.0
20–29	0.5 (0.1–2.1)	8.9 (4.8–15.8)	76.5 (68.8–82.8)	12.5 (8.3–18.6)	1.5 (0.5–4.6)	0.0
All 30	0.3 (0.1–1.3)	3.8 (2.4–6.0)	35.8 (32.1–39.7)	34.1 (30.1–38.4)	15.3 (12.8–18.1)	10.7 (7.4–15.2)
All current smokers	20.0 (18.4–21.8)	20.1 (18.3–22.0)	39.3 (37.2–41.5)	12.8 (11.1–14.8)	4.7 (3.8–5.7)	3.1 (2.2–4.2)

Figure 2.8 Percentage distribution of smoking intensity among high school students, by number of cigarettes smoked per day during 30 days preceding the survey; YRBS , 2009; the USA

Adolescents that experience symptoms of depression are at higher risk of starting to smoke than non-depressed adolescents. For instance, high school students with depressive disorders are substantially more likely (28.3%) to smoke cigarettes and become nicotine dependent in North Dakota (Muus, 2012) than persons without disorders (16.0%). Thus, the level of depression affects NDL. It is associated with smoking behavior, though inconsistently, and is strongly associated with unsuccessful cessation attempts (Selya, 2013).

At the same time, it was believed that the nicotine helps to alleviate the depression symptoms. In contrast, some studies (Goodman, 2000) suggest that current smoking predicts depressive symptoms. Non-depressed nonsmokers among adolescents are more likely to become depressed if they started smoking. It is obvious that additional evidence is needed to justify the relationship between mental health and developmental disorders and smoking.

There is a suggestive evidence that NDL appear to be heritable, and parental smoking may partially influence offspring smoking of adolescents through NDL (Fergusson, 1998). Thus, it was found that parental smoking correlates with NDL among non-smokers through exposure to second-hand smoking (Selya, 2012).

NDL influences the susceptibility ratio, progression, cessation and relapse flow rates.

2.2.9 Alternative nicotine delivery

Adolescence is a time of change and experimentation. Adolescents may be experimenting with different tobacco products as well as trying alcohol and other drugs. Therefore, the use of multiple nicotine delivery systems and subsequent smoking development is prevalent among youth. According to Figure 2.9, less than half of high school tobacco users reported using a single product. The statistics of tobacco use by grade is provided in appendix 5. Because young people associate the use of one form of tobacco with the use of other tobacco products, it is particularly important to monitor all forms of tobacco use in this age group (SR, 2012).

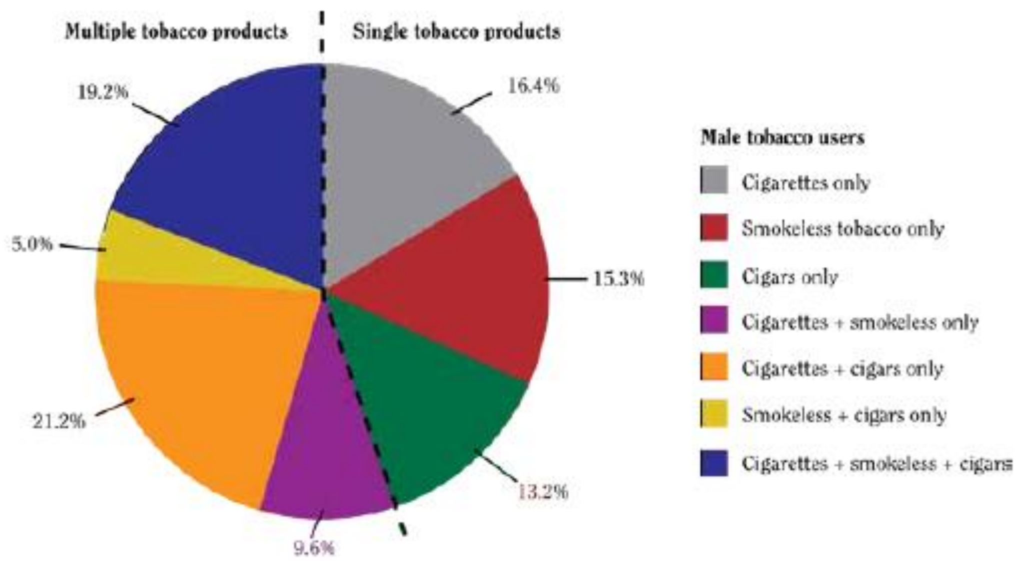


Figure 2.9 Prevalence of current use of multiple tobacco products among high school students; YRBS , 2009; the USA

At the same time, the use of smokeless tobacco, e-cigarettes, their alternatives, and NRT also make their contribution to the intake of nicotine. Thus, the use of multiple tobacco products may reinforce addiction, as well as lead to greater health problems (SR, 2012).

The nicotine intake absorbed into blood during the smoking session is different for tobacco products. Therefore, it was assumed that nicotine intake varies in the range from 0.5 to 2 mg after such session. NRT was eliminated from the research as it is not so significant at this age.

E-cigarettes

According to section 1.2, e-cigarettes are becoming popular among adolescents in North Dakota. In 2014, e-cigarettes were the most commonly used tobacco products among middle (3.9%) and high (13.4%) school students (Johnston, 2015). The availability of flavors affects the frequency and intensity of smoking. The stylish design and relatively easy accessibility influence the susceptibility to initiation. E-cigarettes also deliver nicotine to bloodstream from 0.5 to 1 mg per one session, and as a result affect BNC and NDL.

There are different pros and cons of using e-cigarettes, and its potential consequences stated in section 1.2. But the following feedbacks are still ambiguous. To avoid the overconfidence in any of them, I hypothesized two possible scenarios of the effect of e-cigarettes on smoking conventional tobacco. This represents potential hopes and fears of stakeholders.

Optimistic scenario

Relying on the arguments of supporters, e-cigarettes are generally found to be lower in toxicants than traditional tobacco. Thus, they could bring potential harm reductions and help quit smoking conventional cigarettes. It is assumed that 15% of current smokers that experiment with e-cigarettes will eventually quit. On the other hand, e-cigarettes can help to cut down the intensity of smoking cigarettes by 20%.

Pessimistic scenario

According to opponents of e-cigarettes, “people who initiate nicotine exposure with e-cigarettes might also be at risk for subsequent use of more toxic products, including cigarettes” (SR, 2014). For instance, 14.6% of those adolescents, who had tried both cigarettes and smokeless tobacco, started experimenting with smokeless tobacco first and then switched to cigarettes (Johnston, 2015). In 2012 it was found that among middle school student who have ever used e-cigarettes 20.3% reported never smoking conventional cigarettes. This number constitutes 7.9% (SR, 2014) among high school users. According to Fremming (2014) “students in North Dakota who have tried e-cigarettes are almost twice as likely to try conventional cigarettes”. I assumed that 10% of those will initiate smoking cigarettes in one year. Moreover, the current advertisement of e-cigarettes can revive the general smoking habit and make it effect on social pressure of conventional cigarettes.

Recently the research conducted by Al-Delaimy (2015) showed that smokers who used e-cigarettes were 59% less likely to quit smoking compared to those smokers who never used e-cigarettes. This finding is also incorporated in the pessimistic scenario.

The future growth in e-cigarette consumption depends on the evidence of negative health consequences and anti-tobacco regulations applied in this sector of tobacco market. But so far a lag in the perception by adolescents of true health risks of e-cigarettes and “naive enthusiasm” (Sterman, 2000) can still reinforce the prevalence in smoking among teenagers. For instance, according to MTF report (Johnston, 2015), the percentage of students who perceive “great risk” in using e-cigarettes regularly at 8th, 10th, and 12th grades constitutes 14.5%, 14.1%, and 14.2% respectively. E-cigarettes have a lower perceived risk for regular use than any other drug in the survey, including alcohol.

The actual health risks of this category of products will be strongly determined by how they will be marketed and how they will be actually used (SR, 2014).

2.3 Model Structure

This section describes the model structure that is based on the model assumptions formulated in section 2.2. The structural representation of the model hypothesis explains how the system of smoking development works, and how problematic behavior occurs.

The detailed documentation of the model that includes equations, units of the parameters, and references to the sources of information used for quantification, is attached to Appendix 6. The IThink model with the appropriate guidelines can be found in the model file. The detailed explanation of the structure is provided on the story-telling layer of the model.

As it is stated in section 2.1., the model structure includes the stage model (Figure 2.1) and several factors organized either as separate parameters or in the modules. The simplified view of the general SFD model structure is depicted in Figure 2.10.

The interrelations between the model parameters form several feedback loops that drive the model behavior. The most substantial feedbacks are generalized in section 2.4.

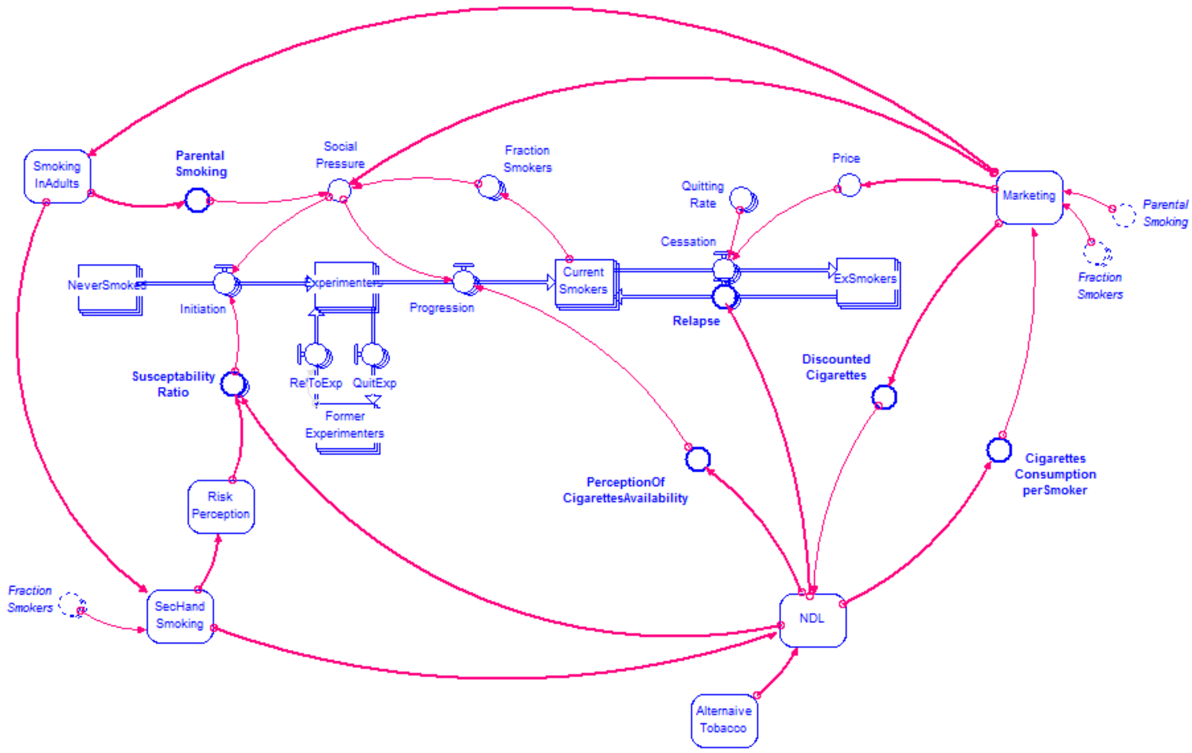


Figure 2.10 The simplified view of the model structure, IThink software

Smoking in Adults module

This sector primarily generates the number of smokers in adults, providing the output for calculation of parental smoking.

The sub-model of smoking development in adults incorporates more simplified structure compared to the adolescents' model. There are only two main stocks: current smokers and ex-smokers. The maturing rates from the adolescents' structure flows into the appropriate stocks. There are transition flows in between, representing cessation and relapse flows.

It is assumed that 30% of smokers initiate their habit in adults (SR, 2012).

The relapse ratio is treated as exogenous in this case. The basic quitting ratio (the fraction of smokers who want to quit smoking) is equal to 0.55, and the relapse ratio – to 0.44. However, it is found that only 46% of quitting attempts are successful (SR, 2014). There is a price effect that influences the cessation rate with an elasticity varying from 0.3 to 0.9 (Ross, 2005).

There are two balancing effects from smoking-related mortality and actual level of prevalence in smoking among adults. The first causality shows the constraint in the reinforcing nature of tobacco epidemics, when smoking leads to the increasing number of deaths and diseases. The second causality shows the constraint in the success of anti-tobacco policies, related to a resistance effect of those adults who continue smoking.

There is also the idea of health risks perception incorporated into the structure of the sector. Thus, it reflects findings used by A. Zagonel for explanation of the societal lifecycles of cigarette smoking (Zagonel, 2012).

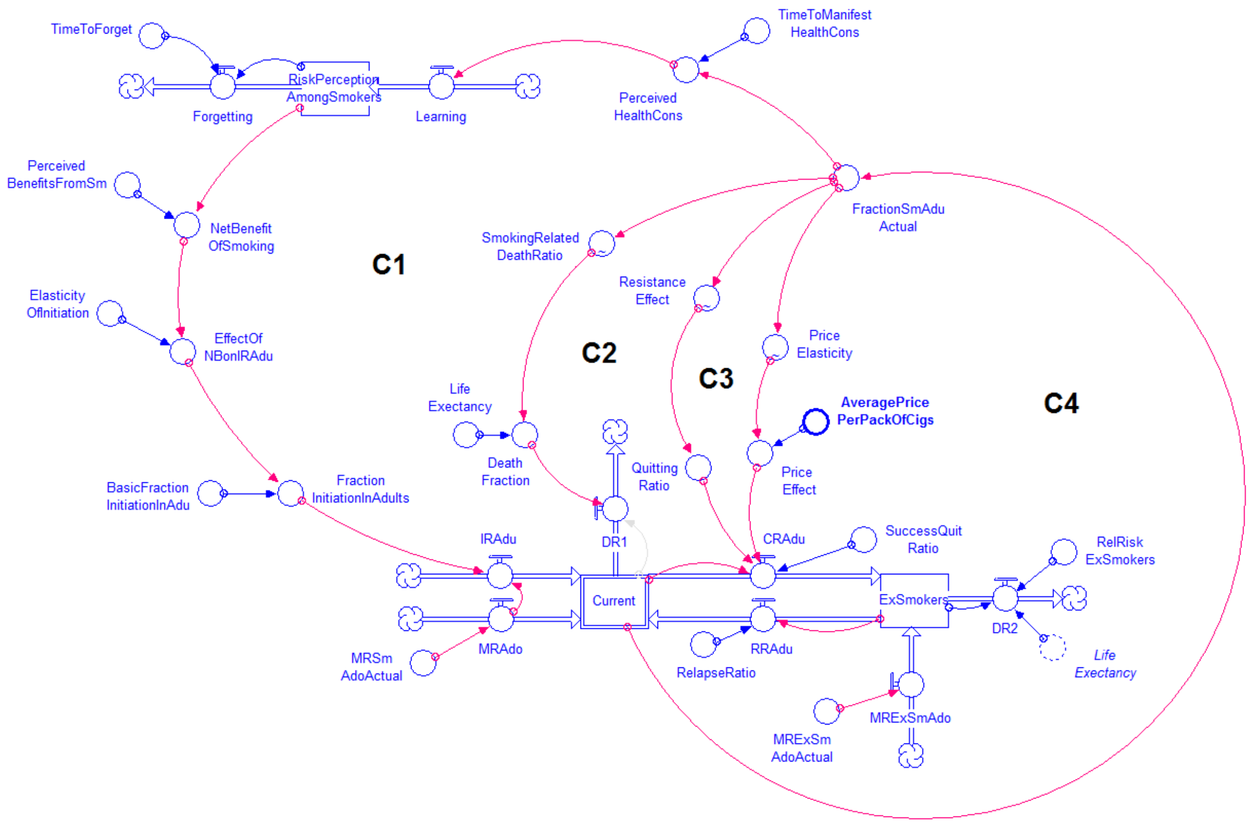


Figure 2.11 The structure of Smoking in Adults module

Second-Hand Smoking module

This sector generates the fraction of second-hand smokers among non-smokers in adolescents. This variable serves as the input to NDL sector. The changes in the fraction also affect the susceptibility ratio.

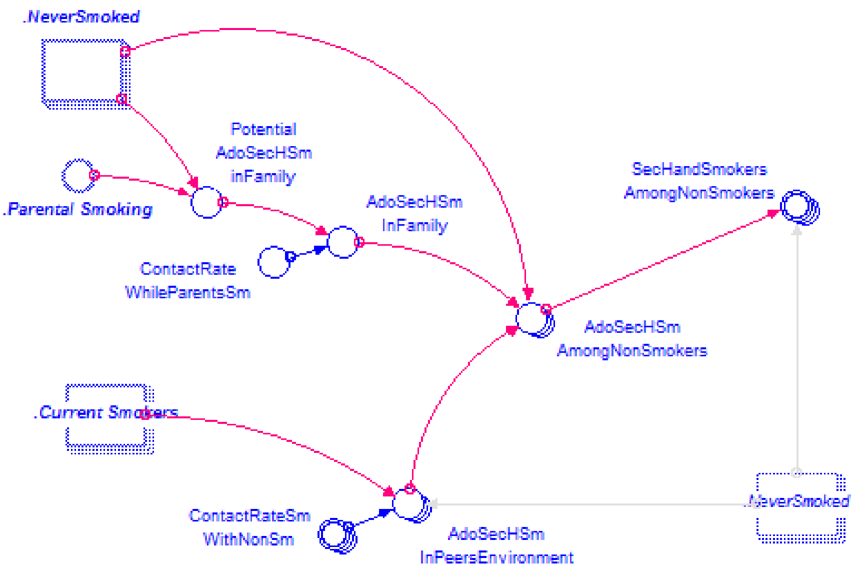


Figure 2.12 The structure of Second-Hand Smoking module

As it is stated in section 2.2, second-hand smoking can be observed mainly in a peer community and in a family. It depends on the current trends in smoking prevalence and the contact rates between smokers and non-smokers.

Risk Perception module

This sector generates the level of perception of health consequences by adolescents (middle and high school students), that mainly affects the susceptibility ratio and motivates adolescents to make a decision on progression in smoking.

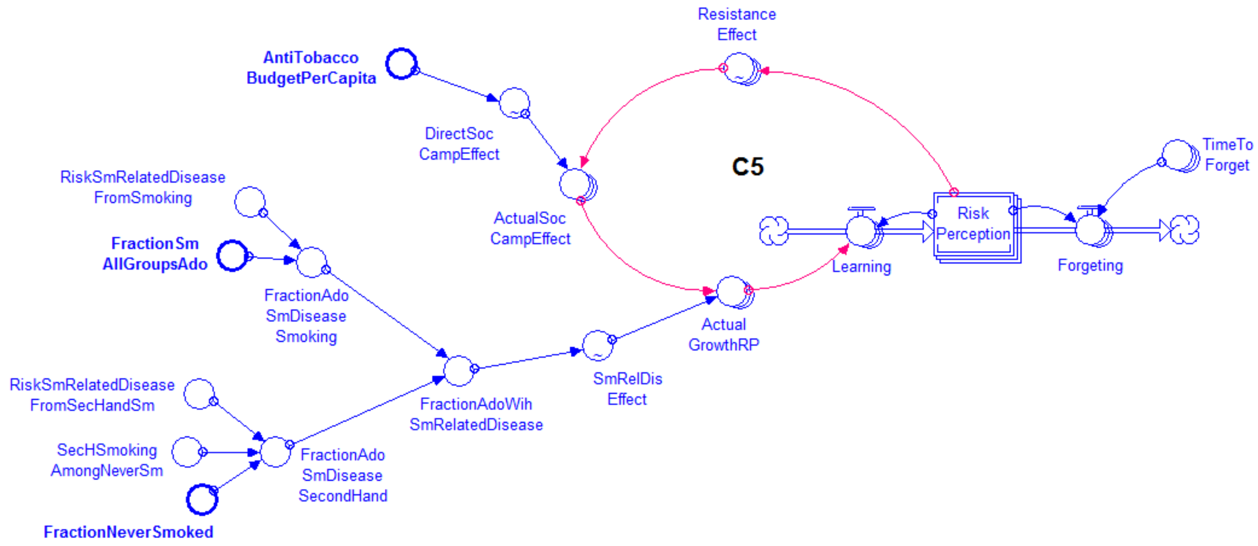


Figure 2.13 The structure of Risk Perception module

The perception of health consequences is represented as a stock accumulating the overall experience and perceived information. It can be depleted as a result of forgetting. The structure contains the array with adolescent age groups.

The actual growth rate of awareness is conceptualized as the basic growth rate that is adjusted to smoking related morbidity and the effects of social campaigns. For instance, in case of increasing prevalence in smoking, the subsequent rise in smoking-related diseases will amplify the learning process and affect the perception of health consequences. On the other hand, federal, state or local anti-tobacco campaigns can stimulate this learning practice as well by informational and educational campaigns.

The actual level of perception has a resistance effect on the effectiveness of social campaigns. It means that after reaching some level of risk perception, it is more difficult to deliver information to people who haven't perceived the health risks yet.

Nicotine Dependence Level (NDL) module

The most substantial sector within the model structure generates the actual NDL for different stages of smoking development and different groups of adolescents.

This sector represents the behavioral (decisions on progression in smoking) and physiological (actual level of nicotine in blood) sides of smoking development. It is focused on behavioral patterns of a person within each developmental stage. This structure shows how smokers progress in frequency of smoking and NDL.

NDL is represented as a stock that is changing over time and is influenced by the desired level of BNC, the level of depression, and second-hand smoking.

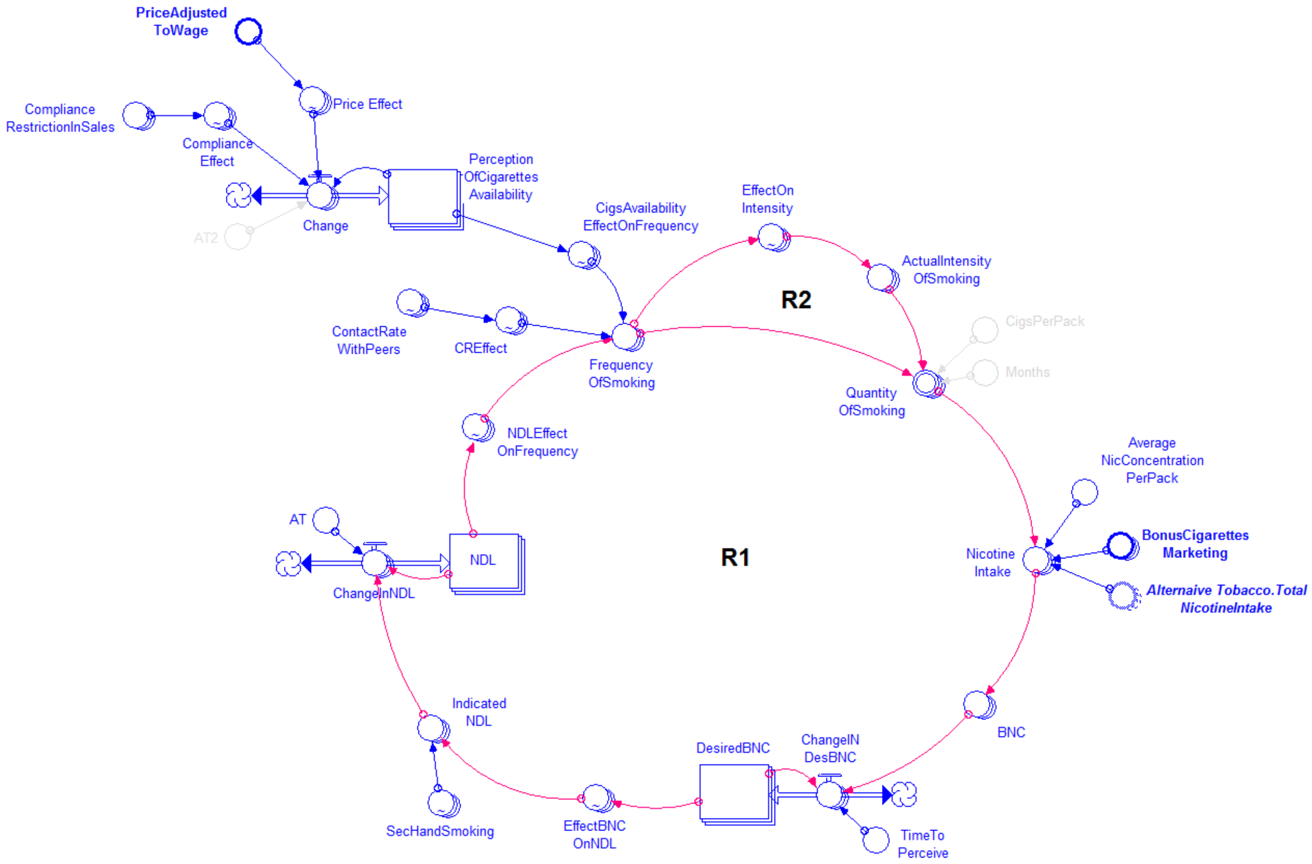


Figure 2.14 The simplified view of the structure of NDL module

The desired level of BNC is updated by the actual level of BNC. This process incorporates a delay. The desired BNC affects the NDL and the frequency of smoking as a result. Frequency and intensity of smoking are used for calculation of the nicotine intake that is delivered into bloodstream. This system feedback is described by J. Sterman (2000) as “floating goals”.

During the modeling of this structure, I faced the problem of multicollinearity that was related to the effect of three interdependent variables on NDL. Closer examination of the issue helped to reformulate the previous misperception and avoid the double-counting in the model.

Alternative Tobacco Module

This sector generates the additional nicotine intake into the bloodstream as a result of the use of alternative tobacco products (smokeless tobacco, cigars, hookahs, etc.). In regard to the research questions formulated in section 1.6, the model is particularly focused on the issue of e-cigarettes and their potential influence on the use of conventional tobacco.

The Nicotine Intake from smokeless tobacco and e-cigarettes is calculated similarly to the NDL sector. The main determinants include the fraction of current smokers (conventional tobacco) who practice the multiple use of tobacco products, the quantity of smoking and an average nicotine concentration per one session.

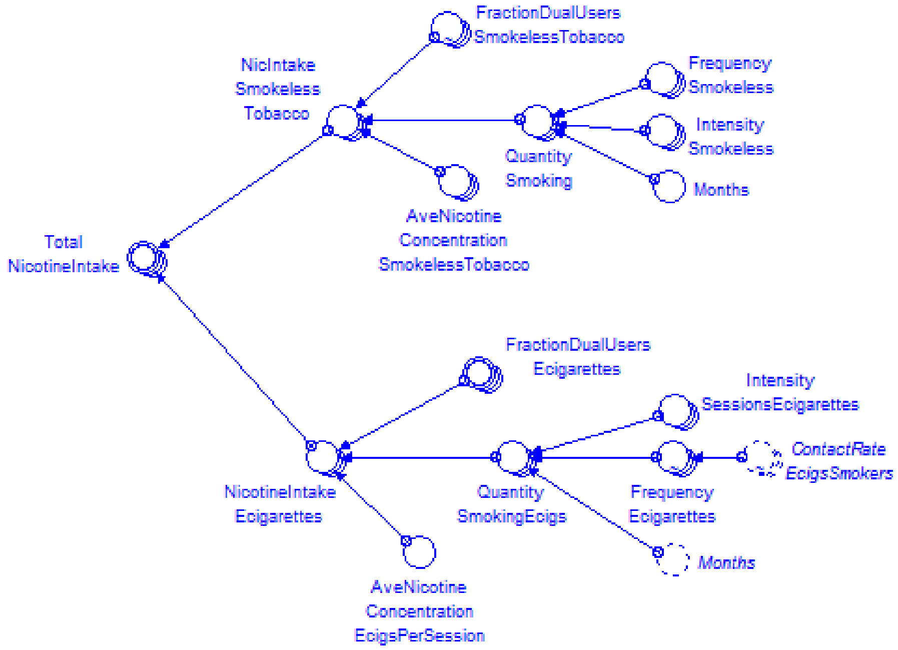


Figure 2.15 The structure of Alternative Tobacco module

Marketing Module

One of the most influential driving forces that amplify smoking development during adolescence is tobacco marketing. This sector generates the retail price per pack of cigarettes, cigarettes consumption among adolescents and adults, marketing expenditures on traditional advertisement and price discounts, and the tax revenue gained by North Dakota (Figure 2.16).

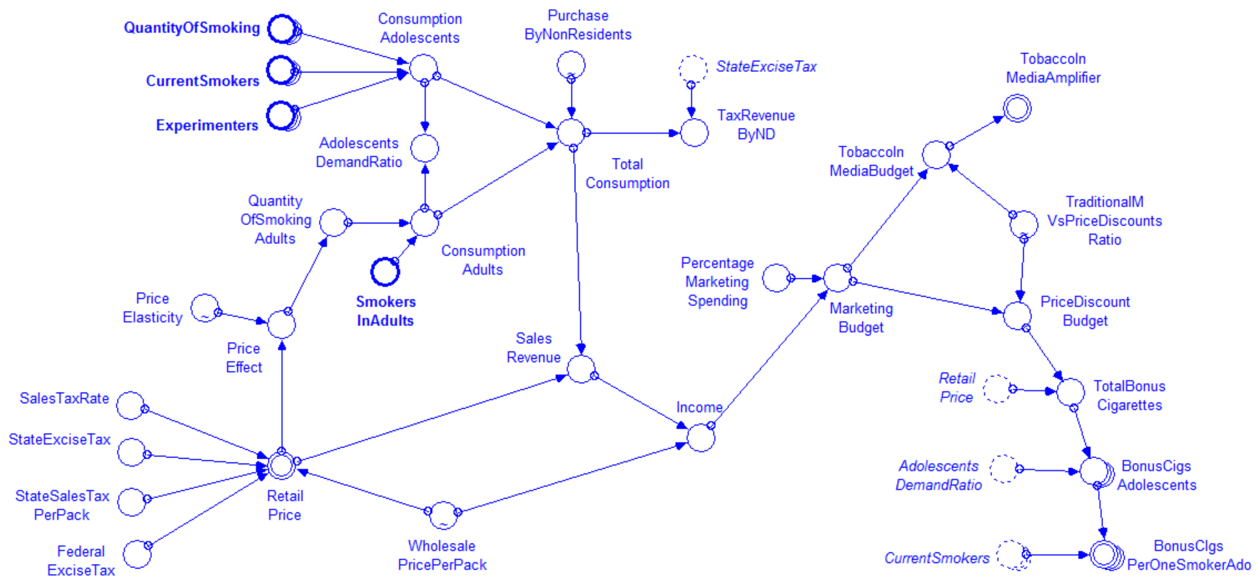


Figure 2.16 The structure of marketing module

The total consumption includes the cigarettes consumption by adults and adolescents, and by non-residents from other states and countries, where the price is much higher than in ND. The total sales are the basis for calculating the sales revenue gained by tobacco companies and the tax revenue gained by ND.

According to Stewart (2006), it is assumed that 30% of income is spent on marketing activities by tobacco companies. Marketing is conceptualized as traditional advertisement and price discounting (bonus cigarettes, coupons, etc.). The amount of investments into traditional marketing influences the tobacco in media amplifier. The price discounting campaigns offer free cigarettes to consumers that contributes to the overall nicotine intake.

2.4 Feedback Perspective

A feedback approach is different from “event-oriented thinking” (Morecroft, 2007) that is incorporated in the regression models described in section 1.6. It assumes that decision and solutions, causes and effects are interrelated and interdependent within the system boundaries. This helps to have an endogenous focus of the problem.

Several substantial feedbacks were identified within the system of smoking development described in sections 2.1 - 2.3. The interrelations that are parts of the feedback loop within the SFD are painted in a red color with a distinct shape of an arrow.

A causal loop diagram (CLD) is a visualization tool of SD methodology that shows feedback processes and helps analyze “the main interdependencies in real-world problem situations” (Morecroft, 2007). Thus, it can be insightful in understanding the roots of endogenous behavior produced within such structure.

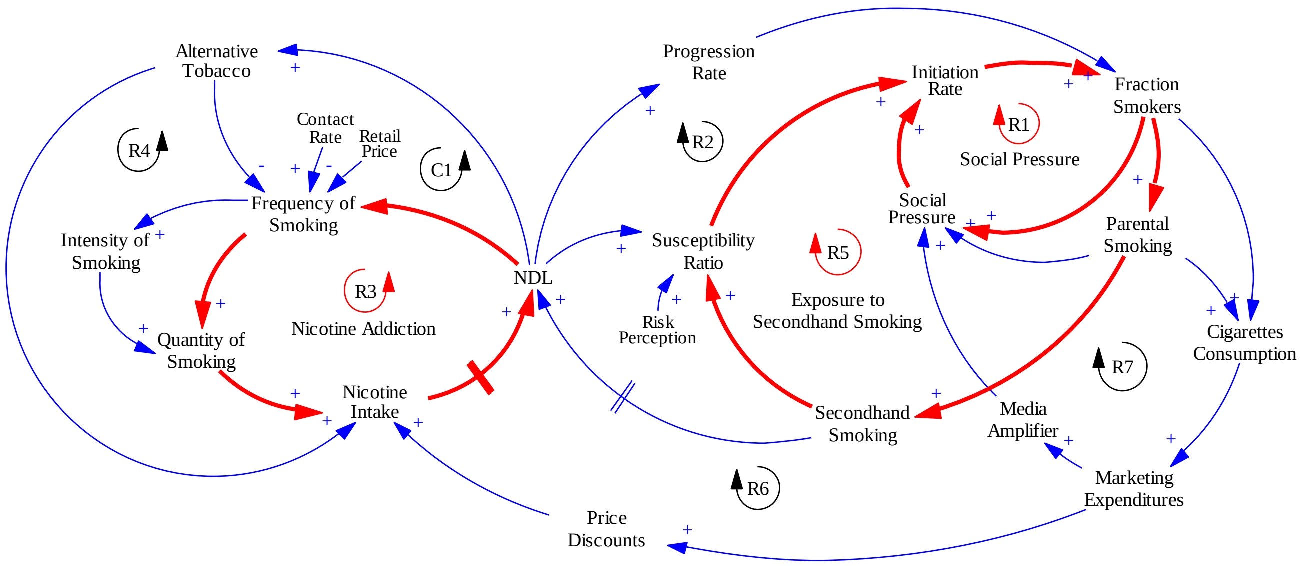


Figure 2.17 A Causal Loop Diagram for development of smoking behavior

In this research the CLD is used for a simplification of the SFD, interpretation of the identified driving forces and their communication to stakeholders. It tells the story of the system, pointing out how certain behavior emerges.

In Figure 2.17 seven major feedback loops are depicted. The epidemiologic nature of smoking incorporates several reinforcing loops (R) that intensify smoking habit among adolescents. There are three of them that represent main factors (social, environmental and behavioral) that cause the increase in prevalence. R1 feedback loop shows the influence of peer pressure. The more are the smokers among adolescents, the more non-smokers initiate smoking to interact with their friends. Similar logic works for parental smoking. R2 and R5 represent the environmental feedback loops driven by second-hand smoking. R3 describes how nicotine addiction amplifies smoking behavior.

There are two counteracting loops (C) that attenuate the driving forces described above. C1 shows how the nicotine intake decreases depression. C2, in turn, is devoted to alternative tobacco use that can potentially cut down the frequency of smoking. There are additional factors such as the retail price and risk perception that alleviate the tobacco epidemic and smoking development.

The reinforcing and counteracting loops interact within the system. For instance, at the beginning of tobacco epidemics the reinforcing drivers dominate. The awareness of health risks is not high enough to prevent people from dangerous practice, and the anti-tobacco policies are not so strong to deal with the emerging dynamics. All of this causes an increase in prevalence of smoking, similarly to what happened in the period of 1880-1964 among adults. Simultaneously health consequences occur, causing the smoking-related diseases and deaths. This problematic behavior accumulates the experience and the capacity for fighting the smoking problem. The tax regulation, informational campaigns, and other policy initiatives are reflected in counteracting loops that start dominating within the system. It leads to a decrease in prevalence. At the same time, new tobacco products are introduced in the market, reviving the dynamics described above.

There are other feedbacks within the system that are not represented in Figure 2.17. For instance, the resistance effect was described in section 2.2.6. The idea incorporates the following counteracting loop (C2) showed in Figure 2.18.

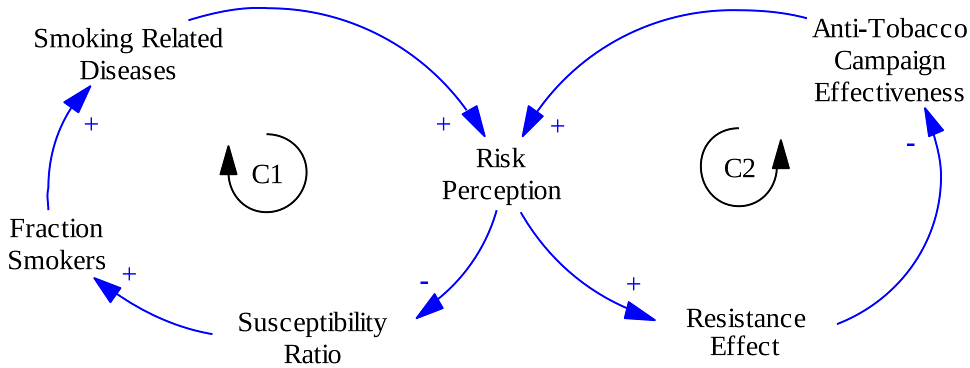


Figure 2.18 A Causal Loop Diagram for Risk Perception

"People responsible for strategy development and facing problem situations often have in mind partial and conflicting views" (Morecroft, 2007). An example of misunderstanding the real system by policy makers is presented in Figure 2.19 (to the left). It was found in the North Dakota's Strategic Plan to Prevent and Reduce Tobacco Use (2008-2013) that one of the goal includes increasing "the percentage of current smokers who have tried to quit to 75 percent, compared to 65.1 percent in 2005" by June 2010. According to the rationale behind this plan, the decrease in prevalence would stimulate those who continue smoking to quit. In fact, it happens the other way around (Johnston, 2015). Less resistant smokers quit first. But those who left are characterized as more resistant to anti-tobacco policies. This feature is represented as a counteracting loop in Figure 2.19 (to the right). The misperception characterizes the "event-oriented worldview" and "open-loop mental map". It evolves the illusion of control and leads to the subsequent policy resistance during the implementation of the policies towards those goals. Such small finding can be helpful in fostering "double-loop learning" (Argyris, 1985) and lead to a potential "shift of mind" (Morecroft, 2007) for policy makers in the field. This idea is incorporated in the model structure.

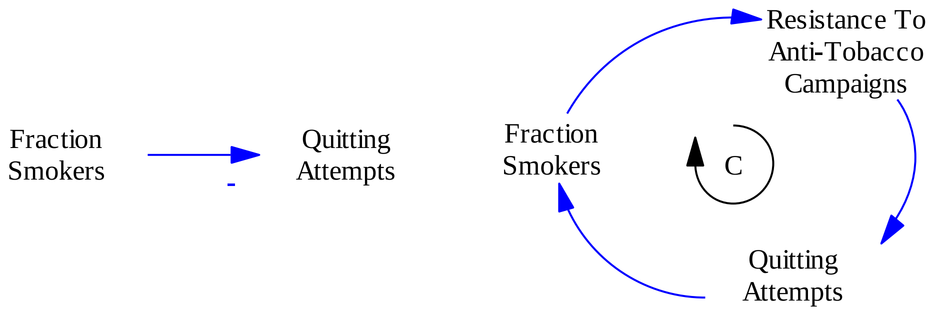


Figure 2.19 A Shift of Mind on an example of Resistance to Anti-Tobacco Policies

Interactions between multiple reinforcing and counteracting loops, and non-linear relationships within the model structure create the uncertainty of smoking development that cannot be predicted mentally. Moreover, the attempts to do so can employ different heuristics and bias. This actually explains the limitation of mental models and shortcomings of qualitative modeling (Vennix, 1996). Referring to the initial research questions, the following quantitative SD simulation is required for empirical testing of described assumptions at the following stage of the research.

This chapter described the model hypothesis within the stock-and-flow structure. The supporting model assumptions provided an argumentation for all substantial causalities related to the problem behavior and quantification of variables. The causal loop diagram creates the basis for understanding the main driving forces within the system. The next chapter will discuss the results of model simulations and will test the model hypothesis.

Chapter 3. Model Behavior

This chapter provides an overview of the simulation results produced by the model structure (discussed in Chapter 2). Simulation is used to reveal smoking development over time, to test initial model hypothesis, and to analyze the resulting behavior. Each graph is supported by the appropriate explanation and conclusions.

The control panel for simulation is placed on the interface layer of the IThink model. It contains sliders, switches and the tables of inputs that allow accomplishing several tests step-by-step. The respective informational guidelines are provided on the same page.

As it was stated in section 2.1, time horizon includes the retrospective simulation in the period of 1992-2014 and forecasting in the period of 2015-2032. The baseline includes the initial values of the stocks and model parameters in 1992.

3.1 Base Run: Explanatory Model 1992-2014

This section shows how the problematic behavior emerged in the past, and discusses its main symptoms. The investigation is focused on the comparative analysis of the resulting behavior with the reference mode formulated in section 1.4. The analysis is supported by the causal loop argumentation relying on Figure 2.17.

The behavior of several target variables is depicted in the simulation graphs. The focus of analysis is on the fraction of smokers (middle school and high school students, all adolescents), the flow rates, parental smoking, NDL, frequency and intensity of smoking, perception of health risks, and second-hand smoking (described in section 1.2 and 2.2).

Exogenous perspective

The first run is based on the initial values of the stage model and the auxiliary factors that are taken as exogenous (a data set and estimations for the period of 1992-2014).

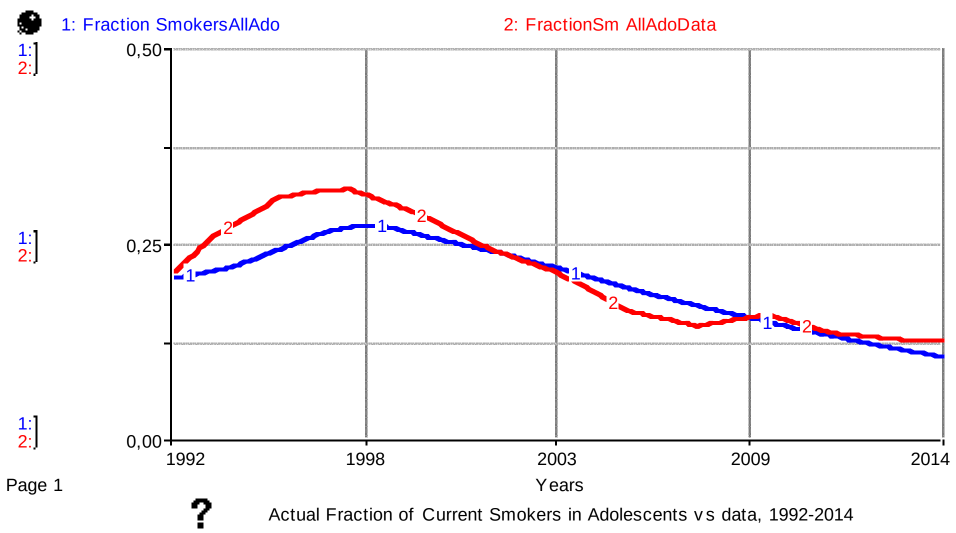


Figure 3.1 The base run: the fraction of smokers among adolescents (1- simulation, 2 – data)

As it is shown in Figure 3.1 the model is able to replicate an increase in the fraction of smokers for the period between 1992 and 1998, and then - a steady decline by 2014. Among the driving forces that caused the escalation in smoking development are:

- social pressure (R1) as the result of an increase in peer pressure and parental smoking, and the effect of traditional marketing;
- an increase in susceptibility of non-smokers to initiate smoking (R2);
- an increase in exposure to second-hand smoking among non-smokers (R2).

These factors caused an increase in the initiation and the progression rates.

In 1998 the Settlement Tobacco Agreement was signed, that resulted in banning tobacco advertisement, and restrictions in cigarettes sales to minors. This action influenced the alleviation of social pressure loop (R1) and a decrease in the perception of cigarettes availability. Simultaneously, those changes motivated adolescents to perceive the health risks related to smoking.

In 2006 a clean air policy was implemented in North Dakota. This regulation prohibited smoking in public areas. As a result, the actual contact rate between smokers was decreased by 30-35%, alleviating R3 loop.

However, the exogenous perspective doesn't show the actual inner causes of changes within the system. This fact motivates us to integrate the substantial modules to the stage model and explore the resulting endogenous behavior.

Endogenous perspective

The next set of simulations incorporates integration of the six substantial modules that create endogenous perspective of the model behavior. For this purpose, the outputs from the appropriate sectors are taken instead of data. This procedure is operationalized in several steps:

a) Integration of all substantial modules

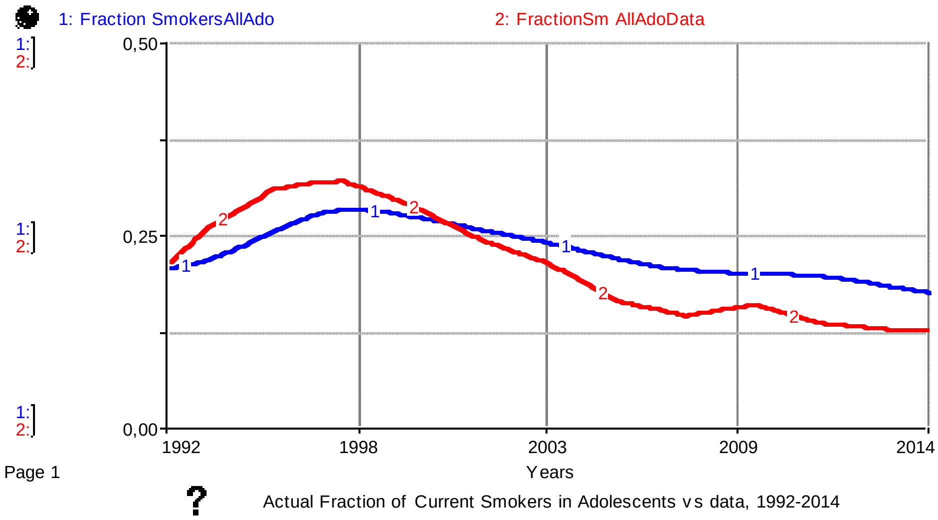


Figure 3.2 The base run: endogenous perspective (1- simulation, 2 – data)

Figure 3.2 represents the model behavior after integration of modules into one solid structure. Compared to Figure 3.1 the modeling results reflect the patterns of historical prevalence in smoking, but with some deviations after 2000. One of the explanations that can be found for this discrepancy relies on the price effects that are considered as significant determinant of tobacco regulations. However, the model in Figure 3.2 is inelastic to the price.

b) Implementation of the price effects

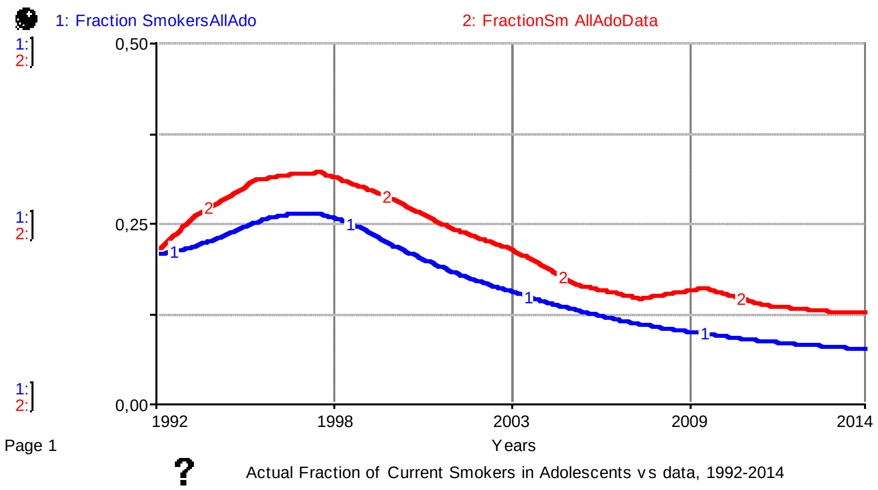


Figure 3.3 The base run: the price effect (1- simulation, 2 – data)

The price influences the model behavior through the elasticity function described in details in section 2.2.7. In this case the modeling behavior has significantly changed (Figure 3.3) compared to the previous simulation. Analyzing the potential causes of the deviations portrayed in the resulting graph, I compared the growth in the retail price of cigarettes to the growth in an average annual wage in North Dakota (Figure 3.4). These observations motivated me to adjust the price to the annual wage and explore the resulting behavior.

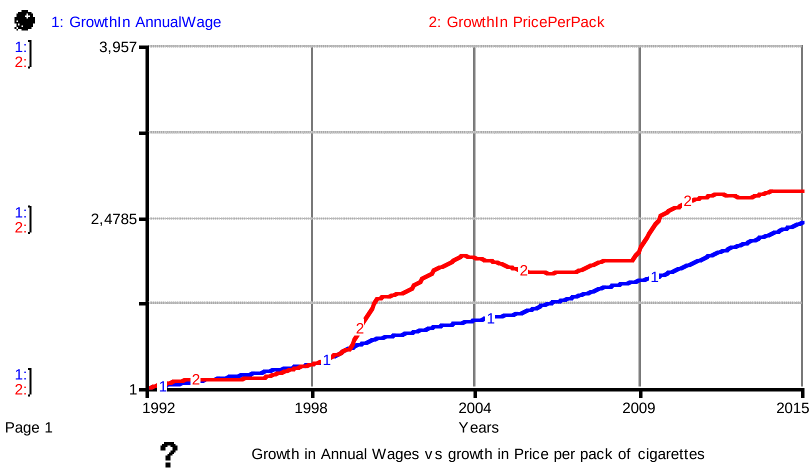


Figure 3.4 Comparison of the growth in annual wages (1) to the growth in the price (2)

c) The price adjustment to the average annual wage in North Dakota

According to the results portrayed in Figure 3.5, the initial hypothesis replicates the main trends in smoking development close to the reference mode.

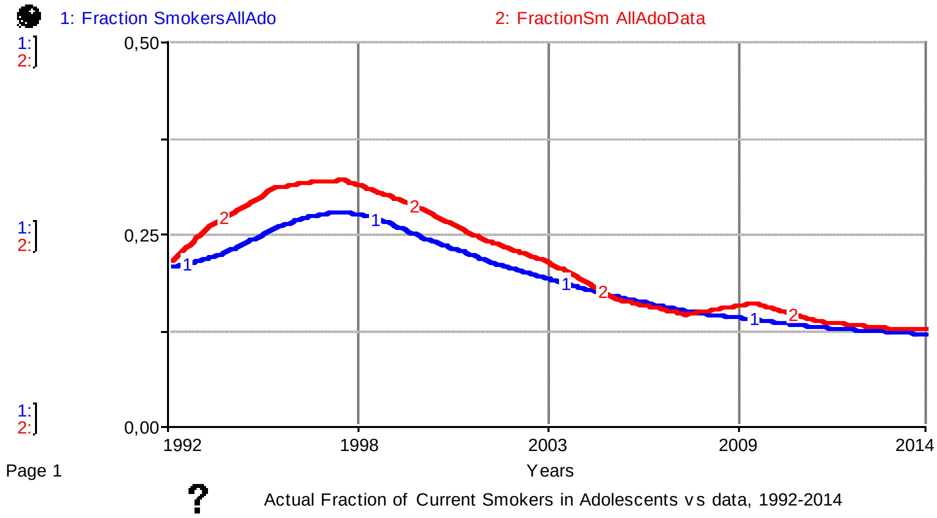


Figure 3.5 The base run: model behavior after the price adjustment (1-simulation, 2 – data)

As for other substantial parameters within the system, firstly, it is possible to analyze the impacts of marketing strategies on the NDL (Figure 3.6).

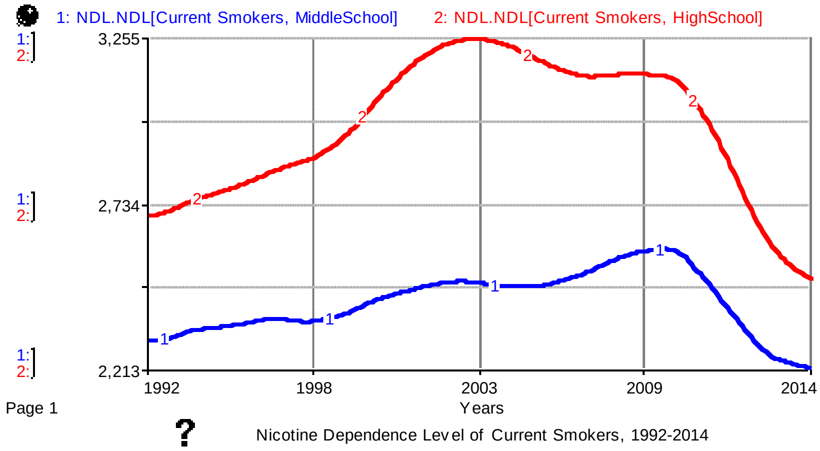


Figure 3.6 Nicotine Dependence Level among middle school (1) and high school students (2)

After the ban on traditional advertisement was imposed in 1998, the marketing strategy of the majority of tobacco companies switched to the price discounting (described in section 2.2.7). It is possible that this change was made deliberately to keep the NDL high enough to prevent smokers from quitting the habit. In 2009 tobacco companies started investing in advertisement of smokeless tobacco and e-cigarettes that weren't regulated by FDA. Thus, the graph (Figure 3.6) shows the decrease in the NDL by that period.

At the same time, it is possible to notice in the simulation results the gradual decrease in perception of cigarettes availability, frequency of smoking, and exposure to second-hand smoking. All of this alleviates R2 and R3 loops.

The income of tobacco companies has been growing since 1996 with drops in 2004 and 2009 due to the changes in the federal tobacco excise tax. The profits are used by tobacco companies to foster the development of new products that targeted the market. Smokeless tobacco, cigars, e-cigarettes and other nicotine delivery system expanded the smoking habit to multiple use of tobacco widely practiced nowadays (Figure 2.10). All of them contribute to the nicotine intake that directly influences the NDL.

3.2 Future Predictions

The 2014 Surgeon General Report states that modeling is widely used to “project future patterns of tobacco use, given various scenarios of tobacco control measures” (SR, 2014). Several existing tobacco control simulation models are focused on providing future perspectives on the progress in quitting conventional tobacco use towards meeting the national health objectives.

For instance, the projections made by Mendez (2000) indicate that the prevalence in adult smoking could be above the Healthy People 2020 objective of 12% even by mid-century, if the current strategies are not changed. Figure 3.7 shows how the potential improvements in cigarette initiation and cessation can result in smoking prevalence by 2050.

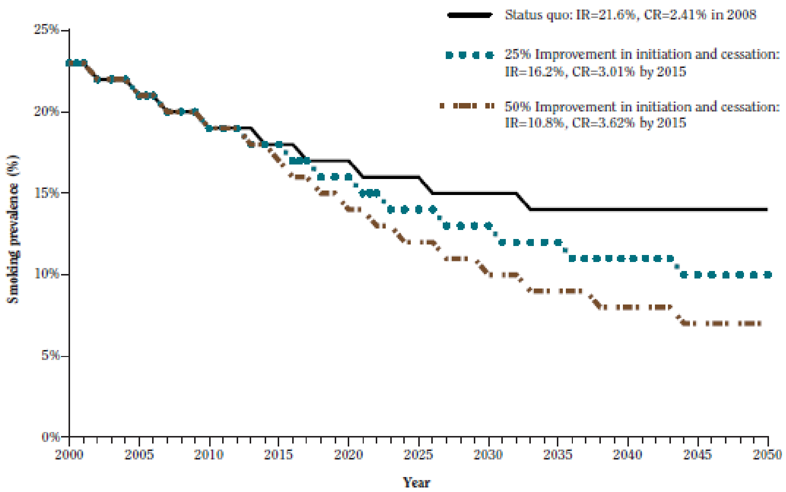


Figure 3.7 Predicted rate of smoking initiation and cessation for US adults, University of Michigan Tobacco Prevalence and Health Effects Model (SR, 2014)

Several what-if scenarios in the model of the societal lifecycle of cigarette smoking (Figure 3.8) even show the potential risk to revive the tobacco epidemic if the level of awareness is not fully maintained and controlled.

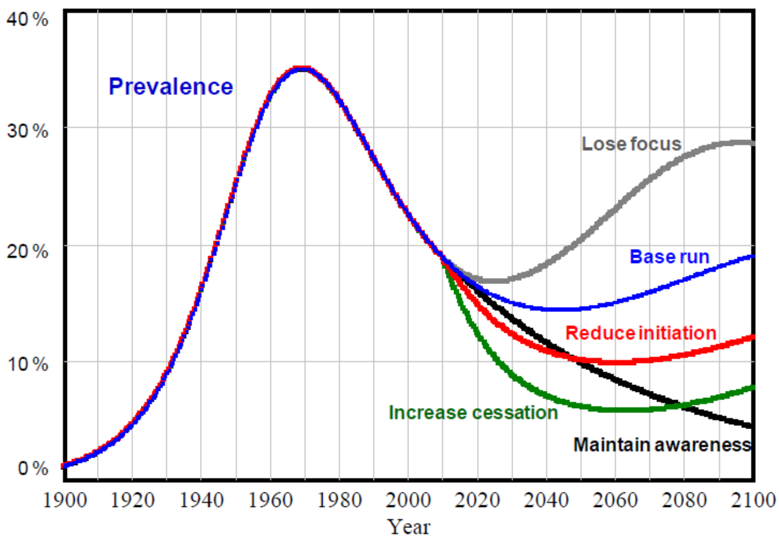


Figure 3.8 The four what-if scenarios of smoking development among adults in the USA, created by A. Zagonel, 2011

At the same time, there is a lack of experiments related to prediction of smoking behavior in adolescents when the smoking habit occurs. This particular section represents the forecast of epidemiologic measures by 2032, attempting to cover the described gap. It is based on the initial model hypothesis and current trends.

Figure 3.9 reveals the future development of smoking behavior among adolescents produced by the model simulations. The graph shows that a decline in the fraction of smokers slows down after 2010. However, there is a slight increase in 2030, similarly to the predictions in Figure 3.7.

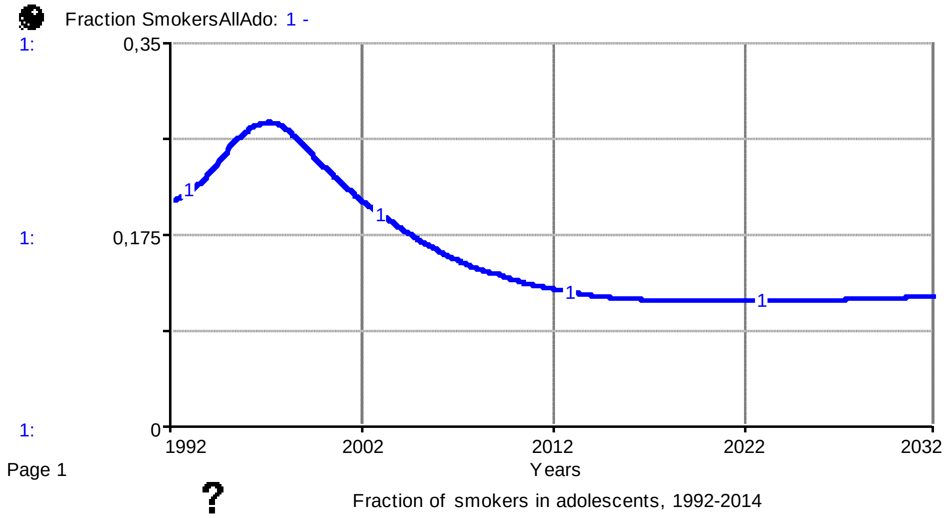


Figure 3.9 Prediction of prevalence in smoking among adolescents by 2032

The Healthy People objectives target 16% of prevalence in smoking among high school students and 12% - among adults by 2020. It is well seen in Figure 3.10 that it will not be possible to meet these goals if the system develops the same way. Therefore, the appropriate interventions are required to continue the decline in the tobacco epidemic.

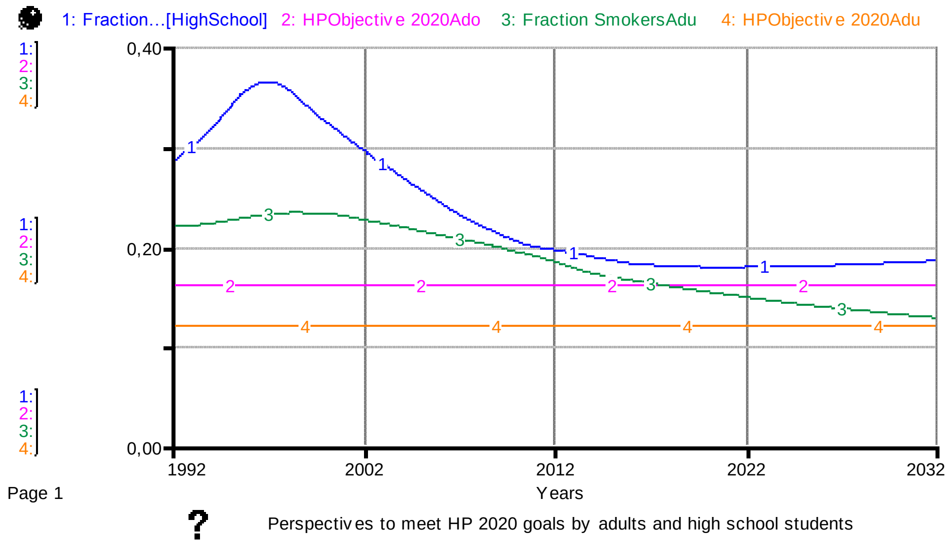


Figure 3.10 Comparison of smoking trends in adults (3) and adolescents (1) with the HP 2020 goals

To sum up, in the long-term perspective the possibility to get the next generation tobacco-free in North Dakota is ambiguous. The main reasons for this might be “generational forgetting” (Zagonel, 2012) of the true health consequences of smoking, the growing average annual wages in contrast to the unchanged state excise tax, innovative marketing measures of tobacco companies, etc. In all of these examples, the reinforcing loops still dominate the system.

The multiple use of tobacco can be considered as an additional threat that leads to uncertain health consequences and potentially intensify the prevalence in smoking cigarettes.

3.3 E-cigarettes Scenarios 2015-2032

When referring the initial research questions described in section 1.4, it is possible to test how a boom in e-cigarettes can potentially affect the system. Relying on the preliminary findings and two scenarios developed in section 2.2.9, the model underwent additional simulations.

The optimistic scenario is based on the assumption that e-cigarettes are less harmful than conventional tobacco and, thereby, are recommended to be used as an alternative to quitting smoking. Contrary to this, the pessimistic scenario states that e-cigarettes don't help quitting the habit and even intensify smoking.

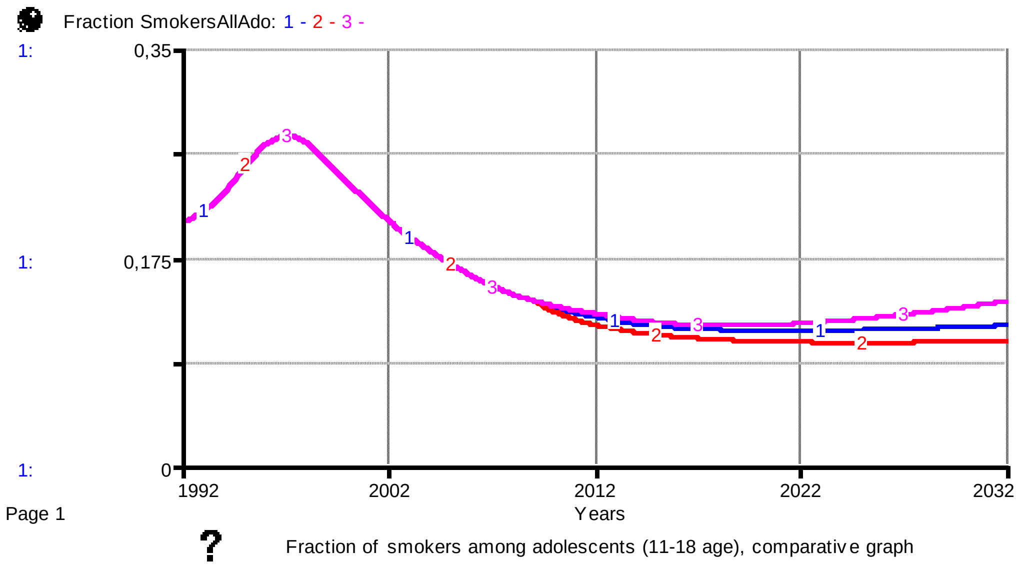


Figure 3.11 E-cigarettes scenarios: the fraction of smokers among adolescents

Relying on the assumptions formulated above, Figure 3.11 shows three main trends in the future development of smoking behavior. The first simulation (curve #1) is the model run for "business as usual" that serves as a base for comparison. The curve #2 represents the optimistic scenario with the decline in the prevalence and stabilization in 2020. The cut down in the intensity of smoking benefits the NDL (Figure 3.12), and alleviates nicotine dependence symptoms. Moreover, this optimistic scenario makes possible to meet the Healthy People objective by 2020.

The curve #3 is the result of the pessimistic scenario that leads to the gradual increase in the fraction of smokers among adolescents after 2015. It almost doesn't make any change in the NDL (Figure 3.12), but increases the contact rate between smokers that potentially can amplify the frequency of smoking.

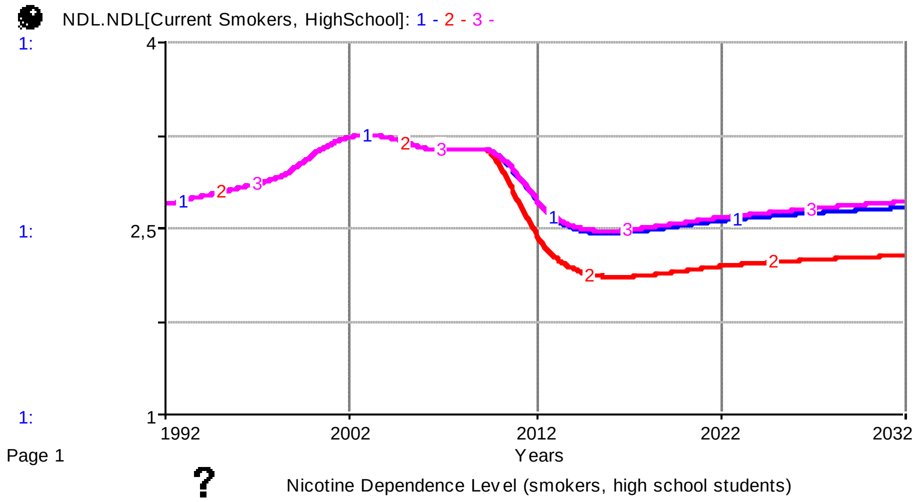


Figure 3.12 E-cigarettes scenarios: the effect on NDL
(1-base run, 2 – optimistic scenario, 3 – pessimistic scenario)

This chapter provides the simulation tests of the initial model hypothesis in the historical perspective. It analyzes the main factors that actually drive the model behavior within the feedback system. According to the future trends, it will not be possible to meet the Healthy People objectives by 2020. These findings require the immediate anti-tobacco intervention on the policy making level in North Dakota.

Chapter 4. Validation

4.1 General Overview of Model Validation

This chapter considers the robustness of the model hypothesis and credibility of the results gained during the simulations. For this purpose, a set of validation tests were established to check how knowledge was obtained and confirmed.

Stakeholders are interested in useful insights about the real system they are involved in. Their future decisions have to be based on reliable and plausible information. Therefore, the results of modeling should be carefully validated. Validity of any conclusions in a model-based study are "crucially dependent on the validity of the model" (Barlas, 1996), including its structure and behavior (Morecroft, 2007). This is also the requirement for further policy design, analysis and implementation.

Informal model validation took place at every stage along the modeling process. The development of model structure was accompanied with discussions with professor Selya and professor Wheat. The preliminary model was introduced to Eric Johnson, the head of TFND, who provided his expertise on the structural interrelations and gave a general feedback on the current trends. The final simulation results were also presented and discussed with the faculty members of Master in Public Health program at UND. The substantial findings were compared to similar SD case studies and modeling approaches. But this type of validation can not be entirely objective (Barlas, 1996) as it might incorporate the human bias, heuristics and certain level of subjectivity.

The formal validation procedure is described by Forrester (1974), Barlas (1996), and Sterman (2000). The selection of certain validation tests was based on the initial research objectives and questions. The main criteria included the specifics of the system under consideration and data available for analysis. Thus, this chapter provides an overview of several validations including behavior pattern, direct-structure, and structure-oriented behavior tests. The validation procedure follows the general logical order. First, the resulting behavior is compared to the reference mode in order to identify if the model replicates the historical patterns of the problematic behavior. This part is the most interesting for the clients. Second, the validity of the structure has to be tested, and only after the structure of the model is perceived adequate, start testing the behavior accuracy.

4.2 Behavior Pattern Tests

These tests are served to evaluate whether the behavior generated by the model corresponds to the real system. The preliminary analysis is accomplished in section 3.2. It concludes that the model is able to replicate the main trends in prevalence in smoking among adolescents observed in the historical perspective (Figure 3.5).

Additionally, I had an overview of other parts of the system in regard to replicate the reference behavior of other parameters. For instance, in case of the prevalence in smoking among adults, Figure 4.1 shows how the resulting behavior reflects the actual changes in the fraction of smokers over time. It is important to notice that the spike in 2011 (curve #2) caused by the changes in the methodology of conducting surveys. This makes it difficult to further compare the subsequent data before and after 2011.

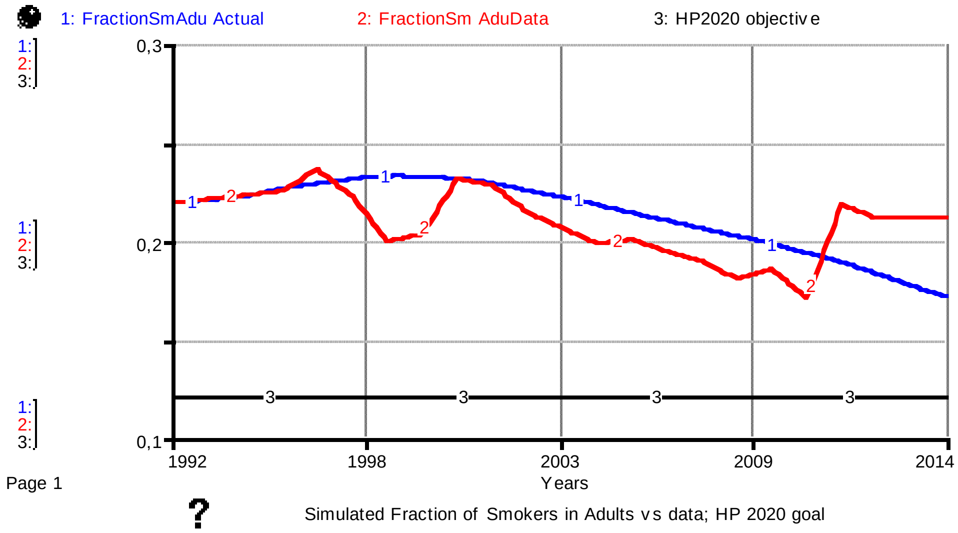


Figure 4.1 Prevalence in smoking among adults: modeling results, actual data and HP objective

Moreover, if to simulate the model by 2100 (in order to replicate the time horizon used by Zagonel (2011) and Mendez (2000)), the results (Figure 4.2) show the relative risk of an increase in prevalence in smoking. Similarly to Figure 3.7 and Figure 3.8, a decline in smoking among adults slows down after 2030 and starts a new rising cycle in the prevalence after 2045. This trend might be related to a decrease in the level of awareness (R2 loop) among adults, a growth in initiation to smoking (Figure 2.11) and a growth in smoking among adolescents. At the same time, according to Figure 4.2 the system is able to meet the HP objective only by 2039. These findings correspond to the patterns presented in the studies mentioned above, and validate the initial assumptions.

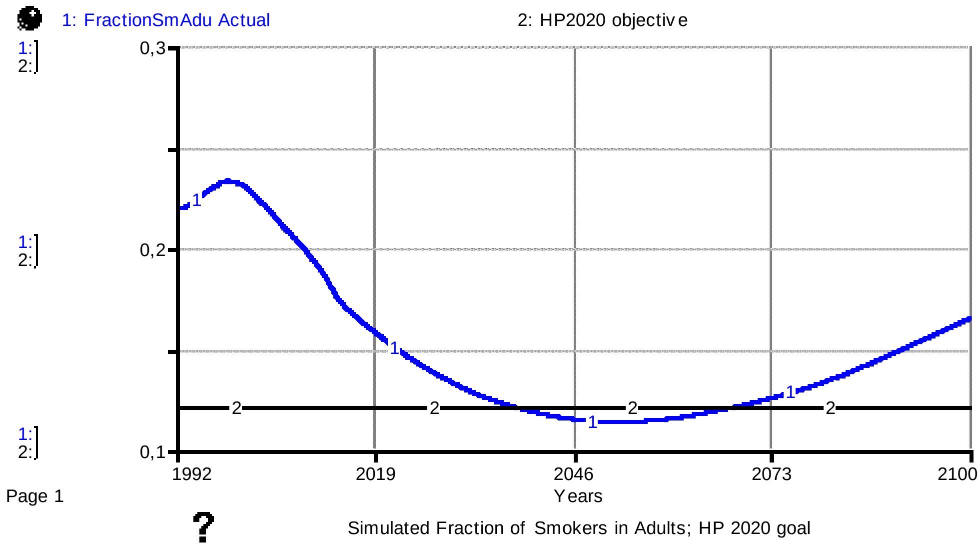


Figure 4.2 Prediction of smoking development in adults by 2100

In case of risk perception, Figure 4.3 demonstrates how the variable generated by the model (1-2) corresponds to the actual data (3-4). In general, the simulation results replicate the historical patterns with moderate level of accuracy. The deviations make up 2.1-8.6%. However, the general trend in both graphs indicates a steady increase in risk perception over time. Referring to the resistance effect described in section 2.2, additional financial assistance is required in order to keep risk perception growing by addressing anti-tobacco programs towards smokers who do not believe in the harmfulness of smoking.

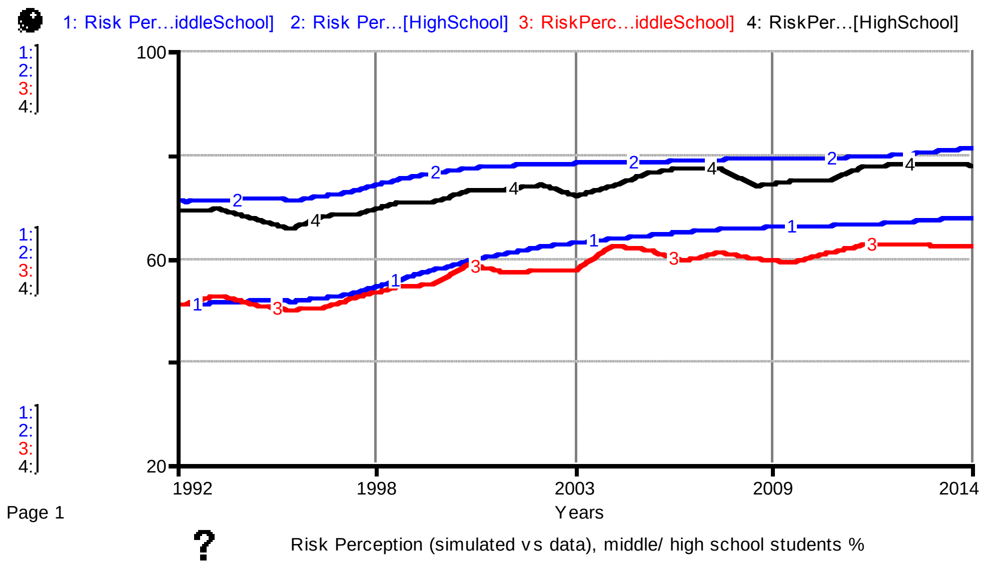


Figure 4.3 Risk Perception: simulation results vs data

If not time restrictions, additional **family member test** could be potentially conducted for other cases of smoking development in adolescents in other states or regions. Moreover, the similar model structure can be tested in the case of e-cigarette or other tobacco products.

4.3 Direct Structure Tests

Direct structure tests (or structure assessment tests (Sterman, 2000)) incorporate the evaluation of the model structure, comparing it to the available and discussed knowledge about the real system. There is no simulation involved.

The description of current smoking trends in section 1.2, the literature overview in section 1.6, and main assumptions made in section 2.1-2.3 are the basis for this analysis.

As it was stated above, the system of smoking development has the high lelel of complexity with the plurality of tobacco products, factors of influence, developmental pathways involved in. Thus, it is hard to replicate and mimic such a soft system. However, the tests conducted in section 4.2 shows that it is possible to capture the general trend. According to J. Morecroft (2007), this structure would be classified as illustrative with plausible scaling and moderate level of fidelity.

Boundary adequacy test

Boundary adequacy tests assess the appropriateness of the model boundary for the research objective formulated in section 1.4. The model boundary determines which variables are treated endogenously, which are treated exogenously, and which are excluded altogether (Figure 4.4). According to Sterman (2000), there is no need to model the whole system of smoking behavior, instead I attempt to create a model to solve a particular problem (high prevalence of smoking) within that system. This motivated me to find a focus and create the boundaries.

As it was discussed in section 1.2 and portrayed in Figure 4.4, the target variables in the case include the prevalence of smoking (both in adolescents and adults), the appropriate values of the stocks, particularly the flow rates and perception of health risks. Moreover, the research objectives require focusing on NDL. All of these variables are generated as endogenous within the model.

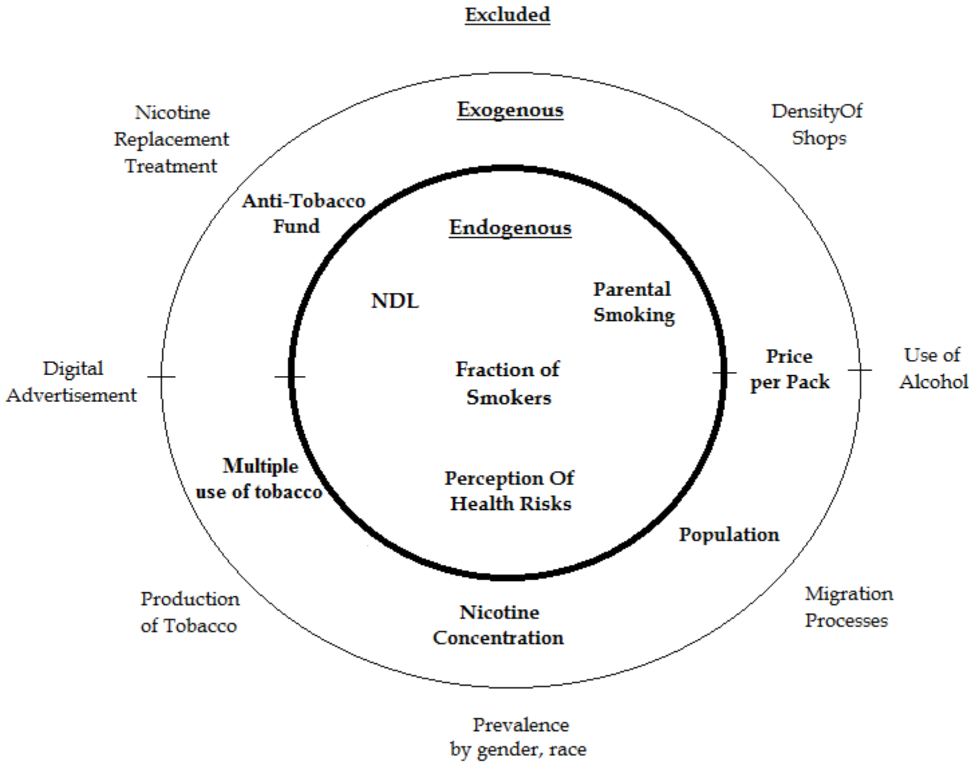


Figure 4.4 Model boundary chart

The system boundaries also consist of exogenous variables that are used as a data set or constant parameters for simulation. There are variables relevant to the smoking development, but not so significant either for the case of North Dakota or for the initial research interests. Such parameters are excluded from the model. The reasons for doing this include the scope of the research, the availability of data, and a possibility to quantify soft variables.

Structure-confirmation test

This test incorporates the comparison of the model equations used in the model with knowledge in the literature and in the real system.

For instance, "quantity of smoking" for experimenters among middle school students is formulated within the model as:

*Frequency_OfSmoking[Experimenters,MiddleSchool]*AveNumber_OfCigsPerDay[Experimenters, MiddleSchool]/CigsPerPack*Months*

Thus, frequency (days in a month) and intensity of smoking (cigarettes per day) make the direct effect on the quantity of smoking (packs per year). If any of these parameters increase, it will lead to immediate change in the quantity of smoking.

Another example can be focused on one of the flow rates within the stage model – the initiation rate. It is determined by the following formula:

*NeverSmoked*Susceptability_Ratio*SocialEffect__OnIR*

In fact, it is difficult to describe the process of initiation to smoking within a social system and to make an accurate numerical estimation of its value. But the general idea incorporates a certain logic. Adolescents base their decision of whether to make the first puff of a cigarette on the general perception of health risks and benefits of smoking. The lack of perceived consequences of smoking or genetic influence makes some part of adolescents open to the idea of smoking in the future which is reflected in the susceptibility ratio. However, not all susceptible adolescents will initiate smoking (SR, 2014). According to the survey conducted in 2010 (MTF), 19,9% of adolescents aged 12-17 in the USA had never smoked, but were susceptible to starting to smoke cigarettes. Thus, additional factors influence the susceptible non-smokers to try the cigarettes, and social pressure is considered as one of the most important. The stronger the pro-tobacco culture, the more non-smokers will make their first puff.

Similar consideration processes were applied to other equations within the model, including progression, cessation and relapse rates, susceptibility ratio, parental smoking, consumption of cigarettes, and anti-tobacco budgeting.

Parameter assessment test

This test considers whether every model parameter has a clear, real-life meaning. It provides a confirmation of the numerical values with an appropriate accuracy.

There were a few ways how the parameters were verified. Some pieces of data for variables were taken directly from the literature or other “family models”: the nicotine concentration in one cigarette, price elasticity, time to forget the health risks, etc. Other exogenous parameters were part of the relevant data sets taken from the statistical reports and surveys: price per pack, federal, local and state taxes, etc. The relative coefficients for social pressure, for example, were discussed and approved during the consultation with professor Selya. All parameters are provided with references that are placed in the information cell within the model file.

In SD validation however, there is very little use of statistical significance testing and SD has often been criticized for this (Sterman, 2000). As it is described in section 2.3, the multicollinearity found in the structure of NDL module was the challenging issue on the stage of formulating the hypothesis, as it made a multiplicative effect on the desired level of BNC. Therefore, the preliminary statistical data analysis can potentially give additional insights.

In general, the system of smoking development consists of many substantial soft variables which are hard to estimate. The behavior of smokers, their decision processes and the perception of health risks bring out complicated non-linear relationships. At the same time, the quantification of soft variables often yields important insight into the dynamics of a system (Sterman, 2000). For instance, the behavioral side of NDL development is one of them. The non-linearity within the subsequent module can be formulated based on such tools as content analysis, surveys, statistical analysis, and psychometrically validated measurement scales. Thus, the non-linear relationships, for instance, between NDL and its effect on frequency of smoking were estimated based on the regression analysis (Selya, 2013).

It is important to mention that during conceptualization of the baseline and estimation of initial values for the stocks in 1992 I faced the lack of data. The benchmarking comparative analysis was used for solving this problem. Thus, the epidemiologic measures of South Dakota which are geographically and socio-economically close to ND were adjusted to the case.

Direct extreme condition test

By this test I evaluate the validity of model equations "under extreme conditions, by assessing the plausibility of the resulting values against the knowledge/anticipation of what would happen under a similar condition in real life" (Barlas, 1996).

The formula for parental smoking can serve as an example:

*(Fraction_SmokersAdu^2+2*Fraction_SmokersAdu*(1-Fraction_SmokersAdu))* ProbabilityBoth_ParentsInFamily+Fraction_SmokersAdu*(1-ProbabilityBoth_ParentsInFamily)*

This parameter shows the probability that at least one parent within a family smokes. It is affected by the fraction of smokers among adults and the probability that both parents are in the family of an adolescent. It ranges from 0 to 1.

Let assume that the fraction of smokers is 1 (so, all adults smoke). In this case, the parental smoking would reflect this information, so it would equal 1 as well. Let assume that all families in North Dakota have both parents, so the certain probability is 1. In this case, the parental smoking would be equal to the fraction of smokers among adults. This extreme test shows that the equation is able to capture the changes within the system accurately.

Similar tests were accomplished for other equations within the model, including the most important ones that describe the fraction of smokers, risk perception, the fraction of secondhand smokers among non-smokers, the frequency of smoking, total nicotine intake, total consumption.

Dimensional consistency test

Dimensional consistency is one of the most basic validation tests. It incorporates the check if all units of the parameters are consistent.

IThink software provides automated dimensional analysis. Figure 4.5 shows that all units have real-world meaning and are consistent in the model equations.

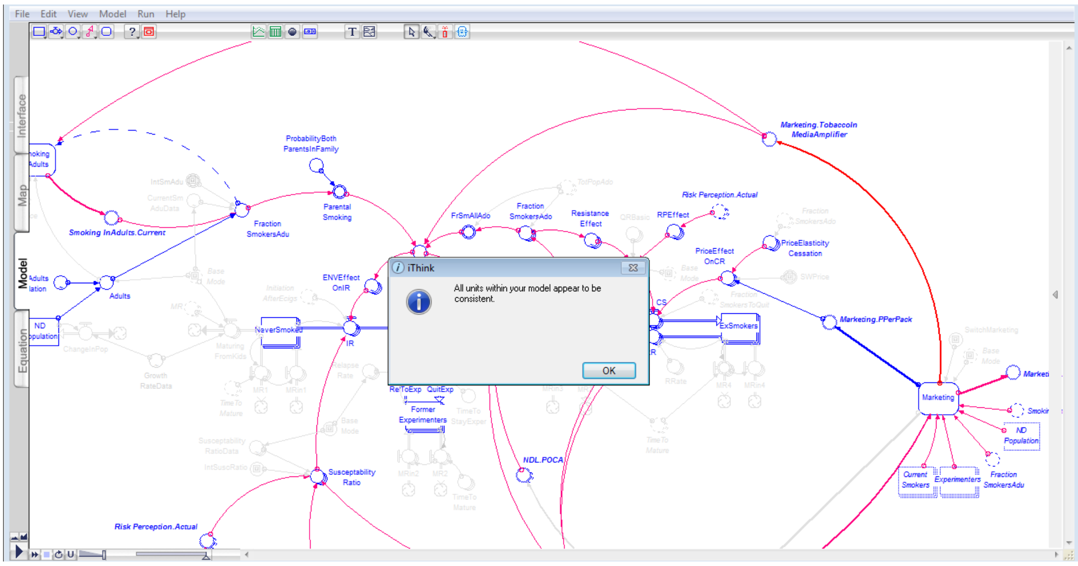
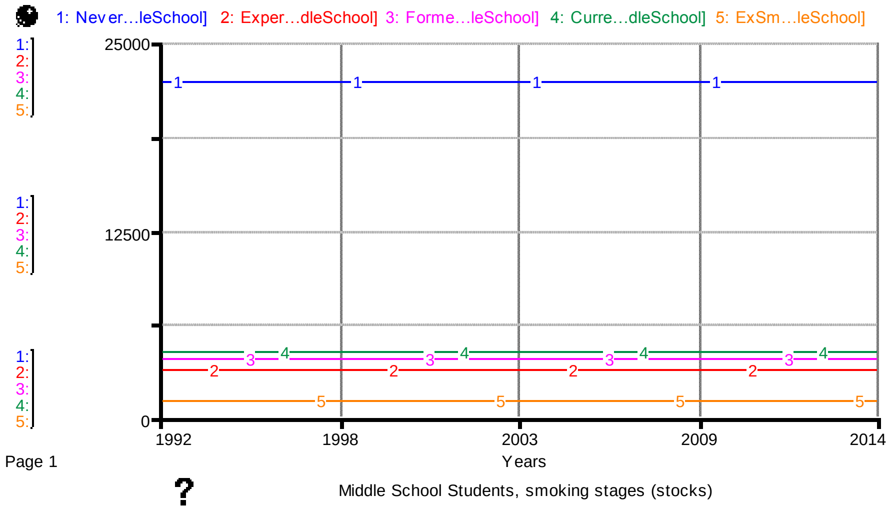


Figure 4.5 The results of unit check test, IThink software

4.3 Structure-Oriented Behavior Tests

This group of validation tests incorporates the analysis of the model structure in terms of behavior that it produces. Several simulations have been accomplished in order to identify any behavioral problems or system errors. These tests are applied to the general model, as well as to separated modules (NDL).

The equilibrium run is simulated first. It does not reflect the real system. The factors that influence flow rates are set constant by choosing appropriate initial values of parameters in the model equations. Thus, the stocks should not change over time (Figure 4.6). The equilibrium test is conducted in all substantial modules of the model.



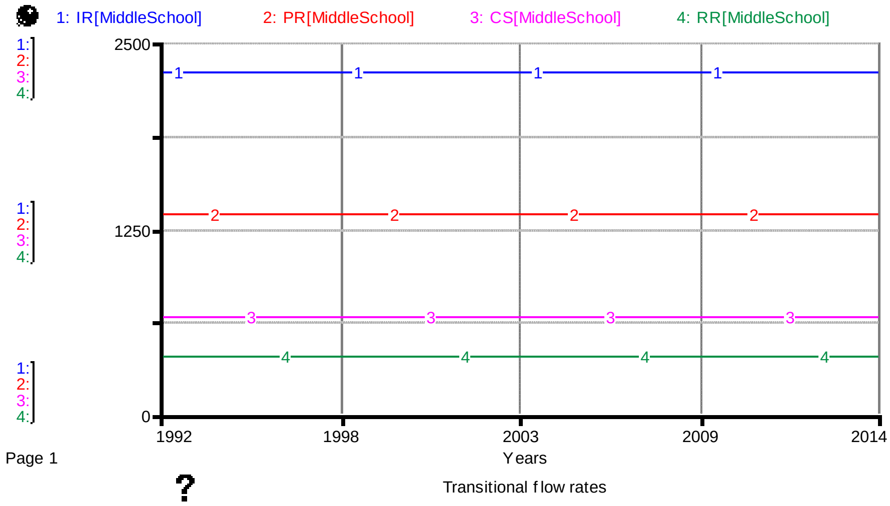


Figure 4.6 The equilibrium run: stocks and the transitional flow rates

According to the simulation results portrayed in Figure 4.6, the model is in equilibrium. The equilibrium conditions allow us to start testing the model structure.

Extreme condition test

The model passes this test if it can generate similar modified behavior under the extreme values of certain parameters. It should plausibly reflect the “modified” real system.

For instance, lets test the model with extreme conditions for the initial values of the stock of non-smokers. In the normal run the stock is equal to 22440 middle school and 12028 high school students. The first test runs the model with the stock initialized as 1 for both age groups. The second test takes the mentioned stock with values of 50000 for middle school and 30000 for high school students. The results of three runs in summarized in Figure 4.7 and Figure 4.8.

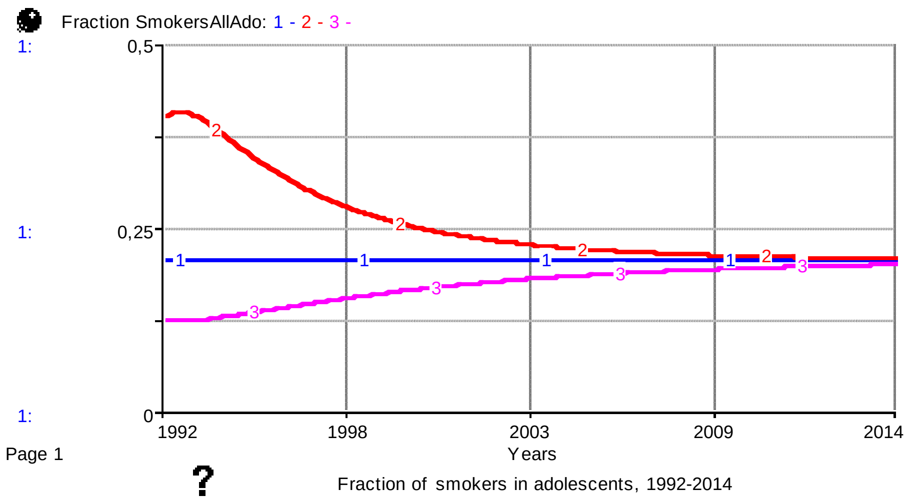


Figure 4.7 Extreme condition test: the fraction of smokers in adolescents

Figure 4.7 shows that the base run (1) and two test runs (2-3) strive to the equilibrium condition of the fraction of smokers in adolescents at the level of 20.6%. However, Figure 4.8 reveals that the stock of non-smokers finds different equilibria in case of test runs compared to the base run. It allows to assume that the model modifies the system behavior accordingly.

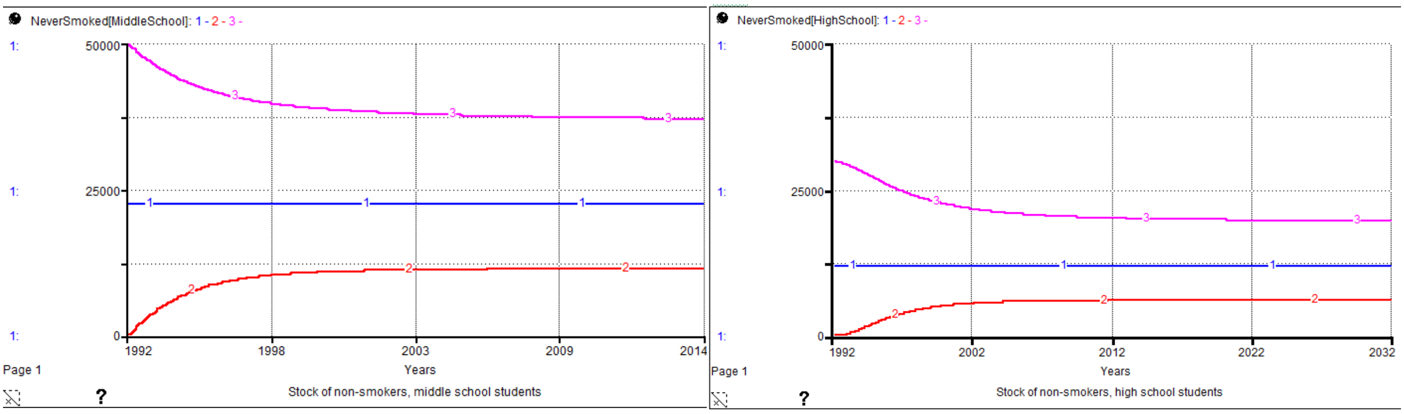


Figure 4.8 Extreme condition test: the stock of non-smokers, middle/high school students

Similar tests were conducted towards other stocks within the stage model and other modules. There were no significant errors found.

Behavior sensitivity test

This test helps to assess the robustness of assumptions described in section 2.2. In general, comprehensive sensitivity analysis is impossible even when restricted to parametric sensitivity, as it would require testing all combinations of assumptions over their plausible range of uncertainty. However, this number of combinations is overwhelming within the model.

Nevertheless, I conducted several tests on how the system behaves under different configurations of the most uncertain parameters within the model. The effect of social pressure on the initiation rate serves an example.

This sensitivity test is related to the effect of social pressure on initiation to smoking among middle school students. This effect is conceptualized relying on the observations made in the historical perspective. The minimum and the maximum values of the effect are set as 0 and 1 respectively. This means that if there is no social pressure then no one will initiate smoking; if the social pressure is 1 (all adults and adolescents smoke) then all susceptible to smoking will initiate the habit. Taking into the consideration the actual initial rate in the period of 1992-2014, the intermediate estimations for the social effect were made.

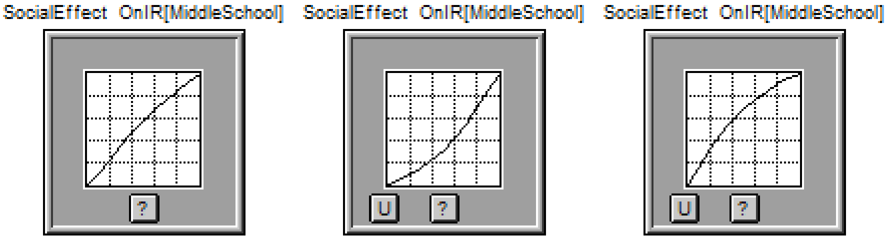


Figure 4.9 Configurations of the social effect on the initiation rate among middle school students

Figure 4.9 demonstrates three configurations of the social effect portrayed in the graphical input device. Figure 4.9 and Figure 4.10 shows the resulting behavior on the initiation rate and the fraction of smokers among all adolescents.

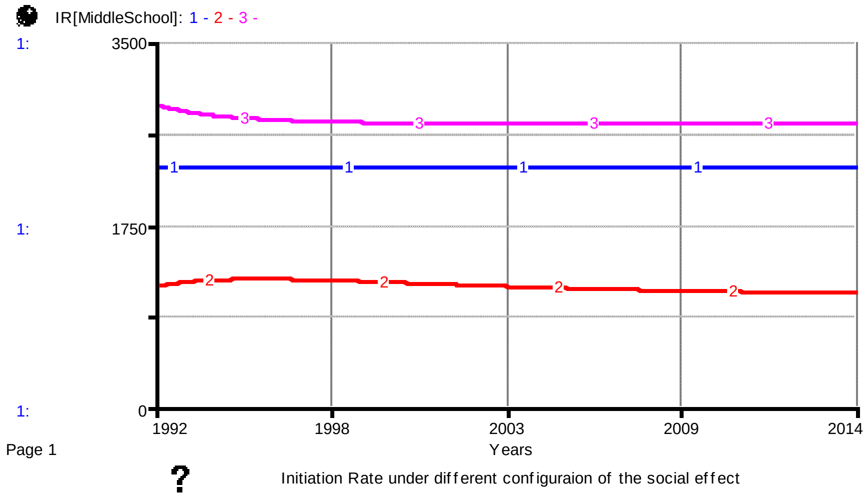


Figure 4.10 The sensitivity test: Initiation rate affected by social pressure

It is well-seen in Figure 4.10 and in Figure 4.11 that changes in the social effect function still lead the resulting parameters to the equilibria. However, the equilibria are found at the different levels. The system is sensitive to social pressure that is found as one of the most important determinants of smoking phenomenon.

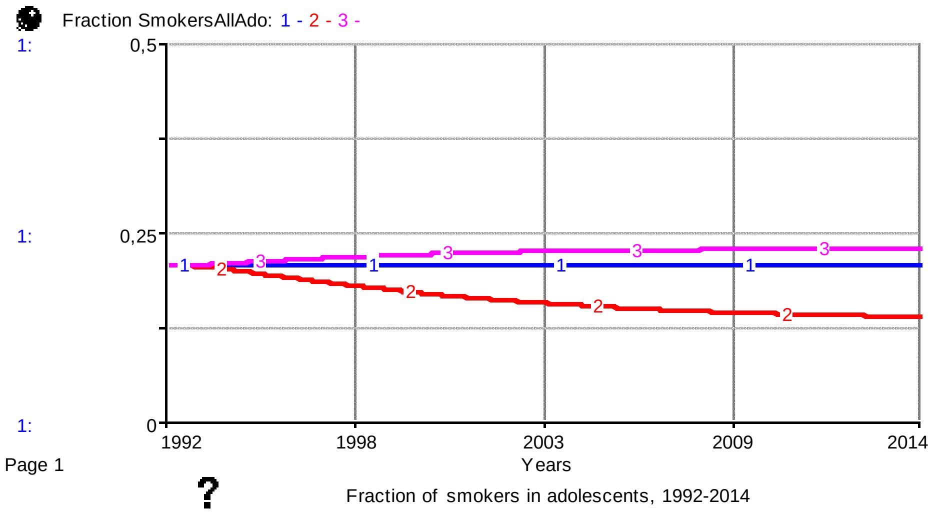


Figure 4.11 The sensitivity test: fraction of smokers among adolescents

Other sets of sensitivity tests were conducted in regard to the price elasticity function, the effect of anti-tobacco campaigns on the risk perception, the effect of policy compliance on the frequency of smoking, the dynamics of ND's population, the influence of NDL on the stage model, the resistance effects, etc. The similar conclusions were made.

Partial model testing

This validation test is focused on the separate modules within the model structure. It helps isolating the source of inappropriate behavior or identifying any other flaw. NDL module, as one of the most substantial parts that influences all the flow rates within the stage model, serves the most appropriate example. The test is conducted separately, without the integration of NDL to the general structure. The subsequent switch of NDL is turned off.

The NDL changes primarily by the quantity of smoking and the nicotine intake within the model. However, the current structure of NDL module doesn't allow testing the hypothesis related to the role of frequency at the later stages of smoking development (Selya, 2013). According to that idea, the higher frequency of smoking would make the bigger effect on NDL compared to the one-time intake of the same amount of cigarettes. This can be observed within the metabolism process in a human organism. However, the impossibility of integration the model of metabolism process to the general model (because of the relatively small dt - 1/8640, hours per year) excludes the potential real consequences of the smoking regularity on the resulting behavior. This is one of the model limitations found during the research project.

However, the estimation of the effect of frequency on smoking intensity used within the model raises the biggest concerns. In Figure 4.12 three configurations of the effect are depicted.

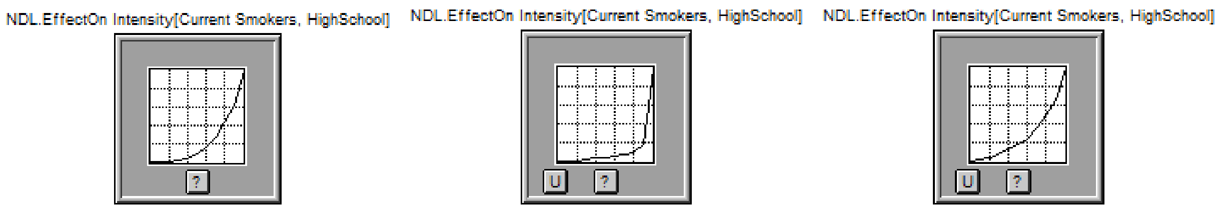


Figure 4.12 The effect of frequency on intensity of smoking

At the same time, Figure 4.13 shows the respond of the system on the changes made in the mentioned effect. The resulting behavior of the Intensity of Smoking still strives to the new equilibrium at the level of 5.36 cigarettes smoked per day. However, it was found that the system is more sensitive to the higher numbers of the function (curve #3) compared to the lower level (curve #2). These findings replicate the characteristics of the real system.

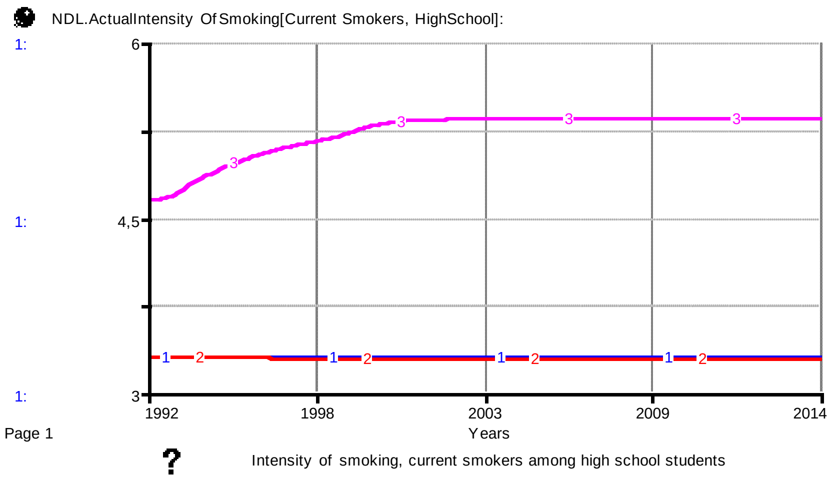


Figure 4.13 Actual Intensity of Smoking under different configurations of the frequency effect

In this chapter several validation tests were conducted, focusing on the model structure and model behavior. They showed that the structure of the model can be considered as plausible with moderate level of accuracy. However, the expanded model boundaries and the plurality of interralation between parameters do not allow conducting a complete validation check.

The behavior of the model reflects the main patterns of the system and replicates the reference mode. At the same time, the estimation of soft variables raises certain concerns, and requires additional analysis to be conducted. However, the system is able to capture the main trends in the smoking development.

Relying on this, the model can be used for further policy design and analysis.

Chapter 5 Policy Design and Implementation

Two substantial reports *Ending the Tobacco Epidemic: A Tobacco Control Strategic Plan* and the *Ending the Tobacco Problem: A Blueprint for the Nation (Bonnie, 2007)* set a vision for the future, calling for ending the epidemic of tobacco smoking as rapidly as possible. But according to the simulation results described in section 3.3, a more aggressive action than the current level of policy implementation should be taken towards meeting the Healthy People 2020 objectives.

This chapter represents how the explanatory model of the dynamic problem transforms into the policy model that helps to "alleviate problematic behavior through system intervention" (Wheat, 2013). For this purpose, the feasible policies are developed and designed for their further cost-effective implementation. The policy tests and analysis are supported with an interactive simulator on the interface layer of the IThink model.

The process of policy design and analysis in this chapter is based on the guide of the Eightfold Path described by E. Bardach (2012).

5.1 Policy Choice

The history of tobacco control in the USA is well-described in the 2012 SR (Chapter 7) (SR, 2012). The general overview of main anti-tobacco policies is provided in section 1.2. They can be arranged into several levels:

- Large community and statewide programs, mass media campaigns;
- Regulatory programs;
- Policies addressing families, schools, or clinical settings;
- Special events or issues, for instance, targeting some vulnerable groups of adolescents;

In the USA, some policy makers focus on individuals and their behavior, while others emphasize policies and programs operating at the societal level (Giovino, 2007). Similarly to this, Flay (1993) made a distinction between levels of causation of anti-tobacco polices: intrapersonal, social, and environmental streams (appendix 7).

The findings in chapter 3 suggest that early intervention among adolescence is critical. Efforts to prevent the onset of tobacco use and progression to regular use should begin in middle school and be sustained over time to maximize their impact. Usually comprehensive state-level tobacco control programs are focused on the prevention of initiation smoking among adolescents, promotion of quitting among adults and adolescents, and elimination of exposure of adolescents and adults to secondhand smoke. They combine community interventions, counter marketing, program policy and regulation, and surveillance and evaluation (SR, 2012).

Several models have been used to examine the impact of strengthening existing tobacco control policies (taxation, smoke free indoor air, and mass media campaigns), and the components of cessation interventions and their delivery (SR, 2014). For instance, Levy (2010) tested the effects of implementing a comprehensive tobacco control strategy with four components directed at reducing the prevalence of smoking in the population: (1) price increases including those that result from cigarette tax increases, (2) smoke-free indoor air laws, (3) mass media/educational policies, and (4) evidence-based and promising new cessation treatment policies. Thus, the simulation modeling is useful in terms of addressing complex questions about future opportunities and suggesting possible leverage points that provide more efficient ways to reduce tobacco use.

After formulating the model hypothesis, simulations and sensitivity analysis conducted in section 4.3, it is possible to make a list of identified leverage points within the model that can be potentially used for intervention into the system (Table 5.1):

Table 5.1 The leverage points and their potential influence within the model

Identified leverage points	Anticipated effects
Price per pack of cigarettes	Decrease in quantity; fostering cessation
Contact rate	Breakage of the peer social networks; Decrease in frequency and intensity
Nicotine concentration in the cigarette	Decrease of nicotine intake
NDL	Decrease in susceptibility, progression, relapse
Flavors availability (in e-cigarettes)	Decrease in frequency
Accessibility to cigarettes	Decrease in frequency
Level of Depression	Decrease in NDL
Social campaigns	Increase of perception of health risks
Alternative tobacco	Fostering cessation
NRT	Fostering cessation; decrease in NDL

During the consideration of the leverage points, it was found that the policy based on lowering the level of nicotine concentration in cigarettes can lead to potential adverse effects in long-term perspective. On the one hand, supporters argue that the implemented policy would substantially decrease the nicotine intake, affecting NDL (R1 and R2 loops). On the other hand, it would increase the intensity of smoking for getting a dose of nicotine that current smokers would still be dependent on. This leads to an increase in quantity of smoking and overall consumption. Thus, it would benefit tobacco producers with greater revenues. Higher profitability would create more opportunities for marketing activities that in the long run would intensify smoking behavior (R3 loop). All of these observations are concluded in the causal loop diagram (Figure 5.1). Such contradicting policy is described by J. Sterman (2000) as low-leverage policy when the system gets transitory improvement before the problem worsens.

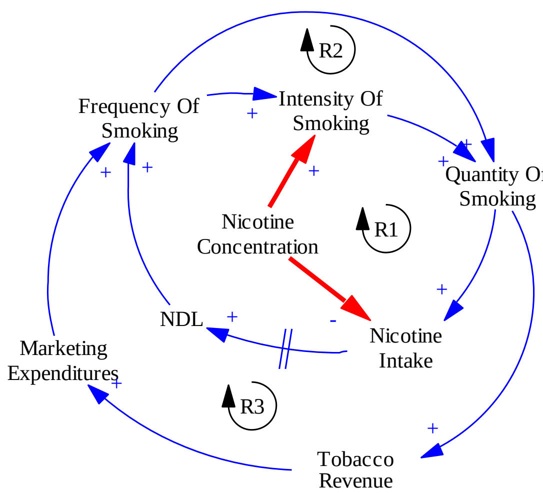


Figure 5.1 A Causal Loop Diagram of implementation "Low nicotine in cigarettes" policy

Relying on the identified leverage points, it is suggested to take into consideration 4 main policy alternatives that are relevant to the case of North Dakota and can be managed on the state level. They will be tested within the model. In general, the strategy can be focused on intensification of conventional policies or implementation of alternative policies.

As it was mentioned in section 1.2, the state tobacco excise tax has not been changed for the last 20 years. However, Figure 3.5 shows how the average annual wage in ND has been increasing over time, exceeding the growth rate of the price of cigarettes after 2012. Thereby, the tobacco tax is one of the most obvious leverage points that should be changed for the purpose of preventing adolescents from progression to regular smoking.

At the same time, the susceptibility ratio to initiate smoking is mainly affected by the level of perceived risks by adolescents. Figure 4.12 shows that there is still potential to increase the level of this indicator. According to the model hypothesis, the wishful change is possible to accomplish by raising the anti-tobacco financial assistance.

Thus, the conventional policies suggest to:

1. Increase the local excise tobacco tax;
2. Foster informational campaigns and sustain in funding the anti-tobacco programs in accordance to the CDC recommendations;

At the same time, it was suggested (Selya, 2013) that prevention policies should be applied to earlier stages of smoking development, while the policies dealing with the alleviation of nicotine dependence symptoms at later stages. This idea can be used for alternative applications of early intervention programs. For instance, strategies to reduce the progression in smoking can be used towards experimenters, and programs that deal with NDL can be incorporated towards the current smokers.

The alternative policies include:

3. Improvement in the policy compliance related to sales restrictions to minors;
4. Flavors ban in e-cigarettes

The next sections discuss the mentioned policies in details, and provide the methodology to test their potential consequences on the system.

5.2 Policy Description and Policy Structure

This section provides a description of the suggested policies and the subsequent model structures for their further testing and implementation.

Policy 1

As it was shown in section 2.2 adolescents are considerably much more sensitive to the price than adults. Thus, an increase in tax rates on tobacco could affect its consumption and prevent the progression in smoking, and thereby improve public health. The state excise tax is 44 cents in North Dakota which is nearly the lowest rate within the USA. The policy 1 suggests revising the tax regulation for tobacco products.

The main idea is to test the potential consequences of implementation of Bills 1811 and 1893 that would have increased the state excise tax rate up to 1 and 1.56 usd respectively. For doing this, the new value will be applied to the tax after 2015.

Additionally, it was discussed with Dr. E. Johnson that the pro-tobacco lobby in the ND's legislature is significant factor that influences the representatives not to vote for the tax increase. Simultaneously, the Secondhand Smoke Study of North Dakota (2014) shows the growing public support towards raising the tax. Relying on these factors, the political will for the tax increase was conceptualized within the new model structure (Figure 5.2).

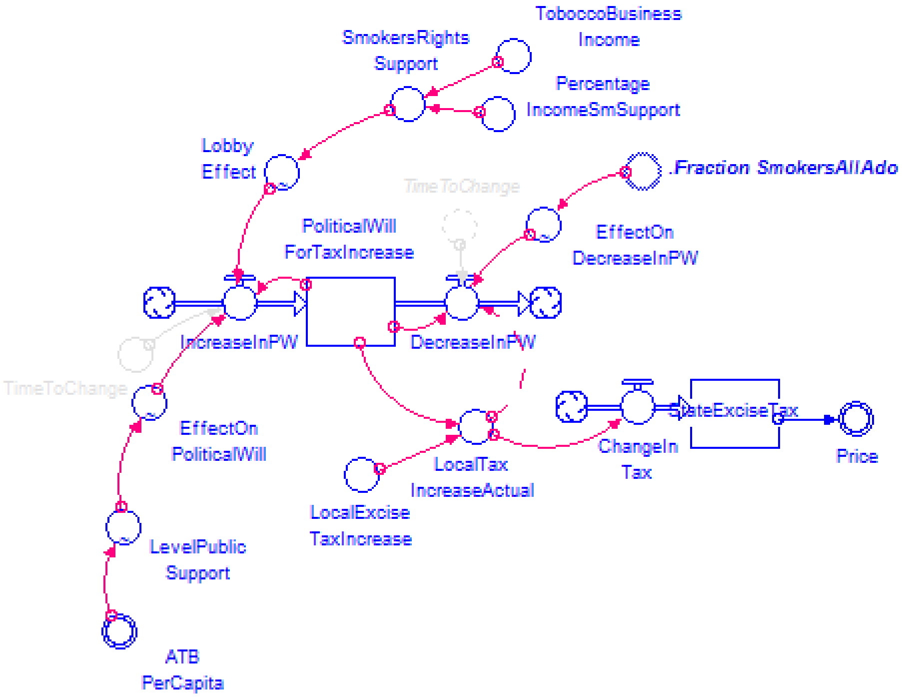


Figure 5.2 The model structure of the political will for the tax increase

According to Figure 5.2, the contradicting interests between smokers and the anti-tobacco community create two counteracting and reinforcing loops that affect the inflow to the stock of political will. Similarly to the principle incorporated in the Smoking in Adults sector, the decrease in the prevalence in smoking directly affects the perception of risks that eventually decreases the political will for the tax increase. According to the last ND's legislature, the stock of political will was initialized at the level of 0.33 (33% of positive votes). The detailed description of a new structure is provided in story-telling chapter at the interface layer of the IThink model.

Policy 2

Informational campaigns have increasingly become "a key strategy in efforts to reduce smoking among youth and young adults" (SR, 2012). Their messages have the potential to influence not only individual behaviors but also social norms. Thus, increased levels of exposure to anti-tobacco media are associated with lower rates of smoking susceptibility (Richardson, 2007).

The effectiveness of informational campaigns is hypothesized to be associated with the level of state investments into certain anti-tobacco efforts. But in fact, all these influences have not kept pace in recent years within the USA, and funding for several of the most innovative statewide programs, in Florida, Massachusetts, Minnesota, Mississippi, Oregon, New York, and Washington, has been sharply reduced or virtually eliminated (SR, 2014). Exposure to counter advertising, funded by states, is now only 3.5% of the recommended levels by CDC levels (28 total rating points – TRP). Contrary to this, North Dakota's anti-tobacco programs are funded in accordance with 97%

of recommendations (776 TRP), so that 77% of the youth in the state is exposed to at least 10 prevention messages per quarter in average (NYTS, 2011-2013).

However, this policy intends to increase the level of state funding up to 20 usd per capita (recommendation of IOM (2007a)) in North Dakota and explore potential consequences. This leads to the subsequent extension of the model structure (Figure 5.3).

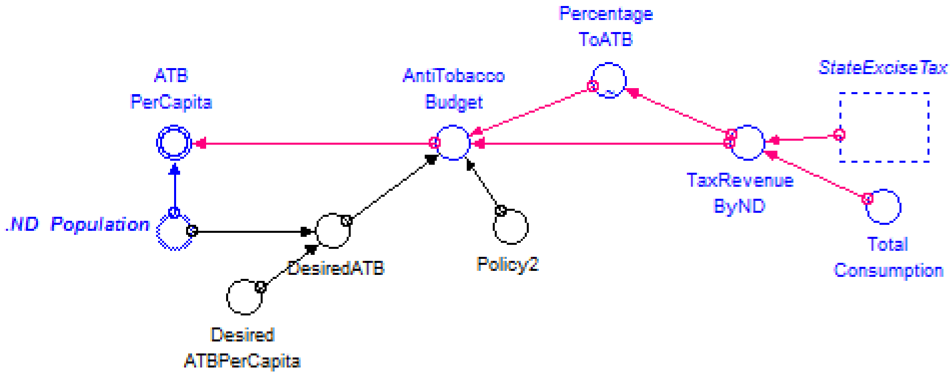


Figure 5.3 The model structure for the desired anti-tobacco budget per capita

This policy eventually has to affect the level of risk perception by adolescents.

Potentially this kind of policy should be more diversified in order to include specific subgroups of adolescents to ensure better effectiveness of informational messages.

Policy 3

This policy suggests improving the compliance of restrictions in cigarettes sales to minors. According to the 2012 Surgeon General's Report (SR, 2012) there is the potential for doing this. Thereby, the policy sliders are provided on the interface layer to change the level of compliance to 95% after 2015. This change should affect the perception of cigarettes availability with the subsequent results on the progression rate and the frequency of smoking.

Policy 4

The aim of the ban on flavors in e-cigarettes is to prevent adolescents from continuous exposure to these booming nicotine products. Studies have revealed that "17 year old smokers are three times as likely to use flavored cigarettes as are smokers over the age of 25" (TFK, 2009).

Thereby, the elimination of flavors in e-cigarettes is assumed to cause the decrease in frequency of e-cigarette smoking by 60% and the decrease in the initiation rate by 40%. These changes will decrease the prevalence in the use of e-cigarettes and, as a result, the nicotine intake generated from this sector affecting the NDL. At the same time, this policy is assumed to lead to 20% relapse from the current e-cigarettes users to conventional tobacco users. In this case, this policy can be considered according to J. Sterman (2000) as high leverage policy, as it leads to some negative consequences (relapse to cigarettes) in short-term perspective, but benefits the community in long-term perspective (worse-before-better).

Additional consequences of policy implementation can be observed under two scenarios described in section 3.4.

5.3 Policy Runs

In the general consideration of the end of tobacco epidemic, “models are recognized as an essential tool for projecting the potential consequences of tobacco control strategies” (SR, 2014). This part provides an overview of simulation results related to the implementation of four conventional and alternative policies discussed in section 5.2. At the end of this section, the results are summarized in the comparative graph.

Figure 5.4 represents the results of the tax policy implementation. The first run (“business as usual”) serves a base for comparison (curve #1). The changes applied to the state tobacco excise tax led to the increase in the cessation rate. Moreover, the decrease in the perception of cigarettes availability influences the system in two ways: through the decisions of adolescents to less progress in smoking; by the decrease in the frequency of smoking that affects the NDL. As a result, the mentioned changes caused the decrease in the prevalence portrayed in Figure 5.4: by 20% in case of the 1 usd tax increase (curve #2); by 25% in case of 1.56 usd tax increase (curve #3).

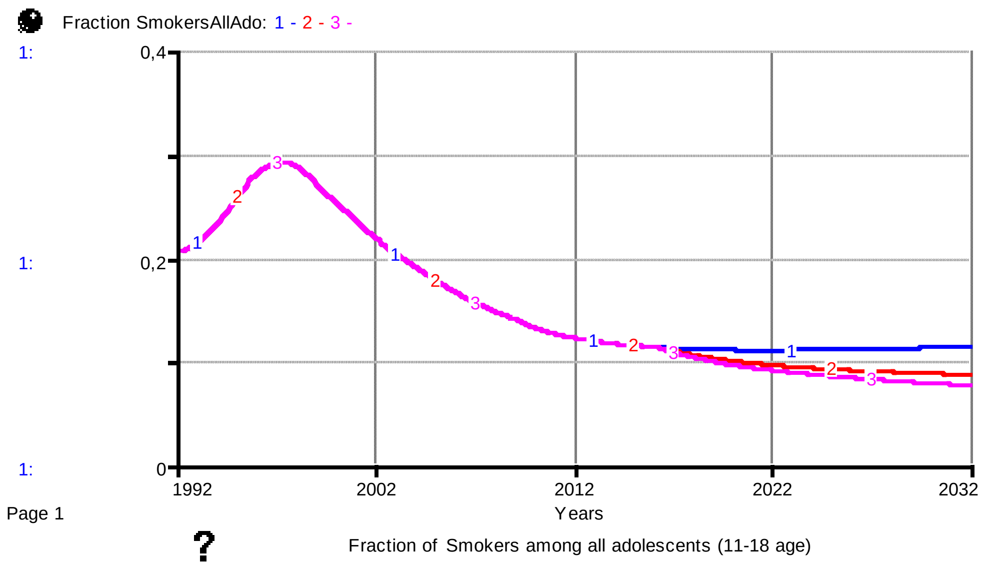


Figure 5.4 The policy run: the results of the increase in the excise tax rate

At the same time 1 usd increase in the tax rate allows meeting the Healthy People objective by 2020 (Figure 5.5).

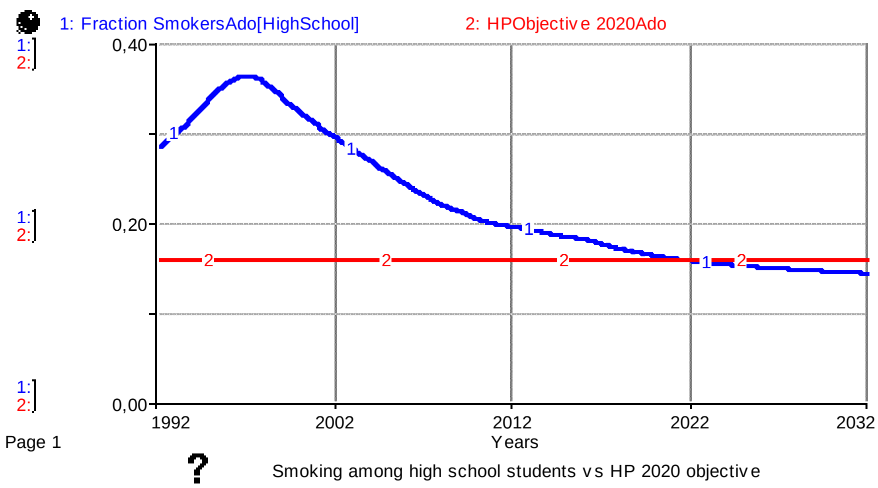


Figure 5.5 The policy run: the results of 1 usd tax increase towards the HP objective by 2020

Figure 5.6 shows the comparative graph portraying the simulation results conducted for all four policies. Moreover, the simulation 7 provides the resulting synergetic effect in case of implementation of all mentioned interventions together. It is well seen that the ban on flavors in e-cigarettes and the informational campaign are less beneficial policies compared to other results as they do not directly influence the NDL.

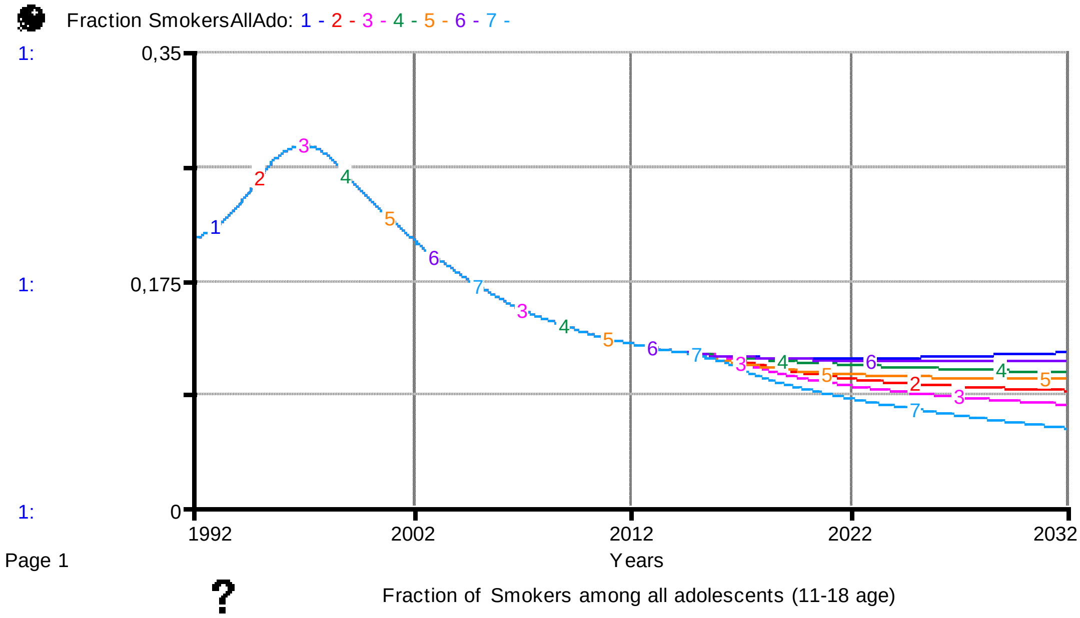


Figure 5.6 The policy run: the results of implementation of four policies

Dr. Satcher (SR, 2012), an expert in anti-tobacco policies, supports "the need for coordinated, multicomponent interventions that combine mass media campaigns, tobacco tax increases, school-based policies and programs, and statewide and community-wide changes in smoke-free policies and norms". Thus, various diversified policies should be included into a comprehensive Strategic State Anti-Tobacco Program of North Dakota. The 2010 USDHHS Strategic Action Plan to end the tobacco epidemic in the USA, the 2008 WHO's MPOWER Framework Convention and the 2014 Community Preventive Services Task Force Recommendation can serve the guidance.

5.4 Cost-effectiveness

This section analyzes policy effectiveness in terms of invested efforts and costs in the interventions to potential policy benefits.

All policies described in section 5.2 are focused on the issues of smoking among adolescents that are directly related to human health in the long-term perspective. The intended results, first of all, improve human well-being and save lives from premature deaths (Figure 5.8) that is already priceless and highly important. The methodology described by A. Boon from Campaign for Tobacco-Free Kids is used for calculation of the total saved lives as a result of policy implementation. Thereby, it was also assumed that almost 30% (SR, 2012) of adolescents among current smokers will die prematurely as adults.

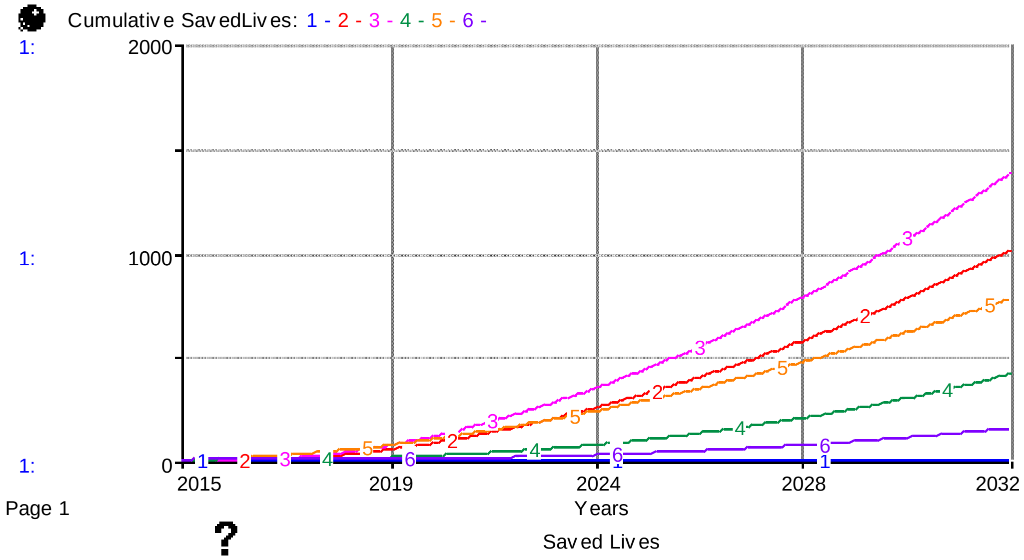


Figure 5.7 Cumulative number of saved lives as a result of policy implementation

According to Figure 5.7, the 1.56 usd increase in the state tobacco excise tax would benefit the society in North Dakota by the highest number of saved lives.

At the same time, there are several methodologies that capture material benefits from the implementation of anti-tobacco programs. As it is stated in section 1.2 smoking is a highly harmful habit. The general health effects of smoking contribute to increased absenteeism, loss of well-being, risk of hospitalization, and have implications for health care and its costs. As a result, the health care costs of smokers exceed those of nonsmokers. Between 11–16% of health care spending of people who had ever tried cigarettes is attributable to smoking (SR, 2012; SR, 2014). It means 5-14% of the total health care expenditures within the USA (Levy, 2010). For instance, among adults aged 45–64 in the USA, annual health care spending was 7,650 usd for recent quitters, 5,540 usd for current smokers, and 5,040 usd for never smokers (SR, 2014). Hodgson (1992) found that smokers incur about 9,379 usd more in lifetime health costs than nonsmokers do.

Moreover, current smokers were more likely to be absent from work than never smokers (SR, 2012). It was found that health-related loss of productive time cost employers 1,685 usd per year per employee that smokes (Stewart, 2006).

The overall harm of smoking-related diseases can be estimated with indicators, such as premature mortality, excess morbidity, disability-adjusted life years lost, changes in disability-adjusted life expectancy, quality-adjusted life years lost, and years of potential life lost. Methodology for all estimations is established and well-described in the 2014 Surgeon General Report (SR, 2014), Chapter 12.

The anti-tobacco policies are focused on the prevention of negative health consequences and health costs. Thus, the main benefits of their implementation are considered as the cost saving from the potential losses in case of “business as usual” scenario. The simulation results gained in section 5.3 shows the following benefits of each policy (the model outputs):

Table 5.2 The policy outcomes matrix, 2032

POLICY		Prevalence in smoking, all adolescents	Saved Lives	Saved health costs, mln usd	Saved productive time costs, mln usd	Change in tax revenue, mln usd	Total benefits, mln usd
Policy 1. State tobacco excise tax	1.44	0.089	1010	31.6	5.68	786	823.3
	2	0.078	1381	43.2	7.76	1153	1204
Policy 2. Informational campaign		0.103	411	12.9	2.3	-4	11.2
Policy 3. Improvement in policy compliance		0.098	776	24.3	4.36	-9	19.66
Policy 4. Ban on flavors in e-cigarettes		0.112	150	4.7	0.85	-2	3.5

At the same time, some of the mentioned policies incorporate implementation costs. For instance, the tax policies require 1 million usd for administrative issues and the informational campaign among the local community. The informational policy leads to the increase in the anti-tobacco budget described in section 5.2. Relying on the experience of other states within the USA (SR, 2014), the implementation of compliance policy requires approximately 0.5 million usd budget per year for setting the regular control on the sales of cigarettes. And finally the flavors ban policy incorporates 1 million usd budget for administrative and informational purposes.

Table 5.3 The comparative cost-benefit analysis of policy implementation by 2032

		Total benefits, mln usd	Total costs, mln usd	Total Net benefits, mln usd
Policy 1. State tobacco excise tax	1	823.3	1	822.3
	1.56	1204	1	1203
Policy 2. Info campaign		11.2	135.4	-124.2
Policy 3. Compliance		19.66	8	11.66
Policy 4. Flavors ban		3.5	1	2.5

Table 5.3 provides an overview of the identified policy costs and benefits. It is noticeable that the increase in the state tobacco excise tax by 1.56 usd is the most promising. It is suggested for further implementation.

5.5 Policy Resistance

The issue of tobacco market combines a lot of different interests of stakeholders that often contradict each other (Figure 1.6). Therefore, anti-tobacco policies face a great resistance on the stages of design and implementation. “Understanding the factors that interrupt progress along the policy trajectory is critical to intervening with smoking behavior” (SR, 2012).

The first point relates to the North Dakota’s legislature that demonstrated a conservative position towards two bills that would have increased the state tobacco excise tax in 2015. Partly it can be explained by a strong lobby of tobacco companies’ interests. As an alternative, the policy can be placed as a measure on a ballot and suggested for voters in North Dakota. For instance, California’s anti-tobacco program (1989) was funded by voter initiatives, as were programs in Massachusetts (from 1993), Arizona (from 1994), and Oregon (from 1996) (SR, 2014).

Secondly, the pro-smokers communities that are supported by tobacco companies actively defend their smoking rights and resist to any anti-tobacco interventions. They form a public opinion that affects the representatives. The resistance towards passing the ban on tobacco flavors in New York can be considered as an example.

Thirdly, the resistance can be demonstrated on the policy implementation stage and related to the incompliance of the policy, for instance, related to the restrictions of tobacco sales to minors. The last check control in Bismarck, ND in April 2015 shows that 3 out of 24 shops sold the cigarettes to minors (Breathe ND, 2015).

Finally, raising the tobacco tax can make a negative impact. For instance, it potentially affects smokers with low and moderate incomes, and harms business owners who attract customers from other states thanks to low tax rates.

Taking into account those risks for policy implementation, we can point out some recommendations to avoid the unanticipated resistance. As minimum, the process of anti-tobacco campaign related to Policy 1.2 should be transparent, informative, and open to the initiatives of communities' activists. The very important indicator in this field is attitudes among people towards new regulations (NDSP, 2014). For instance, 66% of population in North Dakota consciously expressed their support to the tax increase by 1.56 usd per pack (NDSP, 2014).

The design and successful implementation of the policy should be well-planned and administrated as it described in the next section.

5.6 Active Policy Channel and Policy Brief

In section 5.4 the Policy 1.2 is proved to be the most cost-effective way to reduce tobacco use among adolescents in North Dakota. It is suggested for further implementation. For the purpose of avoiding the policy resistance mentioned in section 5.5, the active policy channel can be developed.

In this case, the main objective for policy makers is to pass the appropriate bill at the next legislature in North Dakota in 2017. The important focus in the preparation to this is on the public awareness and support. It can be accomplished by several steps:

- To provide trustworthy testimonies on the necessity of the bill implementation and sufficient evidence of health benefits to the community. This can be accomplished by providing experts' opinions, the results of the medical research and modeling studies, and the successful cases from other states (California) and countries (Canada);
- To organize public hearings where it would be possible to counterargument the lobby of tobacco business' interests;
- To create the alliance of the policy supporters that have the reliable reputation within the community. This tobacco control advocacy campaign can include government agencies, NGOs (TFND, Breathe ND), health organizations, school and university officials, sport celebrities, private organizations, individual medical practitioners;
- To arrange the mass-media campaign on TV, in the newspapers, and in the Internet.

Additionally, it is necessary to provide the comprehensive discussion of the bill at the Tobacco Prevention and Control Advisory Committee and get its support. The description of the policy and its implementation plan is provided in the Policy Brief (appendix 8) that can be used for communicating the policy suggestions to the policy makers and stakeholders.

Moreover, there are several potential risks related to implementation of the tax policy. For instance, the increase in the price of cigarettes without addressing the NDL can lead to the transition of smokers to other tobacco products, alcohol or drugs. At the same time, there are other undesired side effects of the high price described in section 2.2.7. In order to avoid potential risks, the strategic state anti-tobacco program should be developed.

In general, the evidence is sufficient to conclude that "mass media campaigns, comprehensive community programs, and comprehensive statewide tobacco control programs can prevent the initiation of tobacco use and reduce its prevalence" (SR, 2012). Moreover, the ND Health Department which is responsible for design and implementation of anti-tobacco policies can take into consideration several up-to-date ideas for improvement the policy effectiveness that have been partially tested by this thesis project:

1. Nowadays, it is extremely important to focus health care policies not only on tobacco control, but on nicotine control. The addictive property of nicotine and nicotine dependence demonstrated in the model allows the tobacco companies to hook up adolescents on new nicotine delivery devices that carry uncertain health risks.

2. The studies in anti-tobacco field have generally found (SR, 2012) that partial bans on advertisement have a small impact on cigarette consumption, primarily because tobacco marketing switches to outlets for advertising and promotion that are not regulated or banned. Total bans on advertising and promotion, in contrast, is associated with a reduction in cigarette consumption. This relates also to the control of digital marketing that is approaching adolescents in the USA and North Dakota particularly.

3. One of the substantial factors that affect smoking behavior is cigarette availability (physical and its perception). Thus, it is also recommended to control the density of stores (tobacco outlets) that sell tobacco products. This can be accomplished with limiting the tobacco business licenses.

4. Smoking embraces different groups of adolescents that initiate and keep smoking according to different reasons. Therefore, the informational campaigns should be diversified enough to find a special approach to reach each of these groups, for instance, to adolescents with disabilities, native Americans, or adolescents from low-income families that are much more prone to smoking than others (described in section 2.2).

5. Interventions that rely on empowering youth or urging them to be activists are a relatively recent approach to preventing tobacco use (SR, 2014). Contrary to the communities of smokers, the officials of ND need support such initiatives and promote the pro-health culture.

6. In terms of high uncertainty towards health consequences of new tobacco products (e-cigarettes), ND officials are recommended to intensify the support to research projects and studies

related to smoking issues, including modeling approaches. Investments into this field can provide sufficient evidence for the particular anti-tobacco policies, prevent the unanticipated side effects, and save the state's financial resources from ineffective use.

7. In terms of the increasing role of genetic influence on susceptibility to tobacco, it is suggested to make early-stage screening of adolescents in order to find those who are genetically predisposed to initiate smoking.

In this chapter, the description of the relevant anti-tobacco policies was provided. The suggested policies and the assumptions on their consequences were tested within the model. The Policy 1.2 was recognized as the most cost-efficient and, thus, recommended for further implementation. It suggests increasing the state tobacco excise tax by 1.56 usd. Potentially this policy can save 1381 lives from the premature deaths and gain 1153 million usd of benefit by 2032. Taking into account potential policy resistance, the active policy channel and the policy brief were developed.

Conclusions

Results

The development of smoking behavior among adolescents can be characterized as a dynamic multiloop, multistate and nonlinear process within a complex social system with the plurality of behavioral pathways. The dynamics of market innovations fosters the system changes, which makes the complexity even greater.

There is a plethora of research initiatives conducted in the field of smoking behavior, including modeling approaches (theoretical, regression, mixture modeling). However, they are primarily event-oriented, providing a fragmentary open-loop picture of the problem. Imperfect information on the state of the system in turn creates a gap in medical and health sciences that has to be covered. Also it potentially causes significant policy resistance.

The SD methodology used in this thesis allowed to create a simulation model and to provide a holistic view on a particular problem within the complex multilevel environment of smoking development. Moreover, the SD approach in combination with the statistical methods and regression analysis helped in dealing with nonlinearities and quantification of soft variables that dominate this social system.

The thesis is organized in accordance with the framework that embraces the problem definition, hypothesis formulation, analysis, policy design, and implementation stages.

Chapter 1 provides an introduction into the problem, pointing out the main factors of smoking development (peer and parental influence, environmental and behavioral factors), potential health consequences, anti-tobacco policies, and current trends in smoking prevalence in the USA and North Dakota in particular.

Tobacco use is recognized as highly addicted especially during early adolescence. It causes various respiratory and cardio-vascular diseases, and leads to premature death. Despite the significant decline in prevalence within the USA since 1964, smoking is practiced by more than 20% of high school students, and is becoming more diversified by the use of new tobacco products emerging in the market.

The prevalence in cigarettes smoking among adults correlates with the development of smoking in adolescents. Almost 90% of adults initiate smoking by the age of 16. Thus, the anti-tobacco policies should be focused on the earlier stages of nicotine addiction.

North Dakota is one of the states that has the lowest tobacco excise tax within the USA (0.44 usd), and, as a result, the lowest retail price per pack of cigarettes. Despite this fact, a significant number of promising anti-tobacco policies has been implemented in the state, and is financially supported in accordance with the CDC recommendations. These counteracting driving forces partly explain the decline in the development of smoking behavior among adolescents that has occurred since 2005.

Sections 1.4 – 1.8 provide a general description of the research objectives and research questions, the analysis of modeling initiatives in the field, an overview of the methodology used, and the research process.

Chapter 2 is devoted to the formulation of a dynamic hypothesis within the model structure. The set of assumptions were made describing the stage model, maturing processes, smoking-related mortality, second-hand smoking, risk perception, development of nicotine dependence, marketing initiatives, and alternative nicotine delivery systems. In terms of e-cigarettes, two scenarios were developed to test initial assumptions found in the literature, and to represent hopes and fears of stakeholders on health consequences of smoking.

This preliminary work helps to conceptualize the model interrelations and estimate initial values of the stocks for further simulations. The overall structure was summarized in causal loop diagram, portraying the major feedback loops that drive the system and produce certain behavior. Among them are social pressure, second-hand smoking, nicotine addiction, and marketing reinforcing loops. The alternative tobacco, and depression belong to the counteracting loops that alleviate the progress in smoking development.

Substantial empirical simulations were conducted in Chapter 3, testing the initial hypothesis towards replicating the reference mode. The integration of modules makes an endogenous perspective of the model. The system is able to produce a problematic behavior, reflecting all major trends in smoking development demonstrated in the period of 1992-2014. At the same time, the predictions to 2032 showed that at the current pace of tobacco control it would not be possible to meet the Healthy People 2020 goal by 2020. Moreover, the perspective of nicotine-free society is very ambiguous because of the existing resistance effects, counteracting forces and delays in policy-making. This motivates to develop appropriate policies to cover the gap in health objectives and to intervene into the system.

The empirical test of two scenarios related to the use of e-cigarettes shows that the multiple use of tobacco products create a number of threats in the long-run. For instance, in case of the pessimistic scenario the prevalence of conventional smoking starts growing up in 2030, reviving the smoking habit and tobacco epidemic.

The validation tests are passed in Chapter 4, including direct structure, structure-oriented behavioral and behavior pattern tests. Despite the lack of data and uncertainty in quantifying the soft variables, the model replicates the real feedback system of smoking development. This helps to verify the credibility of the modeling results. The model validity allows switching to next steps of policy formulation.

Chapter 5 discusses the leverage points within the system (price, contact rate, flavors, peer pressure, and NDL) and suggests three main policy options. They include tax regulation, informational campaign and improvement in policy compliance. According to those suggestions, the extensions of the model structure were accomplished. The policy runs and subsequent cost-benefit analysis show that the increase in the state tobacco excise tax by 1.56 usd is the most promising policy with minimum implementation costs and maximum benefits (1381 saved lives and 50.96 million usd saved costs by 2032). Moreover, only this kind of policy allows meeting the Healthy People 2020 objective in adolescents, if it is implemented in 2016. Additionally, the policy resistance analysis was conducted, and the action policy plan was developed and summarized in the policy brief.

Moreover, certain recommendations are suggested to North Dakota Health Department with the purpose of improving the state's strategic anti-tobacco program, and increasing the efficiency of certain interventions. They are related to nicotine control, diversification of anti-tobacco activities at the level of different vulnerable groups among adolescents, a comprehensive ban on advertisement and tobacco marketing, family education, and treatment of nicotine addiction and depression in early adolescence.

Prevention efforts must include both adolescents and young adults to encompass initial experimentation and progression to daily use. Only comprehensive state program can help in dealing with the emerging challenges towards the end of tobacco epidemic.

System thinking fosters the process of learning and demonstrates how the "black box" of the real system can be managed by stakeholders. Identified gaps in argumentation of certain policies (lowering the nicotine concentration, increase in quitting rate) motivate to make "a shift of mind", expanding boundaries of limited mental models, and avoiding policy resistance. The understanding of those highly interrelated processes in smoking development can improve the decision-making process in the field of health care.

The results of this thesis were presented to the faculty members of Master in Public Health program at UND. The conclusions are intended to be published as journal articles, and devoted to the integration of regression analysis and the method of system dynamics, and policy analysis in the field of smoking in adolescence.

Limitations and Further Improvements

Sterman (2000) stated that all models are wrong because they are simplifications of reality. Morecroft (2007) added that there is not a single perfect model. This emphasizes the complexity of real systems, impossibility to embrace all variety of details, imperfection of initial information and methodology for its analysis and validation. Smoking belongs to the "soft" system where many of the quantities in question are not directly measurable. Thus, it poses particularly severe difficulties (Homer, 2012).

While working on this thesis, I have also faced some conceptual and technical problems.

First of all, taking into account the research objectives of this thesis project and available time for the research intervention, the boundaries of the model were set, which are depicted on Figure 4.2. The research scope reflects the deviations between the model behavior and the reference mode. As it was suggested by the experts, the boundary could be additionally extended to sectors of alternative drugs and alcohol, tobacco production and distribution, NRT, labor immigration, depression, religiosity, etc. This would allow to observe additional aspects of the problem and to test the appropriate hypothesis.

Secondly, I have faced some problems related to the quality of data used within the model. For instance, the methodology for conducting surveys has changed since 2011, which makes it difficult to compare data between different periods under observation. Another example refers to difficulties in quantification of certain soft variables within the system (multidimensional nicotine dependence, perception of health risks, cigarette availability, effects of social pressure on initiation and progression rates), which causes uncertainties and deviations in the model simulations.

Thirdly, the model is still highly aggregated which is made deliberately in accordance to the research objectives. However, more details are required, particularly on audience segmentation (observation of different vulnerable groups in adolescence), genetic effects, tobacco distribution, area representation (neighborhoods), etc. Also, the stage model of smoking development can include additional interim stages, suggested by Gilpin (1999) and others.

Fourthly, the technical problem of model simulation with a relatively small dt is described in the thesis. It motivates to observe more closely the process of metabolism in a human organism in a separate sub-model. It can be based on hourly perspective and incorporate the diversified approach for different nicotine products.

Fifthly, the sector of e-cigarettes should be extended. The observation of this “hot topic” would allow identifying the potential consequences in the tobacco market. Moreover, the new nicotine substitutes such as cotinine can further extend this research.

Finally, the current model structure can be tested in the cases of other regions and states.

Moreover, the complex system of smoking development and policy implementation combines contradicting interests of main stakeholders. The current model requires additional opinions on the hypothesis formulation and validation. This creates a unique opportunity to apply Group Model Building methodology to the case. The seed model can be used for this purpose.

The current experience in the thesis demonstrates that the SD models in smoking development have a great potential to be integrated with other modeling approaches and various software (regression analysis, agent-based modeling, etc.).

Glossary

Addiction	clinical diagnosis of nicotine dependence as defined by the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders 4th ed. (DSM-IV-TR) (American Psychiatric Association 2000), an adult must exhibit at least three of the primary symptoms of substance dependence, generally at any time during the same 12-month period
Adolescents	young people between the ages of 10 and 19 years, according to WHO (2015)
Cohort effects	differentiation of the trends across various grade levels as changes in use occurring earlier in adolescence work their way up the age spectrum, according to MTF (Johnston, 2014)
Cold Turkey	approach to quit smoking immediately
Current smokers	people reported having ever tried to smoke a cigarette and some cigarette smoking in the past 30 days
Diversification of smoking	use of two (dual use) or more tobacco products
E-cigarette	battery-powered devices that heat a liquid nicotine solution inside a cigarette-shaped tube that users draw on to inhale a nicotine-filled vapor
Former smokers	people reported having ever tried a cigarette but reported no use in the last 30 days
Frequency of smoking	the number of days in the last 30 days that a person smoked a cigarette
Frequent smoking	having smoked on $\geq$ 20 of the previous 30 days
High school students	adolescents aged by 15-18, 9-12 grade – YTS
Initiation	having ever tried tobacco; the first puff
Intensity of smoking	the number of cigarettes smoked per day, characterized by the frequency and heaviness of cigarette smoking
Intermittent smokers	smoking on "some days," or less than daily or frequently
Middle school students	adolescents aged by 11-14, 5 (6) -8 grade – YTS
Never smokers	people reported never trying to smoke a cigarette, no cigarette smoking in the past 30 days, and no quit attempts in the last 6 months.
Parental smoking	smoking of at least one parent within the family
Perceived risk	measured by the question, "How much do you think people risk harming themselves (physically or in other ways), if they try cigarettes once or twice." MTF (Johnston, 2014)
Population-attributable fraction (PAF)	the percentage of the disease morbidity or mortality that is attributable to an exposure
Relative Risk (RR)	estimation used for comparison of death rates in smokers with death rates in never smokers
Second-hand smoke	the smoke that fills restaurants, offices or other enclosed spaces when people burn tobacco products such as cigarettes, bidis and water pipes
Susceptibility to smoking	the absence of a firm commitment not to smoke cigarettes or, conversely, a willingness to experiment with cigarette smoking
Tobacco product	the products that consists of the tobacco leaves or any substances made of the tobacco
Tobacco use	use of one or more tobacco products
Quality-adjusted life year (QALY)	a measure of disease burden, including both the quality and the quantity of life lived
Quantity of smoking	number of cigarettes smoked per year

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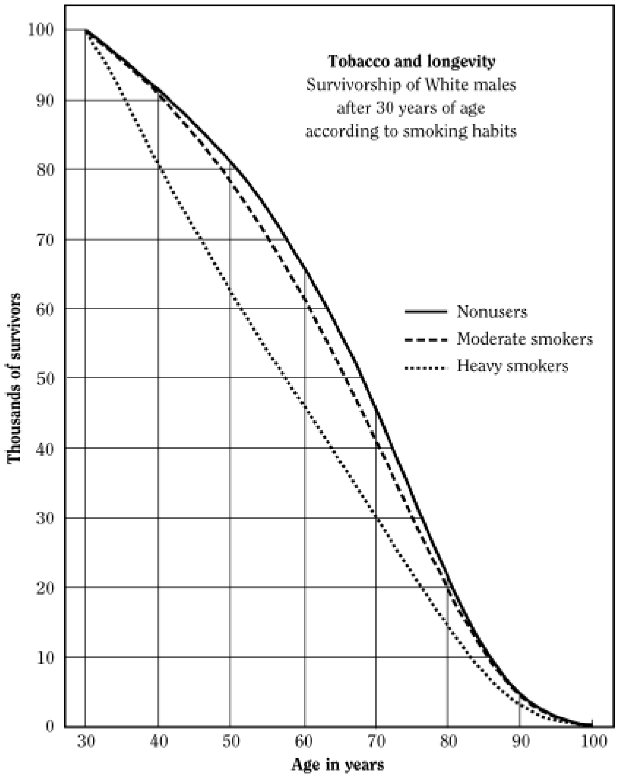
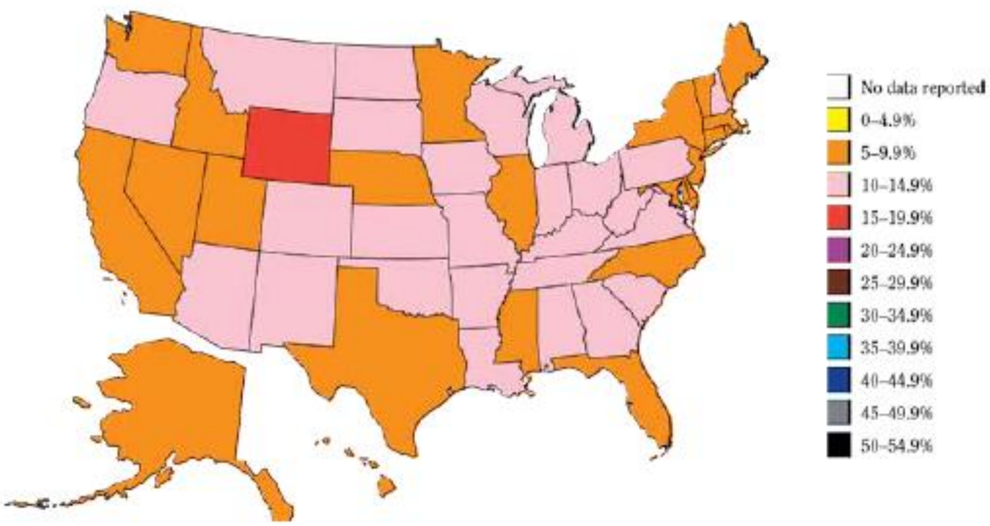
Appendix 1.

Survivorship lines of life tables for White males falling into three categories relative to the usage of tobacco, Pearl, 1938 (Pearl, 1938)



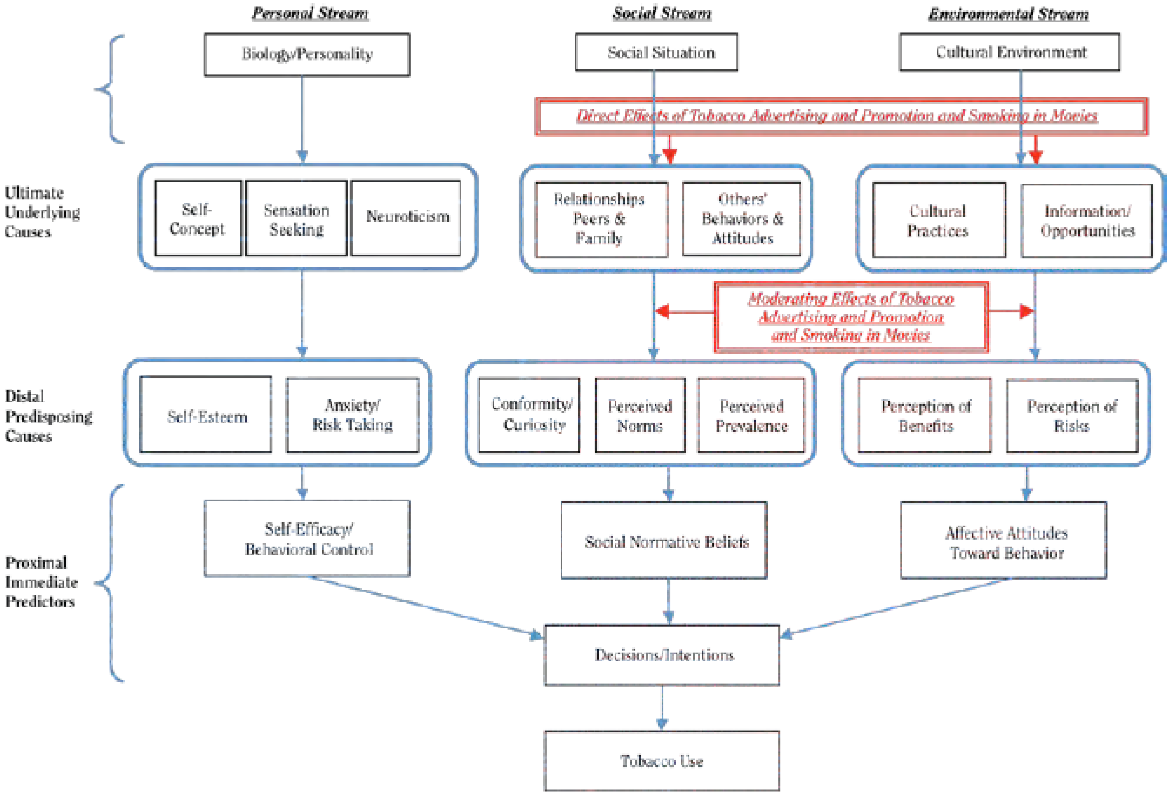
Appendix 2.

Percentage who currently smoke cigarettes, 12-17 years, by state; NSDUH 2006-2010, USA



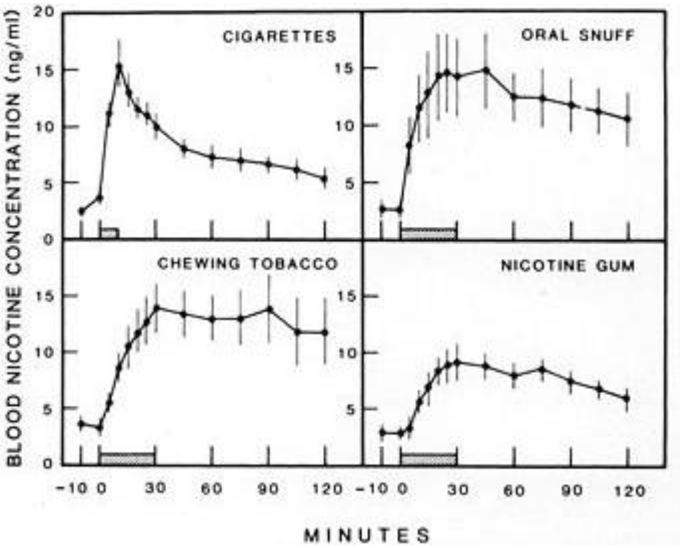
Appendix 3.

Structure supporting the effect of marketing on youth smoking based on the Theory of Triadic Influence, Flay, 2009 (SR, 2012)



Appendix 4.

Duration of metabolism process for different nicotine delivery systems (SR, 2012)



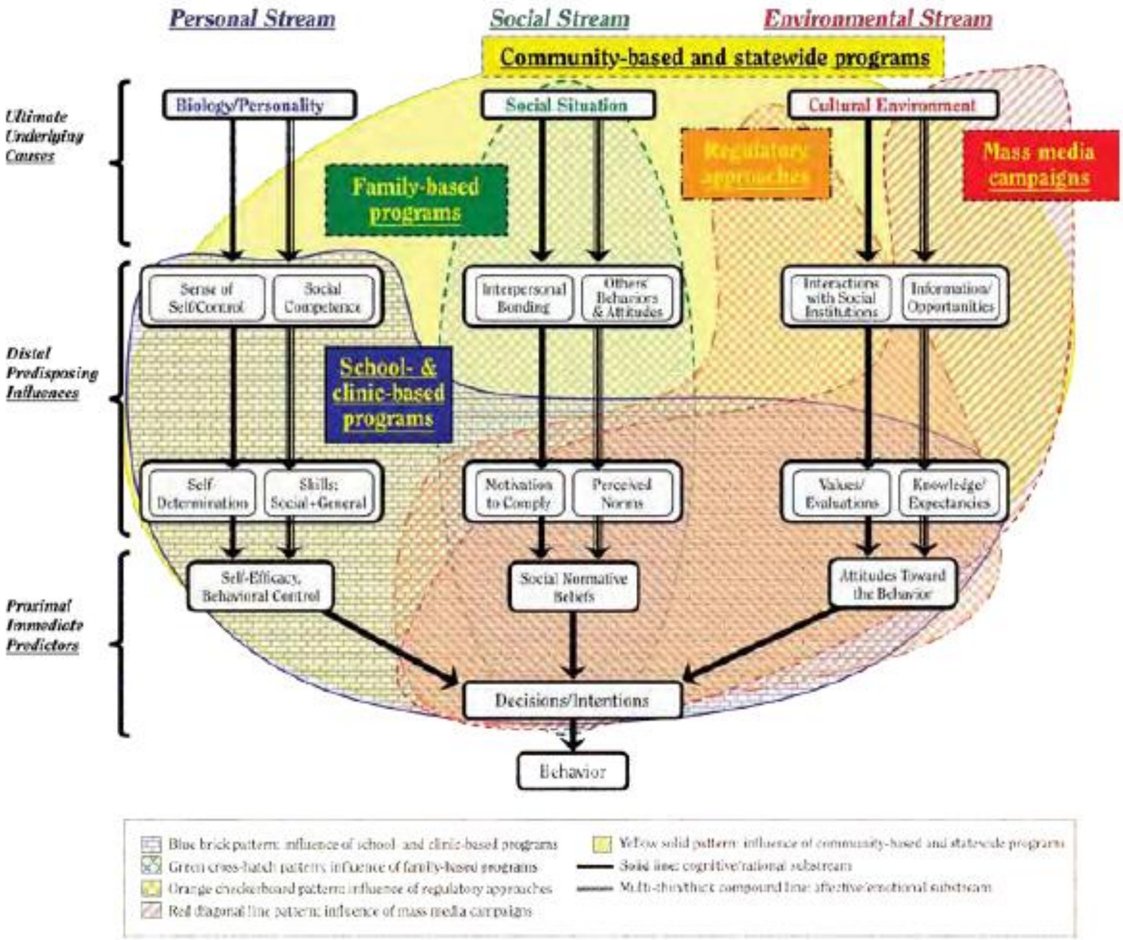
Appendix 5.

Percent current use of tobacco by product, school level, and gender; NYTS 2011-2012 ; the USA

	Total				Female				Male			
	2011		2012		2011		2012		2011		2012	
	%	(95% CI)	%	(95% CI)	%	(95% CI)	%	(95% CI)	%	(95% CI)	%	(95% CI)
Middle School												
Tobacco[b]	7.5	(6.5–8.8)	6.7	(5.8–7.7)	5.9	(4.7–7.4)	5.6	(4.7–6.7)	9.0	(7.9–10.3)	7.8	(6.7–9.0)
Both combustible & noncombustible tobacco[c]	1.9	(1.5–2.5)	2.0	(1.6–2.5)	1.6	(1.2–2.1)*	1.6	(1.2–2.1)*	2.2	(1.7–3.0)	2.5	(2.0–3.1)
Only combustible[d]	4.5	(3.7–5.5)	3.7	(3.2–4.3)	3.8	(2.8–5.0)	3.5	(2.8–4.4)	5.2	(4.3–6.2)†	3.9	(3.4–4.5)†
Only noncombustible[e]	1.1	(0.8–1.4)	1.0	(0.7–1.3)	0.5	(0.3–0.9)	0.5	(0.3–0.8)	1.6	(1.2–2.3)	1.4	(1.0–2.0)
Cigarettes	4.3	(3.5–5.2)	3.5	(2.8–4.3)	4.0	(3.1–5.2)	3.2	(2.5–4.0)	4.5	(3.7–5.5)	3.8	(3.0–4.7)
Cigars	3.5	(2.8–4.2)	2.8	(2.4–3.4)	2.5	(1.9–3.4)	2.4	(1.9–3.2)	4.3	(3.4–5.4)	3.2	(2.7–3.8)
Smokeless tobacco	2.2	(1.8–2.7)	1.7	(1.3–2.1)	1.4	(1.0–2.0)	1.2	(0.8–1.6)	3.0	(2.3–3.8)	2.2	(1.7–2.9)
Pipes	2.2	(1.7–2.9)	1.8	(1.4–2.3)	1.8	(1.3–2.5)	1.7	(1.3–2.3)	2.7	(2.1–2.5)	1.9	(1.4–2.4)
Bidis	1.7	(1.3–2.2)†	0.6	(0.5–0.7)†	1.4	(1.0–1.9)†	0.4	(0.3–0.7)†	1.9	(1.4–2.6)†	0.7	(0.5–1.0)†
Kreteks	1.1	(0.9–1.4)†	0.5	(0.4–0.7)†	0.9	(0.6–1.3)†	0.4	(0.3–0.7)†	1.3	(1.0–1.6)†	0.6	(0.4–0.9)†
Hookah	1.0	(0.8–1.4)	1.3	(1.0–1.7)	1.0	(0.6–1.6)	1.0	(0.7–1.4)	1.1	(0.7–1.5)	1.5	(1.1–2.2)
Snus	0.9	(0.6–1.2)	0.8	(0.6–1.0)	0.8	(0.5–1.2)	0.6	(0.4–0.9)	1.0	(0.6–1.4)	1.0	(0.7–1.4)
Dissolvable tobacco	0.3	(0.2–0.4)*	0.5	(0.4–0.8)*	0.3	(0.2–0.5)*	0.4	(0.2–0.6)*	0.3	(0.1–0.5)*	0.7	(0.4–1.1)*
Electronic cigarettes	0.6	(0.4–0.9)†	1.1	(0.9–1.5)†	0.4	(0.2–0.7)†	0.8	(0.6–1.1)†	0.7	(0.4–1.3)†	1.5	(1.1–2.1)†
High School												
Tobacco	24.3	(22.1–26.6)	23.3	(21.6–25.2)	19.0	(17.0–21.1)	18.1	(16.2–20.1)	29.4	(26.6–32.4)	28.3	(26.2–30.6)
Both combustible & noncombustible tobacco	6.2	(5.1–7.5)	6.8	(5.9–7.9)	2.0	(1.5–2.6)†	3.4	(2.8–4.2)†	10.3	(8.4–12.4)	10.1	(8.6–11.7)
Only combustible	15.7	(14.6–16.8)	14.4	(13.2–15.6)	16.3	(14.4–18.3)	14.2	(12.6–15.9)	15.0	(13.8–16.3)	14.6	(13.3–15.9)
Only noncombustible	2.4	(1.8–3.2)	2.1	(1.7–2.7)	0.7	(0.4–1.1)	0.5	(0.3–0.7)	4.1	(3.1–5.5)	3.7	(2.9–4.8)
Cigarettes	15.8	(13.7–18.1)	14.0	(12.5–15.7)	13.8	(11.7–16.2)	11.7	(10.2–13.4)	17.7	(15.2–20.4)	16.3	(14.5–18.3)
Cigars	11.6	(10.5–12.7)	12.6	(11.4–13.9)	7.4	(6.3–8.6)	8.4	(7.2–9.8)	15.7	(14.3–17.2)	16.7	(15.0–18.5)
Smokeless tobacco	7.3	(5.9–9.0)	6.4	(5.5–7.5)	1.6	(1.2–2.2)	1.5	(1.1–2.1)	12.9	(10.4–15.9)	11.2	(9.5–13.0)
Pipes	4.0	(3.4–4.6)	4.5	(4.0–5.2)	2.8	(2.2–3.4)	3.2	(2.7–3.9)	5.1	(4.3–6.0)	5.8	(5.0–6.7)
Bidis	2.0	(1.6–2.5)†	0.9	(0.7–1.1)†	1.0	(0.7–1.4)†	0.5	(0.3–0.7)†	2.9	(2.3–3.7)†	1.3	(1.0–1.7)†
Kreteks	1.7	(1.4–2.0)†	1.0	(0.8–1.2)†	0.8	(0.6–1.2)†	0.5	(0.3–0.7)†	2.4	(1.9–2.9)†	1.5	(1.1–1.9)†
Hookah	4.1	(3.4–5.0)†	5.4	(4.6–6.3)†	3.5	(2.8–4.4)	4.5	(3.7–5.4)	4.8	(3.7–6.1)	6.2	(5.3–7.3)
Snus	2.9	(2.3–3.7)	2.5	(2.0–3.0)	0.8	(0.5–1.1)	0.9	(0.7–1.3)	5.1	(3.9–6.6)	3.9	(3.2–4.9)
Dissolvable tobacco	2.0	(1.6–2.5)†	0.8	(0.6–1.0)†	0.1	(0.1–0.4)*	0.6	(0.4–0.9)*	0.6	(0.4–1.0)	1.0	(0.8–1.4)
Electronic cigarettes	1.5	(1.2–2.0)†	2.8	(2.3–3.5)†	0.7	(0.5–1.0)†	1.9	(1.5–2.4)†	2.3	(1.7–3.1)†	3.7	(2.9–4.8)†

Appendix 6.

Approaches to smoking prevention overlaid on the Theory of Triadic Influence



July 2015

Saving Lives – Saving Money: Excise Tax Increase Helps Ending Tobacco Epidemic in North Dakota

Each year, tobacco epidemic kills hundreds of lives in North Dakota and costs the state 247 million usd health care expenditures. It is one of the leading causes of preventable death, exceeding the number of deaths from car accidents, suicide or AIDs by four times. The state currently has one of the highest smoking rates among adults (21.2%) and adolescents (12.6%) within the USA. At the same time, the state excise tax for tobacco products hasn’t been changed for 20 years while the average annual wage grows by 2-5% each year. The tax accounts 44 cents that is one of the lowest rates in the country.

89% of adults initiate smoking in adolescence when the nicotine dependence starts to develop. Exposure to cigarettes is well-known cause of various negative health consequences. Approximately 14,000 North Dakota adolescents are projected to die prematurely due to smoking.

According to the latest surveys in 2014, 71.4% among high school students and almost 50% among middle school students perceive cigarettes as available. The price of tobacco matters a lot for teenagers in this case.

Healthy People 2020 Objective

The national health care programs set 16% prevalence for high school students and 12% prevalence for adults as a goal in tobacco use by 2020.
The modeling project conducted at UND in 2015 shows that there is a low chance to meet the objectives with the current pace of anti-tobacco efforts in North Dakota. Moreover, if the tax rate remains unchanged during the next 5 years the new increase will be faced in the prevalence trends among adolescents.
This finding motivates to look for an alternative way to decrease the smoking prevalence and take an immediate action in the tobacco policy within the state.

Policy Suggestion

Basing on the scientific-based experiments, it is suggested to increase the state excise tobacco tax by 1.56 usd. As a result the retail price would change up to 4.97 usd per pack of cigarettes which is near the border-states’ average.
This action would make possible to meet the objective by 2020 and potentially bring significant benefits to the North Dakota’s community.

Win-Win-Win Solution

The policy implementation would potentially improve human well-being with certain benefits to stakeholders.

Health Win

Tobacco tax increases are recognized as one of the most cost-effective ways to reduce smoking, especially among kids. The current policy can help to decrease the prevalence to 7.8% among all adolescents and save 1381 lives from premature death by 2032.

Budget Win

The change in the tobacco tax rate would increase the overall tobacco tax revenue gained in North Dakota by 1153 billion usd. Moreover, the policy would save 43.2 million usd of health care costs and 7.76 million usd of potential costs related to productive time loss.

Political Win

The state poll consistently has found overwhelming public support for tobacco tax increase. Almost 66% of voters within North Dakota support the implementation of the current policy.

Potential Risks

Raising the tobacco tax can potentially affect smokers with low incomes, and harm business owners who attract customers from other states due to low tax rates. Thus, it is necessary to provide additional support in helping quitting cigarettes for vulnerable groups of smokers and prepare the business owners to the new regulations in the market.

Moreover, the tax increase can influence smokers to switch to other alternative smokeless tobacco, for instance, e-cigarettes in case of adolescents.

Policy Advocacy

The policy is supported by North Dakota Tobacco Prevention and Control Executive Committee and a wide number of representatives from NGOs, educational and health institutions, local communities:

North Dakota Center for Prevention and Tobacco Control
Breathe ND
Tobacco Free North Dakota
American Lung Association
American Cancer Society
North Dakota Medical Association
Campaign for Tobacco-Free Kids
Grand Forks Public Health Department
University of North Dakota
Minot STAMP Tobacco Prevention Coalition

Appendix 8. Model Documentation

The model documentation contains all equations, units and notes used in the model. The subsequent description helps to replicate the modeling results.

Cumulative_HealthCostSaving(t) = Cumulative_HealthCostSaving(t - dt) + (ChangeIn_HealthCosts) * dt
INIT Cumulative_HealthCostSaving = 0
Units: dollars

INFLOWS:

ChangeIn_HealthCosts = If time>2015 then NumberOfTeens_PreventedFromSmoking*AveHealthCost_PerSmoker else 0
Units: dollars/Years

Cumulative_ProductiveTimeCostSaving(t) = Cumulative_ProductiveTimeCostSaving(t - dt) + (ChangeIn_PrTimeCost) * dt
INIT Cumulative_ProductiveTimeCostSaving = 0
Units: dollars

INFLOWS:

ChangeIn_PrTimeCost = If time> 2015 then NumberOfTeens_PreventedFromSmoking*AveProductiveTime_CostPerEmployee else 0
Units: dollars/Years

Cumulative_SavedLives(t) = Cumulative_SavedLives(t - dt) + (ChangeLives) * dt
INIT Cumulative_SavedLives = 0
Units: People

INFLOWS:

ChangeLives = If Time>2015 then NumberOfTeens_PreventedFromSmoking*RiskToFace_PrematureDeaths else 0
Units: person/Years

Current_Smokers[MiddleSchool](t) = Current_Smokers[MiddleSchool](t - dt) + (PR[Groups_of_Adolescents] + RR[Groups_of_Adolescents] + MRin3[Groups_of_Adolescents] - CS[Groups_of_Adolescents] - MR3[Groups_of_Adolescents]) * dt
INIT Current_Smokers[MiddleSchool] = 4316
Units: people

Current_Smokers[HighSchool](t) = Current_Smokers[HighSchool](t - dt) + (PR[Groups_of_Adolescents] + RR[Groups_of_Adolescents] + MRin3[Groups_of_Adolescents] - CS[Groups_of_Adolescents] - MR3[Groups_of_Adolescents]) * dt
INIT Current_Smokers[HighSchool] = 10242
Units: people

INFLOWS:

PR[MiddleSchool] = Experimenters[MiddleSchool]*NDL.PCA[MiddleSchool]*SocialEffect__OnPR[MiddleSchool]*NDL.NDLEffect[Experimenters, MiddleSchool]+Alt_Tobacco.Relapse_ToCigs[MiddleSchool]
Units: person/yr

PR[HighSchool] = Experimenters[HighSchool]*NDL.PCA[HighSchool]*SocialEffect__OnPR[HighSchool]*NDL.NDLEffect[Experimenters, HighSchool]+Alt_Tobacco.Relapse_ToCigs[HighSchool]
Units: person/yr

RR[MiddleSchool] = ExSmokers[MiddleSchool]*RRate[MiddleSchool]*NDL.NDLEffect[Ex_Smokers, MiddleSchool]
Units: person/yr

RR[HighSchool] = ExSmokers[HighSchool]*RRate[HighSchool]*NDL.NDLEffect[Ex_Smokers, HighSchool]

Units: person/yr

MRin3[MiddleSchool] = 0
Units: people/year

MRin3[HighSchool] = MR3[MiddleSchool]
Units: people/year

OUTFLOWS:
CS[MiddleSchool] =
Current_Smokers[MiddleSchool]*Quitting_Rate[MiddleSchool]*Successful_QuittingFra[MiddleSchool]*
NDL.NDLEffect[Current_Smokers,MiddleSchool])*PriceEffect_OnCR[MiddleSchool]+
Current_Smokers[MiddleSchool]*Fraction_Smo kersToQuit[MiddleSchool]
Units: person/yr

CS[HighSchool] =
(Current_Smokers[HighSchool]*Quitting_Rate[HighSchool]*Successful_QuittingFra[HighSchool]*N
DL.NDLEffect[Current_Smokers, HighSchool])*PriceEffect_OnCR[HighSchool]+
Current_Smokers[HighSchool]*Fraction_SmokersT oQuit[HighSchool]
Units: person/yr

MR3[MiddleSchool] = Current_Smokers[MiddleSchool]/TimeTo_Mature[MiddleSchool]
Units: person/yr

[MiddleSchool](t) = Experimenters[MiddleSchool](t - dt) + (IR[Groups_of_Adolescents] +
RelToExp[Groups_of_Adolescents] - PR[Groups_of_Adolescents] - QuitExp[Groups_of_Adolescents]) * dt
INIT Experimenters[MiddleSchool] = 3066
Units: people

Experimenters[HighSchool](t) = Experimenters[HighSchool](t - dt) + (IR[Groups_of_Adolescents] +
RelToExp[Groups_of_Adolescents] - PR[Groups_of_Adolescents] - QuitExp[Groups_of_Adolescents]) * dt INIT
Experimenters[HighSchool] = 4077
Units: people

INFLOWS:

IR[Groups_of_Adolescents] =
NeverSmoked*Susceptibility_Ratio*SocialEffect__OnIR+Initiators_FromEcigsUsers
Units: person/yr

RelToExp[Groups_of_Adolescents] = Former_Experimenters*Relapse_Rate +(if time=2016 then
Alt_Tobacco.Cessation else 0)
Units: person/year

OUTFLOWS:

PR[MiddleSchool] =
Experimenters[MiddleSchool]*NDL.PCA[MiddleSchool]*SocialEffect__OnPR[MiddleSchool]*NDL.
NDLEffect[Experimenters, MiddleSchool]+Alt_Tobacco.Relapse_ToCigs[MiddleSchool]
Units: person/yr

PR[HighSchool] =
Experimenters[HighSchool]*NDL.PCA[HighSchool]*SocialEffect__OnPR[HighSchool]*NDL.NDLEff
ect[Experimenters, HighSchool]+Alt_Tobacco.Relapse_ToCigs[HighSchool]
Units: person/yr

QuitExp[Groups_of_Adolescents] = Experimenters/TimeTo_StayExper-PR
Units: person/yr

ExSmokers[MiddleSchool](t) = ExSmokers[MiddleSchool](t - dt) + (CS[Groups_of_Adolescents] +
MRin4[Groups_of_Adolescents] - RR[Groups_of_Adolescents] - MR4[Groups_of_Adolescents]) * dt INIT
ExSmokers[MiddleSchool] = 1079
Units: people

ExSmokers[HighSchool](t) = ExSmokers[HighSchool](t - dt) + (CS[Groups_of_Adolescents] +
MRin4[Groups_of_Adolescents] - RR[Groups_of_Adolescents] - MR4[Groups_of_Adolescents]) * dt INIT
ExSmokers[HighSchool] = 4775
Units: people

INFLOWS:

CS[MiddleSchool] = (Current_Smokers[MiddleSchool]*Quitting_Rate[MiddleSchool]*Successful_QuittingFra[MiddleSchool]*NDL.NDLEffect[Current_Smokers, MiddleSchool])*PriceEffect_OnCR[MiddleSchool]+Current_Smokers[MiddleSchool]*Fraction_SmokersToQuit[MiddleSchool]
Units: person/yr

CS[HighSchool] = (Current_Smokers[HighSchool]*Quitting_Rate[HighSchool]*Successful_QuittingFra[HighSchool]*NDL.NDLEffect[Current_Smokers, HighSchool])*PriceEffect_OnCR[HighSchool]+ Current_Smokers[HighSchool]*Fraction_SmokersToQuit[HighSchool]
Units: person/yr

MRin4[MiddleSchool] = 0
Units: people/year

MRin4[HighSchool] = MR4[MiddleSchool] Units: people/year

OUTFLOWS:

RR[MiddleSchool] = ExSmokers[MiddleSchool]*RRate[MiddleSchool]*NDL.NDLEffect[Ex_Smokers, MiddleSchool]
Units: person/yr

RR[HighSchool] = ExSmokers[HighSchool]*RRate[HighSchool]*NDL.NDLEffect[Ex_Smokers, HighSchool]
Units: person/yr

MR4[MiddleSchool] = ExSmokers[MiddleSchool]/TimeTo_Mature[MiddleSchool] Units: person/yr

MR4[HighSchool] = ExSmokers[HighSchool]/TimeTo_Mature[HighSchool]
Units: person/yr

Former_Experimenters[MiddleSchool](t) = Former_Experimenters[MiddleSchool](t - dt) + (QuitExp[Groups_of_Adolescents] + MRin2[Groups_of_Adolescents] - MR2[Groups_of_Adolescents] - RelToExp[Groups_of_Adolescents]) * dt
INIT Former_Experimenters[MiddleSchool] = 3817
Units: people

Former_Experimenters[HighSchool](t) = Former_Experimenters[HighSchool](t - dt) + (QuitExp[Groups_of_Adolescents] + MRin2[Groups_of_Adolescents] - MR2[Groups_of_Adolescents] - RelToExp[Groups_of_Adolescents]) * dt
INIT Former_Experimenters[HighSchool] = 4607
Units: people

INFLOWS:

QuitExp[Groups_of_Adolescents] = Experimenters/TimeTo_StayExper-PR
Units: person/yr

MRin2[MiddleSchool] = 0
Units: people/year

MRin2[HighSchool] = MR2[MiddleSchool]
Units: people/year

OUTFLOWS:

MR2[MiddleSchool] = Former_Experimenters[MiddleSchool]/TimeTo_Mature[MiddleSchool]
Units: person/yr

MR2[HighSchool] = Former_Experimenters[HighSchool]/TimeTo_Mature[HighSchool]
Units: person/yr

RelToExp[Groups_of_Adolescents] = Former_Experimenters*Relapse_Rate +(if time=2016 then Alt_Tobacco.Cessation else 0)
Units: person/year

ND__Population(t) = ND__Population(t - dt) + (ChangeInPop) * dt
INIT ND__Population = 639480
Units: people

AnnualAveWage_NorthDakotaAllOccup = GRAPH(If Price_Adjustment=0 then 1992 else TIME)
(1992, 18834), (1993, 19343), (1994, 19986), (1995, 20651), (1996, 21338), (1997, 22047), (1998, 22780) (1999, 25133), (2000, 26805), (2001, 27530), (2002, 28640), (2003, 29380), (2004, 30180), (2005, 30850) (2006, 32440), (2007, 33650), (2008, 35150), (2009, 36010), (2010, 37040), (2011, 38870), (2012, 40850) (2013, 42410), (2014, 44100)
Units: dollars/Years

AveHealthCost_PerSmoker = 9379
Units: dollars/person

AveProductiveTime_CostPerEmployee = 1685
Units: dollars/person

Base_Mode = 0
Units: Dimensionless

BasicSuccess_InQuitting = 0.6
Units: Dimensionless

ChangeIn_Intensity = 0.2
Units: Dimensionless

ChangeIn_QuittingSuccess = 0.59
Units: Dimensionless

CurentSm_AdoData[MiddleSchool] = GRAPH(TIME)
(1992, 6243), (1993, 6635), (1994, 7130), (1995, 7490), (1996, 7505), (1997, 7204), (1998, 6105), (1999, 4914), (2000, 4079), (2001, 3494), (2002, 3278), (2003, 3126), (2004, 3034), (2005, 2903), (2006, 2547), (2007, 1926), (2008, 1902), (2009, 2367), (2010, 2068), (2011, 1797), (2012, 1595), (2013, 1414)
Units: people

CurentSm_AdoData[HighSchool] = GRAPH(TIME)
(1992, 11350), (1993, 13307), (1994, 14151), (1995, 15012), (1996, 15702), (1997, 16407), (1998, 16644) (1999, 16792), (2000, 15842), (2001, 13544), (2002, 11233), (2003, 9518), (2004, 7926), (2005, 6515), (2006, 8969), (2007, 8174), (2008, 8057), (2009, 8519), (2010, 7351), (2011, 6772), (2012, 6728), (2013, 6771)
Units: people

CurrentSm_AduData = GRAPH(if Base_Mode=0 then 1992 else TIME)
(1992, 102278), (1993, 103689), (1994, 104966), (1995, 106393), (1996, 112087), (1997, 105951), (1998, 95458), (1999, 97812), (2000, 111673), (2001, 111441), (2002, 105707), (2003, 102815), (2004, 99722), (2005, 101484), (2006, 99193), (2007, 97372), (2008, 93450), (2009, 96680), (2010, 89332), (2011, 116620), (2012, 115451), (2013, 118869) Units:People

ECigsEffect_OnIntensity[Groups_of_Adolescents] = If Scenario1=0 then 1 else (if time>2009 then (1-Alt_Tobacco.FractionDualUsers_Ecigarettes*ChangeIn_Intensity) else 1)
Units: Dimensionless

FractionAdults___InPopulation = GRAPH(TIME) (1992, 0.725), (2014, 0.75)
Units: Dimensionless

FractionSm_AduData = GRAPH(TIME)
(1992, 0.22), (1993, 0.222), (1994, 0.224), (1995, 0.226), (1996, 0.237), (1997, 0.223), (1998, 0.2), (1999, 0.204), (2000, 0.232), (2001, 0.229), (2002, 0.215), (2003, 0.207), (2004, 0.199), (2005, 0.201), (2006, 0.195), (2007, 0.19), (2008, 0.181), (2009, 0.186), (2010, 0.171), (2011, 0.219), (2012, 0.212), (2013, 0.212)
Units: Dimensionless

FractionSm_AllAdoData = FractionSm_AllAdoData1/100
Units: Dimensionless

FractionSm_AllAdoData1 = GRAPH(TIME)
(1992, 21.6), (1993, 25.7), (1994, 28.4), (1995, 31.1), (1996, 31.8), (1997, 32.1), (1998, 30.5), (1999, 28.9

(2000, 26.7), (2001, 24.5), (2002, 22.9), (2003, 21.3), (2004, 18.9), (2005, 16.4), (2006, 15.5), (2007, 14.5 (2008, 15.2), (2009, 15.9), (2010, 14.7), (2011, 13.5), (2012, 13.1), (2013, 12.7)
Units: Dimensionless

FractionTo_QuitSuccessSm = 0.15
Units: Dimensionless

Fraction_NeverSmoked = (NeverSmoked[MiddleSchool]+NeverSmoked[HighSchool])/(TotPopAdo[MiddleSchool]+TotPopAdo[HighS chool])
Units: Dimensionless

Fraction_SmokersAdo[Groups_of_Adolescents] = Current_Smokers/TotPopAdo
Units: Dimensionless

Fraction_SmokersAdu = if IntSmAdu=0 then CurrentSm_AduData/Adults else Smoking_InAdults.Current/Adults
Units: Dimensionless

Fraction_SmokersAllAdo = (Fraction_SmokersAdo[MiddleSchool]*TotPopAdo[MiddleSchool]+Fraction_SmokersAdo[HighSchool]*Tot PopAdo[HighSchool])/(TotPopAdo[MiddleSchool]+TotPopAdo[HighSchool])
Units: Dimensionless

Fraction_SmokersToQuit[Groups_of_Adolescents] = If Scenario1=0 then 0 else (if time>2009 then Alt_Tobacco.FractionDualUsers_Ecigarettes*FractionTo_QuitSuccessSm/TimeToQuit else 0)
Units: 1/Years

FrSmAdoData[MiddleSchool] = GRAPH(TIME)
(1992, 0.122), (1993, 0.155), (1994, 0.184), (1995, 0.197), (1996, 0.201), (1997, 0.196), (1998, 0.165), (1999, 0.134), (2000, 0.117), (2001, 0.1), (2002, 0.0975), (2003, 0.095), (2004, 0.093), (2005, 0.089), (2006, 0.073), (2007, 0.057), (2008, 0.065), (2009, 0.073), (2010, 0.0645), (2011, 0.056), (2012, 0.049), (2013, 0.042)
Units: Dimensionless

FrSmAdoData[HighSchool] = GRAPH(TIME)
(1992, 0.291), (1993, 0.324), (1994, 0.358), (1995, 0.385), (1996, 0.406), (1997, 0.415), (1998, 0.41), (1999, 0.406), (2000, 0.38), (2001, 0.353), (2002, 0.328), (2003, 0.302), (2004, 0.262), (2005, 0.221), (2006, 0.216), (2007, 0.211), (2008, 0.218), (2009, 0.224), (2010, 0.209), (2011, 0.194), (2012, 0.192), (2013, 0.19)
Units: Dimensionless

Growth_RateData = GRAPH(TIME)
(1992, 0.231), (1993, 0.0531), (1994, 0.0531), (1995, 0.0531), (1996, 0.0531), (1997, 0.053), (1998, 0.053), (1999, 0.053), (2000, 0.0529), (2001, 0.498), (2002, 0.496), (2003, 0.49), (2004, 0.493), (2005, 0.488), (2006, 0.486), (2007, 0.484), (2008, 0.481), (2009, 0.479), (2010, 0.218), (2011, 1.79), (2012, 2.35), (2013, 2.76), (2014, 1.55) Units: 1/Years

HPObjective_2020Ado = 0.16
Units: Dimensionless

HPObjective_2020Adu = 0.12
Units: Dimensionless

Initiation_RateForECigsUsers = 0.3
Units: 1/Years

Initiators_FromEcigsUsers[Groups_of_Adolescents] = if Scenario2=0 then 0 else (if time>2009 then Alt_Tobacco.Potentially_SusceptibleToStart_SmokingCigs*Initiation_RateForECigsUsers else 0)
Units: people/years

IntAltTobacco = If Integration_Modules=0 then 0 else 1
Units: Dimensionless

Integration_Modules = 0
Units: Dimensionless

IntRiskPerc = If Integration_Modules=0 then 0 else 1

Units: Dimensionless

IntSmAdu = If Integration_Modules=0 then 0 else 1
Units: Dimensionless

IntSuscRatio = If Integration_Modules=0 then 0 else 1
Units: Dimensionless

MR[Groups_of_Adolescents] = MR1+MR2+MR3+MR4
Units: people/Years

NDPopulation__Data = GRAPH(TIME)
(1992, 639480), (1993, 639820), (1994, 640160), (1995, 640500), (1996, 640840), (1997, 641180), (1998, 641520), (1999, 641860), (2000, 642200), (2001, 645414), (2002, 648628), (2003, 651824), (2004, 655056), (2005, 658270), (2006, 661484), (2007, 664698), (2008, 667912), (2009, 671126), (2010, 672591), (2011, 684867), (2012, 701345), (2013, 723393), (2014, 739482)
Units: People

NetFlowCSm[Groups_of_Adolescents] = PR+RR-MR3-CS
Units: people/Years

NumberOfTeens_PreventedFromSmoking = If (TotPopAdo[MiddleSchool]+TotPopAdo[HighSchool])*PolicyResults_InPrevalence>1 then (TotPopAdo[MiddleSchool]+TotPopAdo[HighSchool])*PolicyResults_InPrevalence else 0
Units: People/Years

Parental_Smoking = (Fraction_SmokersAdu^2+2*Fraction_SmokersAdu*(1-Fraction_SmokersAdu))*ProbabilityBoth_ParentsInFamily+Fraction_SmokersAdu*(1-ProbabilityBoth_ParentsInFamily) Units: Dimensionless

Policy4 = 0
Units: Dimensionless

PolicyResults_InPrevalence = If Base_Mode=0 then 0 else (If time>2015 then (ProjectedPrevalence_BusinessAsUsual-Fraction_SmokersAllAdo)/TimeToMature else 0)
Units: 1/Years

PriceEffect_OnCR[Groups_of_Adolescents] = If SWPrice=0 then 1 else ((Price_AdjustedTo_Wages/INIT(Price_AdjustedTo_Wages)))^PriceElasticity_Cessation Units: Dimensionless

PriceElasticity_Cessation[MiddleSchool] = GRAPH(Fraction_SmokersAdo)
(0.00, 0.3), (0.0667, 0.651), (0.133, 0.758), (0.2, 0.812), (0.267, 0.836), (0.333, 0.855), (0.4, 0.864), (0.467, 0.879), (0.533, 0.885), (0.6, 0.888), (0.667, 0.891), (0.733, 0.894), (0.8, 0.894), (0.867, 0.894), (0.933, 0.897), (1.00, 0.9)
Units: Dimensionless

PriceElasticity_Cessation[HighSchool] = GRAPH(Fraction_SmokersAdo)
(0.00, 0.3), (0.1, 0.482), (0.2, 0.642), (0.3, 0.746), (0.4, 0.803), (0.5, 0.842), (0.6, 0.861), (0.7, 0.876), (0.8, 0.885), (0.9, 0.888), (1.00, 0.9)
Units: Dimensionless

Price_AdjustedTo_Wages = Marketing.PPerPack/(AnnualAveWage_NorthDakotaAllOccup)
Units: Years/pack

Price_Adjustment = 0
Units: Dimensionless

ProbabilityBoth_ParentsInFamily = 0.72
Units: Dimensionless

ProjectedPrevalence_BusinessAsUsual = GRAPH(TIME)
(2014, 0.119), (2015, 0.117), (2016, 0.116), (2017, 0.115), (2018, 0.114), (2019, 0.114), (2020, 0.113), (2021, 0.113), (2022, 0.113), (2023, 0.114), (2024, 0.114), (2025, 0.114), (2026, 0.114), (2027, 0.115), (2028, 0.115), (2029, 0.116), (2030, 0.117), (2031, 0.117), (2032, 0.118)
Units: Dimensionless

QRBasic[MiddleSchool] = 0.25
Units: 1/Years

QRBasic[HighSchool] = 0.5
Units: 1/Years

Quitting_Rate[Groups_of_Adolescents] = If Base_Mode=0 then QRBasic*RPEffect else QRBasic*Resistance__Effect*RPEffect
Units: 1/Years

Relapse_Rate[MiddleSchool] = GRAPH(If Base_Mode=0 then 1992 else TIME)
(1992, 0.2), (1993, 0.292), (1993, 0.353), (1994, 0.381), (1994, 0.393), (1995, 0.401), (1995, 0.413), (1996, 0.426), (1996, 0.43), (1997, 0.434), (1998, 0.434), (1998, 0.434), (1999, 0.43), (1999, 0.43), (2000, 0.43), (2000, 0.426), (2001, 0.426), (2001, 0.426), (2002, 0.413), (2002, 0.405), (2003, 0.397), (2004, 0.389), (2004, 0.377), (2005, 0.373), (2005, 0.365), (2006, 0.357), (2006, 0.345), (2007, 0.337), (2007, 0.32), (2008, 0.32), (2009, 0.288), (2009, 0.272), (2010, 0.255), (2010, 0.251), (2011, 0.247), (2011, 0.235), (2012, 0.219), (2012, 0.191), (2013, 0.182), (2013, 0.178), (2014, 0.162)
Units: 1/years

Relapse_Rate[HighSchool] = GRAPH(If Base_Mode=0 then 1992 else TIME)
(1992, 0.32), (1993, 0.364), (1993, 0.397), (1994, 0.454), (1994, 0.487), (1995, 0.511), (1995, 0.525), (1996, 0.539), (1996, 0.544), (1997, 0.544), (1998, 0.544), (1998, 0.544), (1999, 0.539), (1999, 0.53), (2000, 0.525), (2000, 0.515), (2001, 0.497), (2001, 0.487), (2002, 0.459), (2002, 0.445), (2003, 0.426), (2004, 0.416), (2004, 0.402), (2005, 0.383), (2005, 0.383), (2006, 0.374), (2006, 0.355), (2007, 0.355), (2007, 0.345), (2008, 0.345), (2009, 0.345), (2009, 0.345), (2010, 0.345), (2010, 0.331), (2011, 0.326), (2011, 0.317), (2012, 0.317), (2012, 0.303), (2013, 0.303), (2013, 0.298), (2014, 0.288)
Units: 1/years

Resistance__Effect[MiddleSchool] = GRAPH(Fraction_SmokersAdo)
(0.01, 0.01), (0.02, 0.141), (0.03, 0.281), (0.04, 0.442), (0.05, 0.573), (0.06, 0.633), (0.07, 0.744), (0.08, 0.824), (0.09, 0.864), (0.1, 0.904), (0.11, 0.935), (0.12, 0.945), (0.13, 0.985), (0.14, 0.985), (0.15, 0.985), (0.16, 1.01), (0.17, 1.03), (0.18, 1.04), (0.19, 1.05), (0.2, 1.06), (0.21, 1.09), (0.22, 1.10), (0.23, 1.11), (0.24, 1.14), (0.25, 1.15), (0.26, 1.18), (0.27, 1.21), (0.28, 1.23), (0.29, 1.25), (0.3, 1.26), (0.31, 1.31), (0.32, 1.33), (0.33, 1.36), (0.34, 1.40), (0.35, 1.42), (0.36, 1.44), (0.37, 1.49), (0.38, 1.56), (0.39, 1.62), (0.4, 1.64), (0.41, 1.66), (0.42, 1.68), (0.43, 1.72), (0.44, 1.74), (0.45, 1.82), (0.46, 1.86), (0.47, 1.89), (0.48, 1.93), (0.49, 1.95), (0.5, 2.00)
Units: Dimensionless

Resistance__Effect[HighSchool] = GRAPH(Fraction_SmokersAdo)
(0.01, 0.01), (0.02, 0.04), (0.03, 0.07), (0.04, 0.1), (0.05, 0.123), (0.06, 0.153), (0.07, 0.176), (0.08, 0.221), (0.09, 0.236), (0.1, 0.273), (0.11, 0.292), (0.12, 0.311), (0.13, 0.326), (0.14, 0.353), (0.15, 0.379), (0.16, 0.431), (0.17, 0.466), (0.18, 0.502), (0.19, 0.537), (0.2, 0.56), (0.21, 0.582), (0.22, 0.612), (0.23, 0.619), (0.24, 0.627), (0.25, 0.642), (0.26, 0.672), (0.27, 0.725), (0.28, 0.732), (0.29, 0.778), (0.3, 0.808), (0.31, 0.845), (0.32, 0.879), (0.33, 0.913), (0.34, 0.936), (0.35, 0.958), (0.36, 0.988), (0.37, 1.03), (0.38, 1.05), (0.39, 1.08), (0.4, 1.08), (0.41, 1.11), (0.42, 1.17), (0.43, 1.20), (0.44, 1.22), (0.45, 1.27), (0.46, 1.30), (0.47, 1.37), (0.48, 1.40), (0.49, 1.45), (0.5, 1.50)
Units: Dimensionless

RiskPerc_DataMTF[MiddleSchool] = GRAPH(TIME)
(1992, 50.8), (1993, 52.7), (1994, 50.8), (1995, 49.8), (1996, 50.4), (1997, 52.6), (1998, 54.3), (1999, 54.8 (2000, 58.8), (2001, 57.1), (2002, 57.5), (2003, 57.7), (2004, 62.4), (2005, 61.5), (2006, 59.4), (2007, 61.1 (2008, 59.8), (2009, 59.1), (2010, 60.9), (2011, 62.5), (2012, 62.6), (2013, 62.4), (2014, 62.1)
Units: Dimensionless

RiskPerc_DataMTF[HighSchool] = GRAPH(TIME)
(1992, 69.2), (1994, 69.5), (1996, 67.6), (1997, 65.6), (1999, 68.2), (2001, 68.7), (2003, 70.8), (2005, 70.8 (2007, 73.1), (2008, 73.3), (2010, 74.2), (2012, 72.1), (2014, 74.0), (2016, 76.5), (2017, 77.6), (2019, 77.3 (2021, 74.0), (2023, 74.9), (2025, 75.0), (2027, 77.7), (2028, 78.2), (2030, 78.2), (2032, 78.0)
Units: Dimensionless

RiskToFace_PrematureDeaths = 0.3
Units: Dimensionless

RPEffect[Groups_of_Adolescents] = GRAPH(Risk_Perception.Actual/INIT(Risk_Perception.Actual))
(0.9, 0.9), (1.00, 1.00), (1.10, 1.12), (1.20, 1.21), (1.30, 1.29), (1.40, 1.35), (1.50, 1.40), (1.60, 1.43), (1.70, 1.46), (1.80, 1.47), (1.90, 1.48), (2.00, 1.50)

Units: Dimensionless

RRate[MiddleSchool] = 0.35
Units: 1/Years

RRate[HighSchool] = 0.45
Units: 1/Years

Scenario1 = 0
Units: Dimensionless

Scenario2 = 0
Units: Dimensionless

SocialEffect__OnIR[MiddleSchool] = GRAPH(Social_Pressure)
(0.00, 0.00), (0.1, 0.124), (0.2, 0.249), (0.3, 0.373), (0.376, 0.466), (0.5, 0.592), (0.6, 0.686), (0.7, 0.769), (0.8, 0.846), (0.9, 0.941), (1.00, 1.00)
Units: Dimensionless

SocialEffect__OnIR[HighSchool] = GRAPH(Social_Pressure)
(0.00, 0.014), (0.1, 0.243), (0.2, 0.462), (0.3, 0.633), (0.376, 0.746), (0.5, 0.817), (0.6, 0.87), (0.7, 0.905), (0.8, 0.941), (0.9, 0.976), (1.00, 1.00)
Units: Dimensionless

SocialEffect__OnPR[MiddleSchool] = GRAPH(Social_Pressure)
(0.00, 0.00), (0.1, 0.148), (0.2, 0.284), (0.3, 0.444), (0.376, 0.565), (0.5, 0.68), (0.6, 0.757), (0.7, 0.834), (0.8, 0.893), (0.9, 0.947), (1.00, 1.00)
Units: Dimensionless

SocialEffect__OnPR[HighSchool] = GRAPH(Social_Pressure)
(0.00, 0.00), (0.1, 0.213), (0.2, 0.373), (0.3, 0.55), (0.376, 0.662), (0.5, 0.757), (0.6, 0.834), (0.7, 0.888), (0.8, 0.935), (0.9, 0.97), (1.00, 0.994)
Units: Dimensionless

Social_Pressure =
MIN(((Parental_Smoking+2*Fraction_SmokersAllAdo)/3)*Marketing.TobaccoIn_MediaAmplifier, 1)
Units: Dimensionless

Successful_QuittingFra[Groups_of_Adolescents] =
BasicSuccess_InQuitting*ActualChange_InQuittingSuccess
Units: Dimensionless

Susceptability_RatioData[MiddleSchool] = GRAPH(If Base_Mode=0 then 1992 else TIME)
(1992, 0.22), (1993, 0.311), (1994, 0.345), (1995, 0.358), (1996, 0.338), (1997, 0.27), (1998, 0.264), (1999, 0.254), (2000, 0.242), (2001, 0.23), (2002, 0.217), (2003, 0.206), (2004, 0.191), (2005, 0.173), (2006, 0.172), (2007, 0.171), (2008, 0.159), (2009, 0.147), (2010, 0.148), (2011, 0.156), (2012, 0.155), (2013, 0.154)
Units: 1/Years

Susceptability_RatioData[HighSchool] = GRAPH(If Base_Mode=0 then 1992 else TIME)
(1992, 0.29), (1993, 0.392), (1994, 0.466), (1995, 0.486), (1996, 0.473), (1997, 0.419), (1998, 0.35), (1999, 0.332), (2000, 0.325), (2001, 0.301), (2002, 0.283), (2003, 0.24), (2004, 0.24), (2005, 0.24), (2006, 0.234), (2007, 0.227), (2008, 0.204), (2009, 0.183), (2010, 0.192), (2011, 0.206), (2012, 0.205), (2013, 0.205)
Units: 1/Years

Susceptibility_Ratio[MiddleSchool] = if IntSuscRatio=0 then Susceptability_RatioData[MiddleSchool] else MIN((1-Risk_Perception.Actual[MiddleSchool])*SecHand_Smoking.Effect[MiddleSchool]*NDL.NDLEffect [NonSmokers, MiddleSchool], 1)/2
Units: 1/Years

Susceptibility_Ratio[HighSchool] = if IntSuscRatio=0 then Susceptability_RatioData[HighSchool] else MIN((1-Risk_Perception.Actual[HighSchool])*SecHand_Smoking.Effect[HighSchool]*NDL.NDLEffect[Non Smokers, HighSchool], 1)
Units: 1/Years

SwitchMarketing = If Integration_Modules=0 then 0 else 1
Units: Dimensionless

SwitchNDL = 0
Units: Dimensionless

SWPrice = 0
Units: Dimensionless

TimeToMature = 8
Units: Years

TimeToQuit = 1
Units: Years

TimeTo_Mature[MiddleSchool] = 4
Units: Years

TimeTo_Mature[HighSchool] = 4
Units: Years

TimeTo_StayExper = 1
Units: Years

TotalAdo_PopData = GRAPH(TIME)
(1992, 74488), (1993, 75060), (1994, 75844), (1995, 75926), (1996, 76058), (1997, 76290), (1998, 77545) (1999, 78027), (2000, 76608), (2001, 73309), (2002, 67920), (2003, 64425), (2004, 62929), (2005, 62092) (2006, 76420), (2007, 72535), (2008, 66308), (2009, 70457), (2010, 67234), (2011, 67000), (2012, 67598) (2013, 69297), (2014, 71949)
Units: people

TotalCost_Saving = (Cumulative_HealthCostSaving+Cumulative_ProductiveTimeCostSaving)/1000000
Units: dollars

TotPopAdo[Groups_of_Adolescents] =
NeverSmoked+Experimenters+Former_Experimenters+Current_Smokers+ExSmokers Units: people

YearOfChange = 2016
Units: Years

Alt Tobacco

EcigsUsers[Groups_of_Adolescents](t) = EcigsUsers[Groups_of_Adolescents](t - dt) + (Initiation[Groups_of_Adolescents] + MRTo2[Groups_of_Adolescents] - Cessation[Groups_of_Adolescents] - MRFrom2[Groups_of_Adolescents]) * dt INIT EcigsUsers[Groups_of_Adolescents] = 0
Units: People

INFLOWS:

Initiation[Groups_of_Adolescents] =
NeverUsers*EffectOn_Initiation*Susceptibility_Ratio*Flavors_Effect+Pulse2010
Units: people/years

MRTo2[MiddleSchool] = 0
Units: people/years

MRTo2[HighSchool] = MRFrom2[MiddleSchool]
Units: people/years

OUTFLOWS:

Cessation[Groups_of_Adolescents] = EcigsUsers*(Cessation_Fraction+Pulse_Flavors)
Units: people/years

MRFrom2[Groups_of_Adolescents] = EcigsUsers/TimeTo_Mature
Units: people/years

ExUsers[Groups_of_Adolescents](t) = ExUsers[Groups_of_Adolescents](t - dt) + (Cessation[Groups_of_Adolescents] + MRTo3[Groups_of_Adolescents] - MRFrom3[Groups_of_Adolescents]) * dt

INIT ExUsers[Groups_of_Adolescents] = 0
Units: People
INFLOWS:
Cessation[Groups_of_Adolescents] = EcigsUsers*(Cessation_Fraction+Pulse_Flavors)
Units: people/years
MRTo3[MiddleSchool] = 0
Units: people/years
MRTo3[HighSchool] = MRFrom3[MiddleSchool] Units: people/years

OUTFLOWS:
MRFrom3[Groups_of_Adolescents] = ExUsers/TimeTo_Mature
Units: people/years

NeverUsers[Groups_of_Adolescents](t) = NeverUsers[Groups_of_Adolescents](t - dt) + (Maturing_FromKids[Groups_of_Adolescents] + MR1To[Groups_of_Adolescents] - Initiation[Groups_of_Adolescents] - MRFrom1[Groups_of_Adolescents]) * dt
INIT NeverUsers[Groups_of_Adolescents] = .TotPopAdo
Units: People
ContactRate_EcigsSmokers[Groups_of_Adolescents] = GRAPH(Fraction_ECigsUsers)
(0.00, 0.00), (0.1, 1.09), (0.2, 1.64), (0.3, 2.16), (0.4, 2.71), (0.5, 3.18), (0.6, 3.70), (0.7, 4.14), (0.8, 4.45), (0.9, 4.71), (1.00, 4.97)
Units: Dimensionless

EcigsIn_MediaAmplifier[Groups_of_Adolescents] = If time>2008 then 2*Saturation_Effect else 1
Units: Dimensionless

EffectOn_Initiation[MiddleSchool] = GRAPH(Social_Pressure)
(0.00, 0.00), (0.1, 0.041), (0.2, 0.071), (0.3, 0.107), (0.4, 0.124), (0.5, 0.136), (0.6, 0.172), (0.7, 0.219), (0.8, 0.367), (0.9, 0.604), (1.00, 1.00)
Units: Dimensionless

EffectOn_Initiation[HighSchool] = GRAPH(Social_Pressure)
(0.00, 0.00), (0.1, 0.041), (0.2, 0.071), (0.3, 0.089), (0.4, 0.112), (0.5, 0.124), (0.6, 0.142), (0.7, 0.219), (0.8, 0.367), (0.9, 0.604), (1.00, 1.00)
Units: Dimensionless
Flavors_Effect[MiddleSchool] = if .Policy4=0 then 1.4 else 1
Units: Dimensionless
Flavors_Effect[HighSchool] = if .Policy4=0 then 1.3 else 1
Units: Dimensionless
FractionDualUsers_Ecigarettes[MiddleSchool] = 0.19
Units: Dimensionless
FractionDualUsers_Ecigarettes[HighSchool] = 0.28
Units: Dimensionless

FractionDualUsers_SmokelessTobacco[MiddleSchool] = GRAPH(TIME)
(1992, 0.041), (1993, 0.068), (1993, 0.074), (1994, 0.074), (1994, 0.074), (1995, 0.074), (1995, 0.068), (1996, 0.068), (1996, 0.068), (1997, 0.068), (1998, 0.068), (1998, 0.081), (1999, 0.108), (1999, 0.135), (2000, 0.162), (2000, 0.176), (2001, 0.209), (2001, 0.209), (2002, 0.209), (2002, 0.23), (2003, 0.284), (2004, 0.291), (2004, 0.291), (2005, 0.291), (2005, 0.291), (2006, 0.297), (2006, 0.297), (2007, 0.297), (2007, 0.297), (2008, 0.297), (2009, 0.297), (2009, 0.304), (2010, 0.324), (2010, 0.345), (2011, 0.365), (2011, 0.365), (2012, 0.365), (2012, 0.365), (2013, 0.365), (2013, 0.385), (2014, 0.399)
Units: 1/person

FractionDualUsers_SmokelessTobacco[HighSchool] = GRAPH(TIME)
(1992, 0.081), (1993, 0.095), (1993, 0.095), (1994, 0.101), (1994, 0.108), (1995, 0.115), (1995, 0.128), (1996, 0.135), (1996, 0.149), (1997, 0.162), (1998, 0.176), (1998, 0.192), (1999, 0.207), (1999, 0.216), (2000, 0.297), (2000, 0.304), (2001, 0.304), (2001, 0.318), (2002, 0.331), (2002, 0.378), (2003, 0.446), (2004, 0.459), (2004, 0.459), (2005, 0.466),

(2005, 0.466), (2006, 0.473), (2006, 0.473), (2007, 0.473), (2007, 0.473), (2008, 0.48), (2009, 0.486), (2009, 0.52), (2010, 0.588), (2010, 0.588), (2011, 0.588), (2011, 0.588), (2012, 0.588), (2012, 0.601), (2013, 0.601), (2013, 0.608), (2014, 0.608)
Units: 1/person

FractionNeverSmoked_ConventionalCigs[MiddleSchool] = 0.203
Units: Dimensionless

FractionNeverSmoked_ConventionalCigs[HighSchool] = 0.079
Units: Dimensionless

FractionQuit_FlavorsBan = 0.5
Units: 1/Years

Fraction_ECigsUsers[Groups_of_Adolescents] = EcigsUsers/.TotPopAdo
Units: Dimensionless

Frequency_Ecigarettes[Groups_of_Adolescents] = GRAPH(ContactRate_EcigsSmokers)
(0.00, 0.00), (0.5, 6.27), (1.00, 10.0), (1.50, 13.2), (2.00, 16.3), (2.50, 19.1), (3.00, 21.6), (3.50, 23.9), (4.00, 26.4), (4.50, 28.5), (5.00, 30.0)
Units: days/month/person

Frequency_Smokeless[MiddleSchool] = 3
Units: Days/month

Frequency_Smokeless[HighSchool] = 8
Units: Days/month

Intensity_SessionsEcigarettes[MiddleSchool] = if .Policy4=0 then 2 else 0.8
Units: session/day

Intensity_SessionsEcigarettes[HighSchool] = if .Policy4=0 then 4 else 1.6
Units: session/day

Intensity_Smokeless[Groups_of_Adolescents] = 1
Units: session/day

Months = 12
Units: Months/Years

MRToAdults[Groups_of_Adolescents] = MRFrom1+MRFrom2+MRFrom3
Units: people/Years

NicIntake_Smokeless_Tobacco[Groups_of_Adolescents] = FractionDualUsers_SmokelessTobacco*Quantity_Smoking*AveNicotine_Concentration_SmokelessTobac co
Units: mg/Years/person

NicotineIntake_Ecigarettes[Groups_of_Adolescents] = FractionDualUsers_Ecigarettes*Quantity_SmokingEcigs*AveNicotine_Concentration_EcigsPerSession
Units: mg/Years/person

Potentially_SusceptibleToStart_SmokingCigs[Groups_of_Adolescents] = EcigsUsers*FractionNeverSmoked_ConventionalCigs
Units: People

Pulse2010[MiddleSchool] = If .Base_Mode=0 then 0 else (If time=2008 then 100 else 0) Units: people/Years

Pulse2010[HighSchool] = If .Base_Mode=0 then 0 else (if time=2008 then 300 else 0) Units: people/Years

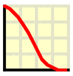
Pulse_Flavors = if .Policy4=0 then 0 else 0+Pulse (FractionQuit_FlavorsBan, 2016, 0) Units: 1/Years

Quantity_Smoking[Groups_of_Adolescents] = Frequency_Smokeless*Intensity_Smokeless*Months
Units: session/Years

Quantity_SmokingEcigs[Groups_of_Adolescents] = Frequency_Ecigarettes*Intensity_SessionsEcigarettes*Months
Units: session/Years/person

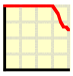
Relapse_RateCigs = 0.05
Units: Dimensionless

Relapse_ToCigs[Groups_of_Adolescents] = if time>2020 then Relapse_RateCigs*Cessation else 0
Units: person/yr



Saturation_Effect[Groups_of_Adolescents] = GRAPH(Fraction_ECigsUsers)
(0.00, 1.00), (0.1, 0.942), (0.2, 0.863), (0.3, 0.771), (0.4, 0.65), (0.5, 0.529), (0.6, 0.346), (0.7, 0.292), (0.8, 0.258), (0.9, 0.225), (1.00, 0.2)
Units: Dimensionless

Social_Pressure[Groups_of_Adolescents] = Fraction_ECigsUsers*EcigsIn_MediaAmplifier
Units: Dimensionless



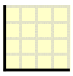
Susceptibility_Ratio = GRAPH(TIME)
(1992, 1.00), (1993, 1.00), (1994, 1.00), (1995, 1.00), (1996, 1.00), (1997, 1.00), (1998, 1.00), (1999, 1.00 (2000, 1.00), (2001, 1.00), (2002, 1.00), (2003, 1.00), (2004, 1.00), (2005, 1.00), (2006, 1.00), (2007, 1.00 (2008, 1.00), (2009, 1.00), (2010, 0.872), (2011, 0.73), (2012, 0.649), (2013, 0.642), (2014, 0.635)
Units: 1/Years

TimeTo_Mature[Groups_of_Adolescents] = 4
Units: Years

Total_NicotineIntake[Groups_of_Adolescents] = If .IntAltTobacco=0 then 0 else NicotineIntake_Ecigarettes+NicIntake_Smokeless_Tobacco
Units: mg/Years/person

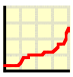
Marketing:

Adolescents_DemandRatio = Consumption_Adolescents/Consumption_Adults
Units: Dimensionless



AnnualAveWage_NDAllOccupations = GRAPH(TIME)
(1992, 18834), (1993, 19343), (1994, 19986), (1995, 20651), (1996, 21338), (1997, 22047), (1998, 22780) (1999, 25133), (2000, 26805), (2001, 27530), (2002, 28640), (2003, 29380), (2004, 30180), (2005, 30850) (2006, 32440), (2007, 33650), (2008, 35150), (2009, 36010), (2010, 37040), (2011, 38870), (2012, 40850) (2013, 42410), (2014, 44100)
Units: dollars/Years

AntiTobacco_Budget = if time<2015 then TaxRevenue_ByND*Percentage_ToATBData else (if Policy2=0 then TaxRevenue_ByND*Percentage_ToATB else MIN(DesiredATB, TaxRevenue_ByND))
Units: dollars/Years



ATBData = GRAPH(TIME)
(1992, 1.22), (1993, 1.32), (1993, 1.42), (1994, 1.42), (1994, 1.42), (1995, 1.42), (1995, 1.42), (1996, 1.42 (1997, 1.52), (1997, 1.52), (1998, 2.33), (1998, 3.14), (1999, 3.34), (1999, 3.45), (2000, 3.55), (2001, 3.65 (2001, 3.65), (2002, 3.65), (2002, 3.65), (2003, 3.75), (2004, 3.75), (2004, 3.75), (2005, 4.16), (2005, 4.16 (2006, 4.26), (2006, 4.56), (2007, 4.56), (2008, 4.46), (2008, 4.36), (2009, 4.26), (2009, 4.66), (2010, 5.37 (2010, 5.78), (2011, 6.08), (2012, 6.08), (2012, 6.18), (2013, 6.59), (2013, 7.70), (2014, 8.41), (2014, 9.63 (2015, 9.22)
Units: dollars/Years

ATB_Actual = MAX(if .Base_Mode=0 then 1220000 else (If .SwitchMarketing=0 then ATBData*1000000 else AntiTobacco_Budget), 0)
Units: dollars/Years

ATB_PerCapita = If .Base_Mode=0 then ATB_Actual/Init(.ND__Population) else ATB_Actual/.ND__Population
Units: dollars/person/Years

BaseLevel_OfPublicSupport = 0.4
Units: Dimensionless

BonusCigs_1992[MiddleSchool] = 0.652348
Units: pack/Years/person

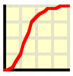
BonusCigs_1992[HighSchool] = 0.824702
Units: pack/Years/person

BonusCigs_Adolescents[MiddleSchool] = TotalBonus_Cigarettes*Adolescents_DemandRatio*0.25
Units: pack/Years

BonusCigs_Adolescents[HighSchool] = TotalBonus_Cigarettes*Adolescents_DemandRatio*0.75
Units: pack/Years

BonusCIgs_PerOneSmokerAdo[MiddleSchool] = If .SwitchMarketing=0 then BonusCigs_1992[MiddleSchool] else BonusCigs_Adolescents[MiddleSchool]/.Current_Smokers[MiddleSchool]
Units: pack/Years/person

BonusCIgs_PerOneSmokerAdo[HighSchool] = If .SwitchMarketing=0 then BonusCigs_1992[HighSchool] else BonusCigs_Adolescents[HighSchool]/.Current_Smokers[HighSchool]
Units: pack/Years/person



BudgetEffect = GRAPH(TobaccoIn_MediaBudget/INIT(TobaccoIn_MediaBudget))
(0.00, 0.8), (0.25, 0.819), (0.5, 0.856), (0.75, 0.907), (1.00, 1.00), (1.25, 1.15), (1.50, 1.28), (1.75, 1.38), (2.00, 1.45), (2.25, 1.49), (2.50, 1.52), (2.75, 1.54), (3.00, 1.55), (3.25, 1.56), (3.50, 1.57), (3.75, 1.58), (4.00, 1.59)
Units: Dimensionless

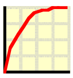
Consumption_Adolescents = NDL.Quantity_OfSmoking[Experimenters, MiddleSchool]*.Experimenters[MiddleSchool]+NDL.Quantity_OfSmoking[Experimenters, HighSchool]*.Experimenters[HighSchool]+NDL.Quantity_OfSmoking[Current_Smokers, MiddleSchool]*.Current_Smokers[MiddleSchool]+NDL.Quantity_OfSmoking[Current_Smokers, HighSchool]*.Current_Smokers[HighSchool]
Units: pack/Years

Consumption_Adults = Smoking_InAdults.Current*Quantity_OfSmoking_Adults
Units: pack/Years

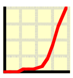
DesiredATB = Desired_ATBPerCapita*.ND__Population
Units: dollars/Years

Desired_ATBPerCapita = 20
Units: dollars/person/Years

EffectOn_DecreaseInPW = GRAPH(.Fraction_SmokersAllAdo/HISTORY(.Fraction_SmokersAllAdo, TIME-1))
(0.00, 1.00), (0.1, 0.957), (0.2, 0.893), (0.3, 0.836), (0.4, 0.771), (0.5, 0.679), (0.6, 0.571), (0.7, 0.468), (0.8, 0.339), (0.9, 0.214), (1.00, 0.00)
Units: Dimensionless



EffectOn_LevelPublic_Support = GRAPH(ATB_PerCapita/INIT(ATB_PerCapita))
(0.00, 0.00), (1.00, 1.00), (4.00, 1.47), (6.00, 1.77), (8.00, 2.04), (10.0, 2.25), (12.0, 2.33), (14.0, 2.38), (16.0, 2.42), (18.0, 2.45), (20.0, 2.47)
Units: Dimensionless



EffectOn_PoliticalWill = GRAPH(ActualLevel_PublicSupport)
(0.00, 0.005), (0.1, 0.0114), (0.2, 0.0159), (0.3, 0.0205), (0.4, 0.0295), (0.5, 0.036), (0.6, 0.055), (0.7, 0.105), (0.8, 0.202), (0.9, 0.343), (1.00, 0.5)
Units: Dimensionless

Federal_ExciseTax = 0.2+STEP(0.04,1993)+STEP(0.1,2000)+STEP(0.05,2002)+STEP(0.62,2009)
Units: dollars/pack

GrowthIn_AnnualWage = AnnualAveWage_NDAllOccupations/INIT(AnnualAveWage_NDAllOccupations)
Units: Dimensionless

GrowthIn_PricePerPack = PPerPack_Data/INIT(PPerPack_Data)
Units: Dimensionless

Income = Sales_Revenue*Wholesale_PartInPrice
Units: dollars/Years

InitialTobIn_MediaAmplifier = if .SwitchMarketing=0 then (if .Base_Mode=0 then 1.5 else (if time<1998 then 1.5 else 1.25)) else 1.5
Units: Dimensionless

Initial_QuantSm_Adults = 290

Units: pack/Years/person

Lobby_InterventionEffect = GRAPH(SmokersRights_Support/1000000)

(0.00, 1.00), (1.50, 0.406), (3.00, 0.24), (4.50, 0.142), (6.00, 0.091), (7.50, 0.051), (9.00, 0.035), (10.5, 0.028), (12.0, 0.024), (13.5, 0.016), (15.0, 0.00)
Units: Dimensionless

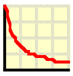
LocalExcise_TaxIncrease = 0
Units: dollars/pack/Years

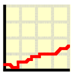
LocalTax_Increase = If PoliticalWill_ForTaxIncrease>0.5 then PULSE(LocalExcise_TaxIncrease, .YearOfChange, 0) else 0
Units: dollars/pack/Years

Marketing_Budget = Income*Percentage_Marketing_Spending
Units: dollars/Years

Percentage_IncomeSmSupport = 0.05
Units: Dimensionless

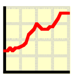
Percentage_Marketing_Spending = 0.2
Units: Dimensionless

Percentage_ToATB = GRAPH(TaxRevenue_ByND/1000000)

(0.00, 0.987), (2.50, 0.892), (5.00, 0.81), (7.50, 0.703), (10.0, 0.612), (12.5, 0.534), (15.0, 0.509), (17.5, 0.466), (20.0, 0.44), (22.5, 0.401), (25.0, 0.366), (27.5, 0.345), (30.0, 0.336), (32.5, 0.315), (35.0, 0.284), (37.5, 0.276), (40.0, 0.267), (42.5, 0.254), (45.0, 0.246), (47.5, 0.237), (50.0, 0.228), (52.5, 0.224), (55.0, 0.22), (57.5, 0.207), (60.0, 0.203), (62.5, 0.203), (65.0, 0.19), (67.5, 0.181), (70.0, 0.172), (72.5, 0.168), (75.0, 0.164), (77.5, 0.159), (80.0, 0.155), (82.5, 0.151), (85.0, 0.151), (87.5, 0.151), (90.0, 0.151), (92.5, 0.147), (95.0, 0.142), (97.5, 0.142), (100, 0.142)
Units: Dimensionless

Percentage_ToATBData = GRAPH(TIME)

(1992, 0.081), (1993, 0.101), (1993, 0.101), (1994, 0.101), (1994, 0.081), (1995, 0.061), (1995, 0.068), (1996, 0.068), (1996, 0.074), (1997, 0.122), (1998, 0.122), (1998, 0.128), (1999, 0.135), (1999, 0.142), (2000, 0.162), (2000, 0.176), (2001, 0.176), (2001, 0.203), (2002, 0.216), (2002, 0.216), (2003, 0.23), (2004, 0.236), (2004, 0.25), (2005, 0.25), (2005, 0.277), (2006, 0.264), (2006, 0.257), (2007, 0.257), (2007, 0.25), (2008, 0.243), (2009, 0.257), (2009, 0.27), (2010, 0.284), (2010, 0.297), (2011, 0.324), (2011, 0.338), (2012, 0.338), (2012, 0.351), (2013, 0.358), (2013, 0.365), (2014, 0.365)
Units: Dimensionless

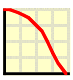
Policy2 = 0
Units: Dimensionless

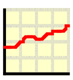
PPerPack = If .Base_Mode=0 then 1.634 else Wholesale__PricePerPack*(1+SalesTaxRate)+Federal_ExciseTax+StateExciseTax+StateSalesTax_PerPack
Units: dollars/pack

PPerPack_Data = GRAPH(TIME)

(1992, 1.68), (1993, 1.78), (1994, 1.80), (1995, 1.79), (1996, 1.83), (1997, 1.94), (1998, 2.05), (1999, 2.24 (2000, 2.98), (2001, 3.07), (2002, 3.38), (2003, 3.60), (2004, 3.53), (2005, 3.39), (2006, 3.35), (2007, 3.37 (2008, 3.54), (2009, 3.54), (2010, 4.19), (2011, 4.41), (2012, 4.51), (2013, 4.45), (2014, 4.55)
Units: dollars/Years

PriceDiscount_Budget = Marketing_Budget*(1-TraditionalM_VsPriceDiscounts_Ratio) Units: dollars/Years

Price_Effect = (if .SWPrice=0 then 1 else (PPerPack/INIT(PPerPack)))^(Price_Elasticity) Units: Dimensionless

Price_Elasticity = GRAPH(.Fraction_SmokersAdu)

(0.00, -0.5), (0.1, -0.509), (0.2, -0.516), (0.3, -0.528), (0.4, -0.543), (0.5, -0.57), (0.6, -0.603), (0.7, -0.645), (0.8, -0.695), (0.9, -0.744), (1.00, -0.8)
Units: Dimensionless

Purchase_ByNonResidents = GRAPH(if .Base_Mode=0 then 1992 else TIME)

(1992, 0.428), (1993, 0.428), (1993, 0.428), (1994, 0.432), (1994, 0.432), (1995, 0.432), (1995, 0.432), (1996, 0.439), (1996, 0.45), (1997, 0.46), (1998, 0.489), (1998, 0.518), (1999, 0.55), (1999, 0.561), (2000, 0.561), (2000, 0.561), (2001, 0.568), (2001, 0.568), (2002, 0.565), (2002, 0.541), (2003, 0.527), (2004, 0.527), (2004, 0.527), (2005, 0.541), (2005, 0.568), (2006, 0.581), (2006, 0.615), (2007, 0.635), (2007,

0.635), (2008, 0.635), (2009, 0.642), (2009, 0.649), (2010, 0.649), (2010, 0.649), (2011, 0.649), (2011, 0.649), (2012, 0.662), (2012, 0.716), (2013, 0.723), (2013, 0.723), (2014, 0.736)
Units: Dimensionless

Quantity_OfSmoking_Adults = Initial_QuantSm_Adults*Price_Effect
Units: pack/Years/person

SalesTaxRate = 0.05
Units: Dimensionless

Sales_Revenue = Total_Consumption*PPerPack
Units: dollars/Years

SmokersRights_Support = Income*Percentage_IncomeSmSupport
Units: dollars/Years

StateSalesTax_PerPack = 0.22
Units: dollars/pack

TaxChange = Pulse(0.15, 1995, 0)+LocalTax_Increase
Units: dollars/pack/Years

TaxRevenue_AsUsual = GRAPH(if time> 2014 then TIME else 0)
(1992, 1.5e+007), (1993, 1.5e+007), (1994, 1.6e+007), (1995, 1.6e+007), (1996, 2.3e+007), (1997, 2.4e+007), (1998, 2.5e+007), (1999, 2.4e+007), (2000, 2.3e+007), (2001, 2.3e+007), (2002, 2.2e+007), (2003, 2e+007), (2004, 2e+007), (2005, 2.1e+007), (2006, 2.2e+007), (2007, 2.4e+007), (2008, 2.4e+007) (2009, 2.3e+007), (2010, 2.2e+007), (2011, 2.2e+007), (2012, 2.4e+007), (2013, 2.7e+007), (2014, 2.8e+007), (2015, 2.8e+007), (2016, 2.8e+007), (2017, 2.7e+007), (2018, 2.7e+007), (2019, 2.7e+007), (2020, 2.7e+007), (2021, 2.7e+007), (2022, 2.7e+007), (2023, 2.6e+007), (2024, 2.6e+007), (2025, 2.6e+007), (2026, 2.6e+007), (2027, 2.6e+007), (2028, 2.6e+007), (2029, 2.6e+007), (2030, 2.6e+007), (2031, 2.6e+007), (2032, 2.6e+007)
Units: dollars/Years

TaxRevenue_ByND = Total_Consumption*StateExciseTax
Units: dollars/Years

TimeToChange = 1
Units: Years

TobaccoIn_MediaAmplifier = If .SwitchMarketing=0 then InitialTobIn_MediaAmplifier else InitialTobIn_MediaAmplifier*BudgetEffect
Units: Dimensionless

TobaccoIn_MediaBudget = Marketing_Budget*TraditionalM_VsPriceDiscounts_Ratio
Units: dollars/Years

TotalBonus_Cigarettes = PriceDiscount_Budget/PPerPack
Units: pack/Years

Total_Consumption = (Consumption_Adults+Consumption_Adolescents)*(1+Purchase_ByNonResidents/(1-Purchase_ByNonResidents))
Units: pack/Years

TraditionalM_VsPriceDiscounts_Ratio = GRAPH(TIME)
(1992, 0.601), (1993, 0.709), (1993, 0.838), (1994, 0.912), (1994, 0.946), (1995, 0.946), (1995, 0.919), (1996, 0.851), (1996, 0.791), (1997, 0.595), (1998, 0.473), (1998, 0.345), (1999, 0.223), (1999, 0.203), (2000, 0.176), (2000, 0.155), (2001, 0.149), (2001, 0.162), (2002, 0.176), (2002, 0.169), (2003, 0.169), (2004, 0.162), (2004, 0.155), (2005, 0.155), (2005, 0.155), (2006, 0.162), (2006, 0.176), (2007, 0.182), (2007, 0.196), (2008, 0.216), (2009, 0.223), (2009, 0.243), (2010, 0.264), (2010, 0.277), (2011, 0.331), (2011, 0.378), (2012, 0.426), (2012, 0.436), (2013, 0.446), (2013, 0.446), (2014, 0.453)
Units: Dimensionless

Wholesale_PartInPrice = Wholesale__PricePerPack/PPerPack
Units: Dimensionless

Wholesale__PricePerPack = GRAPH(TIME)
(1994, 0.88), (1995, 0.91), (1996, 0.95), (1997, 1.00), (1998, 1.35), (1999, 1.88), (2000, 2.00), (2001, 2.30 (2002, 2.35), (2003, 2.37), (2004, 2.37), (2005, 2.39), (2006, 2.44), (2007, 2.46), (2008, 2.49), (2009, 2.51 (2010, 2.54), (2011, 2.56),

(2012, 2.60), (2013, 2.60), (2014, 2.63), (2015, 2.65), (2016, 2.67), (2017, 2.68 (2018, 2.72), (2019, 2.74), (2020, 2.77), (2021, 2.79), (2022, 2.81), (2023, 2.88), (2024, 2.89), (2025, 2.89 (2026, 2.91), (2027, 2.93), (2028, 2.96), (2029, 2.98), (2030, 3.00), (2031, 3.05), (2032, 3.04), (2033, 3.04 (2034, 3.04)
Units: dollars/pack

NDL:

DesiredBNC[NonSmokers, MiddleSchool](t) = DesiredBNC[NonSmokers, MiddleSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[NonSmokers, MiddleSchool] = 0.0001
Units: mg/day/person

DesiredBNC[NonSmokers, HighSchool](t) = DesiredBNC[NonSmokers, HighSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[NonSmokers, HighSchool] = 0.0001
Units: mg/day/person
DesiredBNC[Experimenters, MiddleSchool](t) = DesiredBNC[Experimenters, MiddleSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[Experimenters, MiddleSchool] = 0.034074
Units: mg/day/person

DesiredBNC[Experimenters, HighSchool](t) = DesiredBNC[Experimenters, HighSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[Experimenters, HighSchool] = 0.073298
Units: mg/day/person

DesiredBNC[Current_Smokers, MiddleSchool](t) = DesiredBNC[Current_Smokers, MiddleSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[Current_Smokers, MiddleSchool] = 1.397624
Units: mg/day/person

DesiredBNC[Current_Smokers, HighSchool](t) = DesiredBNC[Current_Smokers, HighSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[Current_Smokers, HighSchool] = 2.203146
Units: mg/day/person

DesiredBNC[Ex_Smokers, MiddleSchool](t) = DesiredBNC[Ex_Smokers, MiddleSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[Ex_Smokers, MiddleSchool] = 0.0001
Units: mg/day/person

DesiredBNC[Ex_Smokers, HighSchool](t) = DesiredBNC[Ex_Smokers, HighSchool](t - dt) + (ChangeIN_DesBNC[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT DesiredBNC[Ex_Smokers, HighSchool] = 0.0001
Units: mg/day/person

NDL[Current_Smokers, MiddleSchool](t) = NDL[Current_Smokers, MiddleSchool](t - dt) + (ChangeInNDL[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT NDL[Current_Smokers, MiddleSchool] = 2.3
Units: Dimensionless

NDL[Current_Smokers, HighSchool](t) = NDL[Current_Smokers, HighSchool](t - dt) + (ChangeInNDL[Smoking_Development_Stages, Groups_of_Adolescents]) * dt
INIT NDL[Current_Smokers, HighSchool] = 2.7
Units: Dimensionless

NDL[Ex_Smokers, MiddleSchool](t) = NDL[Ex_Smokers, MiddleSchool](t - dt) + (ChangeInNDL[Smoking_Development_Stages, Groups_of_Adolescents]) * dt INIT NDL[Ex_Smokers, MiddleSchool] = 1.7
Units: Dimensionless

NDL[Ex_Smokers, HighSchool](t) = NDL[Ex_Smokers, HighSchool](t - dt) + (ChangeInNDL[Smoking_Development_Stages, Groups_of_Adolescents]) * dt INIT NDL[Ex_Smokers, HighSchool] = 1.9
Units: Dimensionless

Perception_OfCigarettes_Availability[MiddleSchool](t) =
Perception_OfCigarettes_Availability[MiddleSchool](t - dt) + (Change[Groups_of_Adolescents]) * dt
INIT Perception_OfCigarettes_Availability[MiddleSchool] = 0.778
Units: 1/year

Perception_OfCigarettes_Availability[HighSchool](t) = Perception_OfCigarettes_Availability[HighSchool](t - dt) + (Change[Groups_of_Adolescents]) * dt
INIT Perception_OfCigarettes_Availability[HighSchool] = 0.891
Units: 1/year

ActualIntensity_OfSmoking[NonSmokers, MiddleSchool] = InitialIntensity_OfSmoking[NonSmokers, MiddleSchool]
Units: cigarettes/day

ActualIntensity_OfSmoking[NonSmokers, HighSchool] = InitialIntensity_OfSmoking[NonSmokers, HighSchool]
Units: cigarettes/day

ActualIntensity_OfSmoking[Experimenters, MiddleSchool] = MIN(InitialIntensity_OfSmoking[Experimenters, MiddleSchool]*EffectOn_Intensity[Experimenters, MiddleSchool], 50)
Units: cigarettes/day

ActualIntensity_OfSmoking[Experimenters, HighSchool] = MIN(InitialIntensity_OfSmoking[Experimenters, HighSchool]*EffectOn_Intensity[Experimenters, HighSchool], 50) Units: cigarettes/day

ActualIntensity_OfSmoking[Current_Smokers, MiddleSchool] =
MIN(InitialIntensity_OfSmoking[Current_Smokers, MiddleSchool]*EffectOn_Intensity[Current_Smokers, MiddleSchool]*.ECigsEffect_OnIntensity[MiddleSchool], 50)
Units: cigarettes/day

ActualIntensity_OfSmoking[Current_Smokers, HighSchool] =
MIN(InitialIntensity_OfSmoking[Current_Smokers, HighSchool]*EffectOn_Intensity[Current_Smokers, HighSchool]*.ECigsEffect_OnIntensity[HighSchool], 50)
Units: cigarettes/day

ActualIntensity_OfSmoking[Ex_Smokers, MiddleSchool] = InitialIntensity_OfSmoking[Ex_Smokers, MiddleSchool]
Units: cigarettes/day

ActualIntensity_OfSmoking[Ex_Smokers, HighSchool] = InitialIntensity_OfSmoking[Ex_Smokers, HighSchool]
Units: cigarettes/day

Affect_Smoking[Smoking_Development_Stages, Groups_of_Adolescents] =
InitialAffect*NicotineEffect_OnAffect
Units: Dimensionless

AT = 1
Units: Years

AT2 = 1
Units: Years

Average_NicConcentration_PerPack = 20
Units: mg/pack

BNC[Smoking_Development_Stages, Groups_of_Adolescents] = Nicotine__Intake/Days
Units: mg/day/person

CigsAvailability_EffectOnFrequency[Groups_of_Adolescents] = GRAPH(PCA/INIT(PCA))
(0.00, 0.00), (0.2, 0.459), (0.4, 0.689), (0.6, 0.831), (0.8, 0.935), (1.00, 1.00), (1.20, 1.06), (1.40, 1.09), (1.60, 1.16), (1.80, 1.26), (2.00, 1.40)
Units: Dimensionless

CigsPerPack = 20
Units: cigarettes/pack

Compliance[MiddleSchool] = 0.78

Units: Dimensionless

Compliance[HighSchool] = 0.73
Units: Dimensionless

Compliance_Effect[MiddleSchool] = GRAPH(Compliance_RestrictionInSales/History(Compliance_RestrictionInSales, Time-1))
(0.00, 0.2), (0.1, 0.192), (0.2, 0.185), (0.3, 0.171), (0.4, 0.166), (0.5, 0.151), (0.6, 0.131), (0.7, 0.108), (0.8, 0.0892), (0.9, 0.0415), (1.00, 0.00), (1.10, -0.0877), (1.20, -0.126), (1.30, -0.148), (1.40, -0.162), (1.50, -0.174), (1.60, -0.186), (1.70, -0.192), (1.80, -0.195), (1.90, -0.195), (2.00, -0.2)
Units: Dimensionless

Compliance_Effect[HighSchool] = GRAPH(Compliance_RestrictionInSales/History(Compliance_RestrictionInSales, Time-1))
(0.00, 0.2), (0.2, 0.115), (0.4, 0.115), (0.6, 0.0815), (0.8, 0.0662), (1.00, 0.00), (1.20, -0.08), (1.40, -0.122), (1.60, -0.154), (1.80, -0.178), (2.00, -0.2)
Units: Dimensionless

Compliance_RestrictionInSales[Groups_of_Adolescents] = if time>2014 then (if .Base_Mode=0 then Compliance_RSData else Compliance) else Compliance_RSData
Units: Dimensionless

Compliance_RSData[MiddleSchool] = GRAPH(if .Base_Mode=0 then 1992 else TIME)
(1992, 0.7), (1993, 0.665), (1994, 0.659), (1995, 0.679), (1996, 0.699), (1997, 0.74), (1998, 0.75), (1999, 0.753), (2000, 0.753), (2001, 0.753), (2002, 0.763), (2003, 0.763), (2004, 0.763), (2005, 0.763), (2006, 0.76), (2007, 0.763), (2008, 0.77), (2009, 0.774), (2010, 0.774), (2011, 0.787), (2012, 0.79), (2013, 0.794) (2014, 0.797)
Units: Dimensionless

Compliance_RSData[HighSchool] = GRAPH(if .Base_Mode=0 then 1992 else TIME)
(1992, 0.6), (1993, 0.541), (1994, 0.507), (1995, 0.507), (1996, 0.574), (1997, 0.622), (1998, 0.622), (1999, 0.622), (2000, 0.622), (2001, 0.642), (2002, 0.642), (2003, 0.649), (2004, 0.669), (2005, 0.669), (2006, 0.662), (2007, 0.669), (2008, 0.676), (2009, 0.676), (2010, 0.689), (2011, 0.703), (2012, 0.703), (2013, 0.716), (2014, 0.73)
Units: Dimensionless

ContactRate_WithPeers[MiddleSchool] = GRAPH(Fraction_Smokers)
(0.00, 0.00), (0.04, 0.634), (0.08, 0.871), (0.12, 0.95), (0.16, 1.00), (0.2, 1.02), (0.24, 1.04), (0.28, 1.06), (0.32, 1.08), (0.36, 1.12), (0.4, 1.13), (0.44, 1.15), (0.48, 1.17), (0.52, 1.19), (0.56, 1.22), (0.6, 1.25), (0.64, 1.28), (0.68, 1.31), (0.72, 1.32), (0.76, 1.35), (0.8, 1.40), (0.84, 1.48), (0.88, 1.57), (0.92, 1.68), (0.96, 1.88), (1.00, 2.00)
Units: Dimensionless

ContactRate_WithPeers[HighSchool] = GRAPH(Fraction_Smokers)
(0.00, 0.00), (0.04, 0.356), (0.08, 0.614), (0.12, 0.782), (0.16, 0.861), (0.2, 0.921), (0.24, 0.95), (0.28, 0.97), (0.32, 1.00), (0.36, 1.02), (0.4, 1.04), (0.44, 1.05), (0.48, 1.07), (0.52, 1.08), (0.56, 1.09), (0.6, 1.09), (0.64, 1.10), (0.68, 1.14), (0.72, 1.15), (0.76, 1.17), (0.8, 1.22), (0.84, 1.26), (0.88, 1.33), (0.92, 1.45), (0.96, 1.63), (1.00, 2.00)
Units: Dimensionless

CREffect[MiddleSchool] = GRAPH(ContactRate_WithPeers)
(0.00, 0.00), (0.1, 0.333), (0.2, 0.581), (0.3, 0.705), (0.4, 0.781), (0.5, 0.819), (0.6, 0.857), (0.7, 0.895), (0.8, 0.933), (0.9, 0.962), (1.00, 1.00), (1.10, 1.03), (1.20, 1.07), (1.30, 1.10), (1.40, 1.14), (1.50, 1.20), (1.60, 1.25), (1.70, 1.34), (1.80, 1.46), (1.90, 1.63), (2.00, 2.00)
Units: Dimensionless

CREffect[HighSchool] = GRAPH(ContactRate_WithPeers)
(0.00, 0.00), (0.1, 0.333), (0.2, 0.486), (0.3, 0.571), (0.4, 0.667), (0.5, 0.743), (0.6, 0.81), (0.7, 0.867), (0.8, 0.924), (0.9, 0.962), (1.00, 1.00), (1.10, 1.03), (1.20, 1.05), (1.30, 1.07), (1.40, 1.08), (1.50, 1.10), (1.60, 1.16), (1.70, 1.25), (1.80, 1.38), (1.90, 1.63), (2.00, 2.00)
Units: Dimensionless

Days = 360
Units: day/Years

EffectBNC_OnNDL[NonSmokers, MiddleSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC,

TIME-1)) (0.00, 1.00), (4.00, 1.00)
Units: Dimensionless

EffectBNC_OnNDL[NonSmokers, HighSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC, TIME-1)) (0.00, 1.00), (4.00, 1.00)
Units: Dimensionless

EffectBNC_OnNDL[Experimenters, HighSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC, TIME-1)) (0.00, 0.5), (0.2, 0.536), (0.4, 0.592), (0.6, 0.685), (0.8, 0.833), (1.00, 1.00), (1.20, 1.08), (1.40, 1.16), (1.60, 1.22), (1.80, 1.27), (2.00, 1.31), (2.20, 1.35), (2.40, 1.38), (2.60, 1.42), (2.80, 1.43), (3.00, 1.45), (3.20, 1.46), (3.40, 1.47), (3.60, 1.48), (3.80, 1.48), (4.00, 1.50)
Units: Dimensionless

EffectBNC_OnNDL[Current_Smokers, MiddleSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC, TIME-1)) (0.00, 0.5), (0.2, 0.563), (0.4, 0.645), (0.6, 0.738), (0.8, 0.853), (1.00, 1.00), (1.20, 1.09), (1.40, 1.16), (1.60, 1.22), (1.80, 1.26), (2.00, 1.30), (2.20, 1.34), (2.40, 1.37), (2.60, 1.39), (2.80, 1.40), (3.00, 1.43), (3.20, 1.44), (3.40, 1.46), (3.60, 1.47), (3.80, 1.49), (4.00, 1.50)
Units: Dimensionless

EffectBNC_OnNDL[Current_Smokers, HighSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC, TIME-1)) (0.00, 0.5), (0.2, 0.526), (0.4, 0.573), (0.6, 0.632), (0.8, 0.734), (1.00, 1.00), (1.20, 1.11), (1.40, 1.21), (1.60, 1.28), (1.80, 1.33), (2.00, 1.37), (2.20, 1.38), (2.40, 1.40), (2.60, 1.43), (2.80, 1.45), (3.00, 1.46), (3.20, 1.47), (3.40, 1.49), (3.60, 1.49), (3.80, 1.50), (4.00, 1.50)
Units: Dimensionless

EffectBNC_OnNDL[Ex_Smokers, MiddleSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC, TIME-1)) (0.00, 1.00), (4.00, 1.00)
Units: Dimensionless

EffectBNC_OnNDL[Ex_Smokers, HighSchool] = GRAPH(DesiredBNC/HISTORY(DesiredBNC, TIME-1)) (0.00, 1.00), (4.00, 1.00)
Units: Dimensionless

EffectOn_Intensity[NonSmokers, MiddleSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 1.00), (0.4, 1.00), (0.8, 1.00), (1.20, 1.00), (1.60, 1.00), (2.00, 1.00), (2.40, 1.00), (2.80, 1.00), (3.20, 1.00), (3.60, 1.00), (4.00, 1.00)
Units: Dimensionless

EffectOn_Intensity[NonSmokers, HighSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 1.00), (3.00, 1.00), (6.00, 1.00), (9.00, 1.00), (12.0, 1.00), (15.0, 1.00), (18.0, 1.00), (21.0, 1.00), (24.0, 1.00), (27.0, 1.00), (30.0, 1.00)
Units: Dimensionless

EffectOn_Intensity[Experimenters, MiddleSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 0.8), (0.5, 0.866), (1.00, 1.00), (1.50, 1.25), (2.00, 1.46), (2.50, 1.66), (3.00, 1.83), (3.50, 1.93), (4.00, 2.00)
Units: Dimensionless

EffectOn_Intensity[Experimenters, HighSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 0.8), (0.25, 0.816), (0.5, 0.837), (0.75, 0.882), (1.00, 1.00), (1.25, 1.15), (1.50, 1.27), (1.75, 1.37), (2.00, 1.42), (2.25, 1.47), (2.50, 1.50)
Units: Dimensionless

EffectOn_Intensity[Current_Smokers, MiddleSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 0.8), (0.35, 0.83), (0.7, 0.884), (1.00, 1.00), (1.40, 1.44), (1.75, 1.85), (2.10, 2.09), (2.45, 2.24), (2.80, 2.37), (3.15, 2.44), (3.50, 2.50)
Units: Dimensionless

EffectOn_Intensity[Current_Smokers, HighSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))

(0.00, 0.8), (0.25, 0.854), (0.5, 0.88), (0.75, 0.934), (1.00, 1.00), (1.25, 1.25), (1.50, 1.56), (1.75, 2.01), (2.00, 2.64), (2.25, 3.44), (2.50, 5.00)
Units: Dimensionless

EffectOn_Intensity[Ex_Smokers, MiddleSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 1.00), (3.00, 1.00), (6.00, 1.00), (9.00, 1.00), (12.0, 1.00), (15.0, 1.00), (18.0, 1.00), (21.0, 1.00), (24.0, 1.00), (27.0, 1.00), (30.0, 1.00)
Units: Dimensionless

EffectOn_Intensity[Ex_Smokers, HighSchool] = GRAPH(Frequency_OfSmoking/INIT(Frequency_OfSmoking))
(0.00, 1.00), (3.00, 1.00), (6.00, 1.00), (9.00, 1.00), (12.0, 1.00), (15.0, 1.00), (18.0, 1.00), (21.0, 1.00), (24.0, 1.00), (27.0, 1.00), (30.0, 1.00)
Units: Dimensionless

Effect__OnNDL[Smoking_Development_Stages, Groups_of_Adolescents] = GRAPH(Affect_Smoking/History(Affect_Smoking, Time-1))
(0.00, 0.8), (0.2, 0.94), (0.4, 0.97), (0.6, 0.981), (0.8, 0.992), (1.00, 1.00), (1.20, 1.01), (1.40, 1.02), (1.60, 1.04), (1.80, 1.09), (2.00, 1.20)
Units: Dimensionless

Fraction_Smokers[MiddleSchool] = If .Base_Mode=0 then 0.124 else (if .SwitchNDL=0 then FrSmAdoData[MiddleSchool] else .Fraction_SmokersAdo[MiddleSchool])
Units: Dimensionless

Fraction_Smokers[HighSchool] = if .Base_Mode=0 then 0.2867 else (if.SwitchNDL=0 then FrSmAdoData[HighSchool] else .Fraction_SmokersAdo[HighSchool])
Units: Dimensionless

Frequency_OfSmoking[NonSmokers, MiddleSchool] = Initial_Frequency[NonSmokers, MiddleSchool] Units: day/month/person
Frequency_OfSmoking[NonSmokers, HighSchool] = Initial_Frequency[NonSmokers, HighSchool]
Units: day/month/person

Frequency_OfSmoking[Experimenters, MiddleSchool] = MIN(Initial_Frequency[Experimenters, MiddleSchool]*NDLEffect_OnFrequency[Experimenters, MiddleSchool]*CREffect[MiddleSchool]*CigsAvailability_EffectOnFrequency[MiddleSchool],4) Units: day/month/person

Frequency_OfSmoking[Experimenters, HighSchool] = MIN(Initial_Frequency[Experimenters, HighSchool]*NDLEffect_OnFrequency[Experimenters, HighSchool]*CREffect[HighSchool]*CigsAvailability_EffectOnFrequency[HighSchool], 5)
Units: day/month/person

Frequency_OfSmoking[Current_Smokers, MiddleSchool] = Min(Initial_Frequency[Current_Smokers, MiddleSchool]*NDLEffect_OnFrequency[Current_Smokers, MiddleSchool]*CREffect[MiddleSchool]*CigsAvailability_EffectOnFrequency[MiddleSchool], 30)
Units: day/month/person

Frequency_OfSmoking[Current_Smokers, HighSchool] = Min(Initial_Frequency[Current_Smokers, HighSchool]*NDLEffect_OnFrequency[Current_Smokers, HighSchool]*CREffect[HighSchool]*CigsAvailability_EffectOnFrequency[HighSchool], 30) Units: day/month/person

Frequency_OfSmoking[Ex_Smokers, MiddleSchool] = Initial_Frequency[Ex_Smokers, MiddleSchool] Units: day/month/person
Frequency_OfSmoking[Ex_Smokers, HighSchool] = Initial_Frequency[Ex_Smokers, HighSchool]
Units: day/month/person

FrSmAdoData[MiddleSchool] = GRAPH(TIME)
(1992, 0.122), (1993, 0.155), (1994, 0.184), (1995, 0.197), (1996, 0.201), (1997, 0.196), (1998, 0.165), (1999, 0.134), (2000, 0.117), (2001, 0.1), (2002, 0.0975), (2003, 0.095), (2004, 0.093), (2005, 0.089), (2006, 0.073), (2007, 0.057), (2008, 0.065), (2009, 0.073), (2010, 0.0645), (2011, 0.056), (2012, 0.049), (2013, 0.042)
Units: Dimensionless

FrSmAdoData[HighSchool] = GRAPH(TIME)

(1992, 0.291), (1993, 0.324), (1994, 0.358), (1995, 0.385), (1996, 0.406), (1997, 0.415), (1998, 0.41), (1999, 0.406), (2000, 0.38), (2001, 0.353), (2002, 0.328), (2003, 0.302), (2004, 0.262), (2005, 0.221), (2006, 0.216), (2007, 0.211), (2008, 0.218), (2009, 0.224), (2010, 0.209), (2011, 0.194), (2012, 0.192), (2013, 0.19)
Units: Dimensionless

Gap[Smoking_Development_Stages, Groups_of_Adolescents] = BNC-DesiredBNC
Units: mg/day/person

Indicated_NDL[NonSmokers, MiddleSchool] = NDL[NonSmokers, MiddleSchool]*Effect__OnNDL[NonSmokers, MiddleSchool]*SecHandSmoking__EffectOnNDL[MiddleSchool]
Units: Dimensionless

Indicated_NDL[NonSmokers, HighSchool] = NDL[NonSmokers, HighSchool]*Effect__OnNDL[NonSmokers, HighSchool]*SecHandSmoking__EffectOnNDL[HighSchool]
Units: Dimensionless

Indicated_NDL[Experimenters, MiddleSchool] = MAX(MIN(NDL[Experimenters, MiddleSchool]*Effect__OnNDL[Experimenters, MiddleSchool]*EffectBNC_OnNDL[Experimenters, MiddleSchool], NDSS_ScaleLimit), NDL[NonSmokers, MiddleSchool])
Units: Dimensionless

Indicated_NDL[Experimenters, HighSchool] = MAX(MIN(NDL[Experimenters, HighSchool]*Effect OnNDL[Experimenters, HighSchool]*EffectBNC_OnNDL[Experimenters, HighSchool], NDSS_ScaleLimit), NDL[NonSmokers, HighSchool])
Units: Dimensionless

Indicated_NDL[Current_Smokers, MiddleSchool] = MAX(MIN(NDL[Current_Smokers, MiddleSchool]*Effect__OnNDL[Current_Smokers, MiddleSchool]*EffectBNC_OnNDL[Current_Smokers, MiddleSchool], NDSS_ScaleLimit), NDL[Ex_Smokers, MiddleSchool])
Units: Dimensionless

Indicated_NDL[Current_Smokers, HighSchool] = MAX(MIN(NDL[Current_Smokers, HighSchool]*Effect OnNDL[Current_Smokers, HighSchool]*EffectBNC_OnNDL[Current_Smokers, HighSchool], NDSS_ScaleLimit), NDL[Ex_Smokers, HighSchool])
Units: Dimensionless
Indicated_NDL[Ex_Smokers, MiddleSchool] = MAX(NDL[Ex_Smokers, MiddleSchool]*Effect__OnNDL[Ex_Smokers, MiddleSchool], NDL[Experimenters, MiddleSchool]) Units: Dimensionless

Indicated_NDL[Ex_Smokers, HighSchool] = MAX(NDL[Ex_Smokers, HighSchool]*Effect__OnNDL[Ex_Smokers, HighSchool], NDL[Experimenters, HighSchool])
Units: Dimensionless

InitialAffect[NonSmokers, MiddleSchool] = 1.5
Units: Dimensionless
InitialAffect[NonSmokers, HighSchool] = 1.7
Units: Dimensionless

InitialAffect[Experimenters, MiddleSchool] = 1.7
Units: Dimensionless

InitialAffect[Experimenters, HighSchool] = 2
Units: Dimensionless

InitialAffect[Current_Smokers, MiddleSchool] = 2.5
Units: Dimensionless

InitialAffect[Current_Smokers, HighSchool] = 3
Units: Dimensionless

InitialAffect[Ex_Smokers, MiddleSchool] = 2.2
Units: Dimensionless

InitialAffect[Ex_Smokers, HighSchool] = 2.5

Units: Dimensionless
InitialIntensity_OfSmoking[NonSmokers, MiddleSchool] = 0.0001
Units: cigarettes/day
InitialIntensity_OfSmoking[NonSmokers, HighSchool] = 0.0001
Units: cigarettes/day
InitialIntensity_OfSmoking[Experimenters, MiddleSchool] = 1.04
Units: cigarettes/day
InitialIntensity_OfSmoking[Experimenters, HighSchool] = 1.11
Units: cigarettes/day
InitialIntensity_OfSmoking[Current_Smokers, MiddleSchool] = 2.8
Units: cigarettes/day
InitialIntensity_OfSmoking[Current_Smokers, HighSchool] = 3.3
Units: cigarettes/day
InitialIntensity_OfSmoking[Ex_Smokers, MiddleSchool] = 0.0001
Units: cigarettes/day
InitialIntensity_OfSmoking[Ex_Smokers, HighSchool] = 0.0001
Units: cigarettes/day
Initial_Frequency[NonSmokers, MiddleSchool] = 0.00001
Units: day/month/person
Initial_Frequency[NonSmokers, HighSchool] = 0.00001
Units: day/month/person
Initial_Frequency[Experimenters, MiddleSchool] = 1
Units: day/month/person
Initial_Frequency[Experimenters, HighSchool] = 2
Units: day/month/person
Initial_Frequency[Current_Smokers, MiddleSchool] = 14.84
Units: day/month/perso
Initial_Frequency[Current_Smokers, HighSchool] = 19.8
Units: day/month/person
Initial_Frequency[Ex_Smokers, MiddleSchool] = 0.00001
Units: day/month/person
Initial_Frequency[Ex_Smokers, HighSchool] = 0.00001
Units: day/month/person
Months = 12
Units: months/Years
NDLEff[NonSmokers, MiddleSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 0.6), (0.1, 0.644), (0.2, 0.668), (0.3, 0.697), (0.4, 0.726), (0.5, 0.755), (0.6, 0.789), (0.7, 0.823), (0.8, 0.876), (0.9, 0.944), (1.00, 1.00), (1.10, 1.09), (1.20, 1.14), (1.30, 1.17), (1.40, 1.21), (1.50, 1.24), (1.60, 1.26), (1.70, 1.30), (1.80, 1.33), (1.90, 1.36), (2.00, 1.40)
Units: Dimensionless

NDLEff[NonSmokers, HighSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 0.506), (0.1, 0.555), (0.2, 0.591), (0.3, 0.633), (0.4, 0.676), (0.5, 0.718), (0.6, 0.755), (0.7, 0.785), (0.8, 0.827), (0.9, 0.912), (1.00, 1.00), (1.10, 1.11), (1.20, 1.18), (1.30, 1.22), (1.40, 1.26), (1.50, 1.30), (1.60, 1.33), (1.70, 1.36), (1.80, 1.40), (1.90, 1.45), (2.00, 1.50)
Units: Dimensionless

NDLEff[Experimenters, MiddleSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 0.6), (0.1, 0.619), (0.2, 0.639), (0.3, 0.673), (0.4, 0.692), (0.5, 0.721), (0.6, 0.755), (0.7, 0.799), (0.8, 0.867), (0.9, 0.935), (1.00, 1.00), (1.10, 1.06), (1.20, 1.11), (1.30, 1.16), (1.40, 1.21), (1.50, 1.24), (1.60, 1.27), (1.70, 1.31), (1.80, 1.35), (1.90, 1.38), (2.00, 1.40)
Units: Dimensionless

NDLEff[Experimenters, HighSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 0.6), (0.1, 0.619), (0.2, 0.648), (0.3, 0.668), (0.4, 0.712), (0.5, 0.736), (0.6, 0.765), (0.7, 0.809), (0.8, 0.842), (0.9, 0.905), (1.00, 1.00), (1.10, 1.08), (1.20, 1.14), (1.30, 1.18), (1.40, 1.21), (1.50, 1.25), (1.60, 1.29), (1.70, 1.32), (1.80, 1.35), (1.90, 1.37), (2.00, 1.39)
Units: Dimensionless

NDLEff[Current_Smokers, MiddleSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 1.50), (0.1, 1.46), (0.2, 1.41), (0.3, 1.36), (0.4, 1.32), (0.5, 1.29), (0.6, 1.25), (0.7, 1.20), (0.8, 1.15), (0.9, 1.10), (1.00, 1.00), (1.10, 0.882), (1.20, 0.797), (1.30, 0.748), (1.40, 0.7), (1.50, 0.658), (1.60, 0.615), (1.70, 0.585), (1.80, 0.542), (1.90, 0.536), (2.00, 0.518)
Units: Dimensionless

NDLEff[Current_Smokers, HighSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 1.50), (0.1, 1.45), (0.2, 1.39), (0.3, 1.32), (0.4, 1.29), (0.5, 1.26), (0.6, 1.23), (0.7, 1.20), (0.8, 1.15), (0.9, 1.08), (1.00, 1.00), (1.10, 0.894), (1.20, 0.821), (1.30, 0.761), (1.40, 0.706), (1.50, 0.664), (1.60, 0.621), (1.70, 0.597), (1.80, 0.548), (1.90, 0.536), (2.00, 0.5)
Units: Dimensionless

NDLEff[Ex_Smokers, MiddleSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 0.6), (0.1, 0.648), (0.2, 0.682), (0.3, 0.716), (0.4, 0.76), (0.5, 0.779), (0.6, 0.828), (0.7, 0.847), (0.8, 0.891), (0.9, 0.925), (1.00, 1.00), (1.10, 1.10), (1.20, 1.16), (1.30, 1.19), (1.40, 1.22), (1.50, 1.26), (1.60, 1.28), (1.70, 1.32), (1.80, 1.34), (1.90, 1.37), (2.00, 1.40)
Units: Dimensionless

NDLEff[Ex_Smokers, HighSchool] = GRAPH(NDL/INIT(NDL))
(0.00, 0.6), (0.1, 0.634), (0.2, 0.653), (0.3, 0.692), (0.4, 0.721), (0.5, 0.76), (0.6, 0.784), (0.7, 0.809), (0.8, 0.847), (0.9, 0.92), (1.00, 1.00), (1.10, 1.10), (1.20, 1.14), (1.30, 1.16), (1.40, 1.20), (1.50, 1.23), (1.60, 1.26), (1.70, 1.31), (1.80, 1.34), (1.90, 1.36), (2.00, 1.40)
Units: Dimensionless

NDLEffect[Smoking_Development_Stages, Groups_of_Adolescents] = If .SwitchNDL=0 then 1 else NDLEff
Units: Dimensionless

NDLEffect_OnFrequency[Smoking_Development_Stages, Groups_of_Adolescents] = GRAPH(NDL/INIT(NDL))
(0.00, 0.0495), (0.2, 0.461), (0.4, 0.679), (0.6, 0.8), (0.8, 0.921), (1.00, 1.00), (1.20, 1.10), (1.40, 1.22), (1.60, 1.38), (1.80, 1.62), (2.00, 2.00)
Units: Dimensionless

NDSS_ScaleLimit = 4
Units: Dimensionless

NicotineEffect_OnAffect[Smoking_Development_Stages, Groups_of_Adolescents] = GRAPH(Nicotine Intake/INIT(Nicotine__Intake))
(0.00, 1.49), (0.2, 1.24), (0.4, 1.13), (0.6, 1.07), (0.8, 1.03), (1.00, 1.00), (1.20, 0.969), (1.40, 0.927), (1.60, 0.854), (1.80, 0.754), (2.00, 0.5)
Units: Dimensionless
Nicotine__Intake[NonSmokers, MiddleSchool] = Quantity_OfSmoking[NonSmokers, MiddleSchool]*Average_NicConcentration_PerPack
Units: mg/Years/person

Nicotine__Intake[NonSmokers, HighSchool] = Quantity_OfSmoking[NonSmokers, HighSchool]*Average_NicConcentration_PerPack
Units: mg/Years/person

Nicotine__Intake[Experimenters, MiddleSchool] = Quantity_OfSmoking[Experimenters, MiddleSchool]*Average_NicConcentration_PerPack
Units: mg/Years/person

Nicotine__Intake[Experimenters, HighSchool] = Quantity_OfSmoking[Experimenters,

HighSchool]*Average_NicConcentration_PerPack
Units: mg/Years/person

Nicotine__Intake[Current_Smokers, MiddleSchool] = MIN(Quantity_OfSmoking[Current_Smokers, MiddleSchool]*Average_NicConcentration_PerPack+Marketing.BonusCIgs_PerOneSmokerAdo[MiddleSchool]*Average_NicConcentration_PerPack+Alt_Tobacco.Total_NicotineIntake[MiddleSchool], 18000) Units: mg/Years/person

Nicotine__Intake[Current_Smokers, HighSchool] = MIN(Quantity_OfSmoking[Current_Smokers, HighSchool]*Average_NicConcentration_PerPack+Marketing.BonusCIgs_PerOneSmokerAdo[HighSchool]*Average_NicConcentration_PerPack+Alt_Tobacco.Total_NicotineIntake[HighSchool], 18000) Units: mg/Years/person

Nicotine__Intake[Ex_Smokers, MiddleSchool] = Quantity_OfSmoking[Ex_Smokers, MiddleSchool]*Average_NicConcentration_PerPack
Units: mg/Years/person

Nicotine__Intake[Ex_Smokers, HighSchool] = Quantity_OfSmoking[Ex_Smokers, HighSchool]*Average_NicConcentration_PerPack
Units: mg/Years/person

PCA[Groups_of_Adolescents] = If .SwitchNDL=0 then PCA_Data else Perception_OfCigarettes_Availability
Units: 1/Years

PCA_Data[MiddleSchool] = GRAPH(if .Base_Mode=0 then 1992 else TIME)
(1992, 0.778), (1993, 0.755), (1994, 0.761), (1995, 0.764), (1996, 0.769), (1997, 0.76), (1998, 0.736), (1999, 0.715), (2000, 0.687), (2001, 0.677), (2002, 0.643), (2003, 0.631), (2004, 0.603), (2005, 0.591), (2006, 0.58), (2007, 0.556), (2008, 0.574), (2009, 0.553), (2010, 0.555), (2011, 0.519), (2012, 0.507), (2013, 0.499)
Units: 1/Years

PCA_Data[HighSchool] = GRAPH(if .Base_Mode=0 then 1992 else TIME)
(1992, 0.891), (1993, 0.894), (1994, 0.903), (1995, 0.907), (1996, 0.913), (1997, 0.896), (1998, 0.881), (1999, 0.883), (2000, 0.868), (2001, 0.863), (2002, 0.833), (2003, 0.807), (2004, 0.814), (2005, 0.815), (2006, 0.795), (2007, 0.782), (2008, 0.765), (2009, 0.761), (2010, 0.756), (2011, 0.736), (2012, 0.739), (2013, 0.714)
Units: 1/Years

Price_Effect[MiddleSchool] = GRAPH(if .SWPrice=0 then 1 else .Price_AdjustedTo_Wages/ HISTORY(.Price_AdjustedTo_Wages, Time-1))
(0.00, 0.3), (0.2, 0.247), (0.4, 0.201), (0.6, 0.15), (0.8, 0.0923), (1.00, 0.00), (1.20, -0.169), (1.40, -0.242), (1.60, -0.265), (1.80, -0.277), (2.00, -0.3)
Units: Dimensionless

Price_Effect[HighSchool] = GRAPH(if .SWPrice=0 then 1 else .Price_AdjustedTo_Wages/ HISTORY(.Price_AdjustedTo_Wages, Time-1))
(0.00, 0.3), (0.2, 0.238), (0.4, 0.174), (0.6, 0.115), (0.8, 0.049), (1.00, 0.00), (1.20, -0.0354), (1.40, -0.0764), (1.60, -0.134), (1.80, -0.202), (2.00, -0.3) Units: Dimensionless

Quantity_OfSmoking[Smoking_Development_Stages, Groups_of_Adolescents] = Frequency_OfSmoking*ActualIntensity_OfSmoking*Months/CigsPerPack
Units: pack/Years/person

SecHandSmoking__EffectOnNDL[MiddleSchool] = GRAPH(IF .SwitchNDL=0 then 1 else SecHand_Smoking.Among_NonSmokers/History(SecHand_Smoking.Among_NonSmokers, Time-1)) (0.00, 0.8), (0.0625, 0.824), (0.125, 0.861), (0.188, 0.881), (0.25, 0.897), (0.313, 0.906), (0.375, 0.917), (0.438, 0.931), (0.5, 0.94), (0.563, 0.949), (0.625, 0.957), (0.688, 0.963), (0.75, 0.973), (0.813, 0.98), (0.875, 0.989), (0.938, 0.995), (1.00, 1.00), (1.06, 1.01), (1.13, 1.01), (1.19, 1.01), (1.25, 1.02), (1.31, 1.02), (1.38, 1.03), (1.44, 1.03), (1.50, 1.04), (1.56, 1.04), (1.63, 1.05), (1.69, 1.05), (1.75, 1.06), (1.81, 1.06), (1.88, 1.06), (1.94, 1.07), (2.00, 1.07), (2.06, 1.08), (2.13, 1.09), (2.19, 1.10), (2.25, 1.11), (2.31, 1.13), (2.38, 1.15), (2.44, 1.18), (2.50, 1.20)
Units: Dimensionless

SecHandSmoking__EffectOnNDL[HighSchool] = GRAPH(IF .SwitchNDL=0 then 1 else SecHand_Smoking.Among_NonSmokers/History(SecHand_Smoking.Among_NonSmokers, Time-1)) (0.00, 0.8), (0.0625, 0.84), (0.125, 0.873), (0.188, 0.897), (0.25, 0.919), (0.313, 0.934), (0.375, 0.945), (0.438, 0.954), (0.5, 0.96), (0.563, 0.966), (0.625, 0.97), (0.688, 0.975), (0.75, 0.98), (0.813, 0.984), (0.875, 0.99), (0.938, 0.995), (1.00, 1.00), (1.06, 1.00), (1.13, 1.01), (1.19, 1.01), (1.25, 1.01), (1.31, 1.02), (1.38, 1.02), (1.44, 1.03), (1.50, 1.03), (1.56, 1.03), (1.63, 1.04), (1.69, 1.04), (1.75, 1.04), (1.81, 1.05), (1.88, 1.06), (1.94, 1.06), (2.00, 1.07), (2.06, 1.07), (2.13, 1.08), (2.19, 1.10), (2.25, 1.11), (2.31, 1.13), (2.38, 1.15), (2.44, 1.18), (2.50, 1.20)
Units: Dimensionless

TimeTo_Perceive = 1
Units: Years

Risk Perception:
Risk_Perception[MiddleSchool](t) = Risk_Perception[MiddleSchool](t - dt) + (Learning[Groups_of_Adolescents] - Forgeting[Groups_of_Adolescents]) * dt
INIT Risk_Perception[MiddleSchool] = 51
Units: 1/Years

Risk_Perception[HighSchool](t) = Risk_Perception[HighSchool](t - dt) + (Learning[Groups_of_Adolescents] - Forgeting[Groups_of_Adolescents]) * dt INIT Risk_Perception[HighSchool] = 71
Units: 1/Years
INFLOWS:
Learning[Groups_of_Adolescents] = Risk_Perception*Actual_GrowthRP Units: 1/Years/Years
OUTFLOWS:
Forgeting[Groups_of_Adolescents] = Risk_Perception/TimeTo_Forget
Units: 1/Years/Years
Actual[Groups_of_Adolescents] = If .Base_Mode=0 then 0.55 else (if .IntRiskPerc=0 then RiskPerception_DataMTF/100 else Risk_Perception/100)
Units: 1/Years
ActualSoc_CampEffect[Groups_of_Adolescents] = DirectSoc_CampEffect*Resistance_Effect
Units: Dimensionless
Actual_GrowthRP[Groups_of_Adolescents] = Basic_GrowthRP*ActualSoc_CampEffect*SmRelDis__Effect
Units: 1/Years
Basic_GrowthRP[MiddleSchool] = If .Base_Mode=0 then 0.114257 else 0.114257
Units: 1/Years
Basic_GrowthRP[HighSchool] = if .Base_Mode=0 then 0.16567 else 0.128698*0+0.16567
Units: 1/Years

DirectSoc_CampEffect = GRAPH(Marketing.ATB_PerCapita/INIT(Marketing.ATB_PerCapita))
(0.00, 0.00), (1.00, 1.00), (2.00, 1.19), (3.00, 1.36), (4.00, 1.49), (5.00, 1.61), (6.00, 1.73), (7.00, 1.83), (8.00, 1.90), (9.00, 1.96), (10.0, 2.00)
Units: Dimensionless

FractionAdoWih_SmRelatedDisease = FractionAdo_SmDisease_Smoking+FractionAdo_SmDisease_SecondHand
Units: Dimensionless
FractionAdo_SmDisease_SecondHand = .Fraction_NeverSmoked*(SecHand_Smoking.Among_NonSmokers[MiddleSchool]+SecHand_Smoking.Among_NonSmokers[HighSchool])/2*RiskSmRelatedDisease_FromSecHandSm
Units: Dimensionless
FractionAdo_SmDisease_Smoking = .Fraction_SmokersAllAdo*RiskSmRelatedDisease_FromSmoking
Units: Dimensionless
Resistance_Effect[MiddleSchool] = GRAPH(Risk_Perception)
(0.00, 1.00), (5.00, 1.00), (10.0, 1.00), (15.0, 1.00), (20.0, 1.00), (25.0, 0.987), (30.0, 0.975), (35.0, 0.959), (40.0, 0.909), (45.0, 0.868), (50.0, 0.827), (55.0, 0.765), (60.0, 0.695), (65.0, 0.592), (70.0, 0.402), (75.0, 0.327), (80.0, 0.285), (85.0, 0.257), (90.0, 0.228), (95.0, 0.214), (100, 0.2)

Units: Dimensionless

Resistance_Effect[HighSchool] = GRAPH(Risk_Perception)
(0.00, 1.00), (5.00, 1.00), (10.0, 1.00), (15.0, 1.00), (20.0, 1.00), (25.0, 0.987), (30.0, 0.976), (35.0, 0.963), (40.0, 0.951), (45.0, 0.922), (50.0, 0.885), (55.0, 0.802), (60.0, 0.737), (65.0, 0.654), (70.0, 0.576), (75.0, 0.465), (80.0, 0.36), (85.0, 0.28), (90.0, 0.242), (95.0, 0.209), (100, 0.2)
Units: Dimensionless

RiskPerception_DataMTF[MiddleSchool] = GRAPH(TIME)
(1992, 50.8), (1993, 52.7), (1994, 50.8), (1995, 49.8), (1996, 50.4), (1997, 52.6), (1998, 54.3), (1999, 54.8 (2000, 58.8), (2001, 57.1), (2002, 57.5), (2003, 57.7), (2004, 62.4), (2005, 61.5), (2006, 59.4), (2007, 61.1 (2008, 59.8), (2009, 59.1), (2010, 60.9), (2011, 62.5), (2012, 62.6), (2013, 62.4), (2014, 62.1)
Units: 1/Years

RiskPerception_DataMTF[HighSchool] = GRAPH(TIME)
(1992, 69.2), (1993, 69.5), (1994, 67.6), (1995, 65.6), (1996, 68.2), (1997, 68.7), (1998, 70.8), (1999, 70.8 (2000, 73.1), (2001, 73.3), (2002, 74.2), (2003, 72.1), (2004, 74.0), (2005, 76.5), (2006, 77.6), (2007, 77.3 (2008, 74.0), (2009, 74.9), (2010, 75.0), (2011, 77.7), (2012, 78.2), (2013, 78.2), (2014, 78.0)
Units: 1/Years

RiskSmRelatedDisease_FromSecHandSm = 0.09
Units: Dimensionless

RiskSmRelatedDisease_FromSmoking = 0.21
Units: Dimensionless
SmRelDis__Effect = GRAPH(FractionAdoWih_SmRelatedDisease)
(0.00, 1.00), (0.0075, 1.00), (0.015, 1.00), (0.0225, 1.01), (0.03, 1.02), (0.0375, 1.03), (0.045, 1.04), (0.0525, 1.05), (0.06, 1.07), (0.0675, 1.10), (0.075, 1.21), (0.0825, 1.24), (0.09, 1.24), (0.0975, 1.27), (0.105, 1.27), (0.112, 1.28), (0.12, 1.29), (0.128, 1.30), (0.135, 1.31), (0.142, 1.32), (0.15, 1.33), (0.158, 1.33), (0.165, 1.33), (0.172, 1.34), (0.18, 1.34), (0.188, 1.35), (0.195, 1.35), (0.202, 1.35), (0.21, 1.36), (0.218, 1.37), (0.225, 1.37), (0.232, 1.37), (0.24, 1.38), (0.248, 1.38), (0.255, 1.38), (0.263, 1.38), (0.27, 1.38), (0.277, 1.39), (0.285, 1.39), (0.292, 1.40), (0.3, 1.40) Units: Dimensionless

TimeTo_Forget[Groups_of_Adolescents] = 10
Units: Years

SecHand Smoking:
AdoSecHSm_AmongNonSmokers[MiddleSchool] = MIN(AdoSecHSm_InPeersEnvironment[MiddleSchool]+AdoSecHSm_InFamily/2, .NeverSmoked[MiddleSchool])
Units: people

AdoSecHSm_AmongNonSmokers[HighSchool] = MIN(AdoSecHSm_InPeersEnvironment[HighSchool]+AdoSecHSm_InFamily/2, .NeverSmoked[HighSchool]) Units: people

AdoSecHSm_InFamily = Potential_AdoSecHSm_inFamily*ContactRate_WhileParentsSm
Units: people

AdoSecHSm_InPeersEnvironment[MiddleSchool] = MIN(.Current_Smokers[MiddleSchool]*ContactRateSm_WithNonSm[MiddleSchool], .NeverSmoked[MiddleSchool]) Units: people

AdoSecHSm_InPeersEnvironment[HighSchool] = MIN(.Current_Smokers[HighSchool]*ContactRateSm_WithNonSm[HighSchool], .NeverSmoked[HighSchool]) Units: people

Among_NonSmokers[Groups_of_Adolescents] = AdoSecHSm_AmongNonSmokers/.NeverSmoked
Units: Dimensionless
ContactRateSm_WithNonSm[MiddleSchool] = if .Base_Mode=0 then 0.5 else (if time<2005 then 0.5 else 0.35)
Units: Dimensionless

ContactRateSm_WithNonSm[HighSchool] = If .Base_Mode=0 then 0.6 else (If time<2005 then 0.6 else 0.4)
Units: Dimensionless

ContactRate_WhileParentsSm = 0.4
Units: Dimensionless

Effect[MiddleSchool] = GRAPH(Among_NonSmokers/Init(Among_NonSmokers))
(0.5, 0.8), (0.625, 0.847), (0.75, 0.896), (0.875, 0.943), (1.00, 1.00), (1.13, 1.02), (1.25, 1.04), (1.38, 1.06), (1.50, 1.09), (1.63, 1.11), (1.75, 1.14), (1.88, 1.17), (2.00, 1.20)
Units: Dimensionless

Effect[HighSchool] = GRAPH(Among_NonSmokers/Init(Among_NonSmokers))
(0.5, 0.8), (0.625, 0.897), (0.75, 0.937), (0.875, 0.97), (1.00, 1.00), (1.13, 1.04), (1.25, 1.06), (1.38, 1.07), (1.50, 1.08), (1.63, 1.09), (1.75, 1.10), (1.88, 1.13), (2.00, 1.20)
Units: Dimensionless

Potential_AdoSecHSm_inFamily = (.NeverSmoked[MiddleSchool]+.NeverSmoked[HighSchool])*.Parental_Smoking Units: people

Smoking InAdults:

Current(t) = Current(t - dt) + (IRAdu + MRAdo + RRAdu - DR1 - CRAdu) * dt
INIT Current = 102278
Units: people

INFLOWS:
IRAdu = ((MRAdo/(1-Fraction_InitiationInAdults))*Fraction_InitiationInAdults)*MAX(Marketing.TobaccoIn_MediaAmplifier-0.2, 1) Units: people/Years

MRAdo = MRSm_AdoActual
Units: people/Years

RRAdu = ExSmokers*RelapseRatio
Units: people/Years
OUTFLOWS:

DR1 = Current*Death_Fraction
Units: people/Years

CRAdu = Current*Quitting_Ratio*SuccessQuit_Ratio*Price__Effect
Units: people/Years

ExSmokers(t) = ExSmokers(t - dt) + (CRAdu + MRExSmAdo - RRAdu - DR2) * dt
INIT ExSmokers = 57561
Units: people
INFLOWS:

CRAdu = Current*Quitting_Ratio*SuccessQuit_Ratio*Price__Effect
Units: people/Years

MRExSmAdo = MRExSm_AdoActual
Units: people/Years
OUTFLOWS:

RRAdu = ExSmokers*RelapseRatio
Units: people/Years

DR2 = ExSmokers/Life_Exectancy*RelRisk_ExSmokers
Units: people/Years
RiskPerception_AmongSmokers(t) = RiskPerception_AmongSmokers(t - dt) + (Learning - Forgetting) * dt
INIT RiskPerception_AmongSmokers = 0.35
Units: Dimensionless
INFLOWS:

Learning = Perceived_HealthCons
Units: 1/Years
OUTFLOWS:

Forgetting = RiskPerception_AmongSmokers/TimeToForget
Units: 1/Years

BasicFraction_InitiationInAdu = 0.3
Units: Dimensionless

BasicQR = 0.55
Units: 1/Years

CurrentSm_AduData = GRAPH(TIME)
(1992, 102278), (1993, 103689), (1994, 104966), (1995, 106393), (1996, 112087), (1997, 105951), (1998, 95458), (1999, 97812), (2000, 111673), (2001, 111441), (2002, 105707), (2003, 102815), (2004, 99722), (2005, 101484), (2006, 99193), (2007, 97372), (2008, 93450), (2009, 96680), (2010, 89332), (2011, 116620), (2012, 115451), (2013, 118869) Units: People

Death_Fraction = (1/Life_Exectancy)*SmokingRelated__DeathRatio
Units: 1/year

EffectOf_NBonIRAdu = NetBenefit_OfSmoking^(Elasticity_OfInitiation) Units: Dimensionless

Elasticity_OfInitiation = 2.4
Units: Dimensionless

FractionSmAdu_Actual = If .Base_Mode=0 then .Fraction_SmokersAdu else (If .IntSmAdu=0 then FractionSm_AduData2 else .Fraction_SmokersAdu)
Units: Dimensionless

FractionSm_AduData = GRAPH(TIME)
(1992, 0.22), (1993, 0.222), (1994, 0.224), (1995, 0.226), (1996, 0.237), (1997, 0.223), (1998, 0.2), (1999, 0.204), (2000, 0.232), (2001, 0.229), (2002, 0.215), (2003, 0.207), (2004, 0.199), (2005, 0.201), (2006, 0.195), (2007, 0.19), (2008, 0.181), (2009, 0.186), (2010, 0.171), (2011, 0.219), (2012, 0.212), (2013, 0.212)

FractionSm_AduData2 = GRAPH(TIME)
(1992, 0.22), (1993, 0.222), (1994, 0.224), (1995, 0.226), (1996, 0.237), (1997, 0.223), (1998, 0.2), (1999, 0.204), (2000, 0.232), (2001, 0.229), (2002, 0.215), (2003, 0.207), (2004, 0.199), (2005, 0.201), (2006, 0.195), (2007, 0.19), (2008, 0.181), (2009, 0.186), (2010, 0.171), (2011, 0.219), (2012, 0.212), (2013, 0.212)
Units: Dimensionless

Fraction_InitiationInAdults = If .Base_Mode=0 then BasicFraction_InitiationInAdu else BasicFraction_InitiationInAdu*EffectOf_NBonIRAdu
Units: Dimensionless

Fraction_SmokersAdults = Current/.Adults
Units: Dimensionless

HP2020_objective = 0.12
Units: Dimensionless

Life_Exectancy = 50
Units: Years

Maturing19__Data = GRAPH(TIME)
(1992, 11300), (1993, 11365), (1994, 11388), (1995, 11431), (1996, 11474), (1997, 11517), (1998, 11365) (1999, 11408), (2000, 11874), (2001, 12631), (2002, 12700), (2003, 12485), (2004, 12691), (2005, 12650) (2006, 12718), (2007, 12443), (2008, 12381), (2009, 12305), (2010, 12372), (2011, 12866), (2012, 12859) (2013, 13276), (2014, 13565)
Units: people/Years

MRExSm_AdoActual = If .Base_Mode=0 then .MR4[HighSchool] else (if .IntSmAdu=0 then MRExSm_AdoData else .MR4[HighSchool])
Units: people/Years

MRExSm_AdoData = Maturing19__Data*((PercEver_SmAdoData-PercSm__AdoData)/100) Units: people/Years

MRSm_AdoActual = If .Base_Mode=0 then .MR3[HighSchool] else (If .IntSmAdu=0 then MRSm_AdoData else .MR3[HighSchool]) Units: person/Years

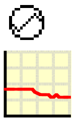
MRSm_AdoData = Maturing19__Data*PercSm__AdoData/100
Units: person/Years

NetBenefit_OfSmoking = Perceived_BenefitsFromSm-RiskPerception_AmongSmokers
Units: Dimensionless

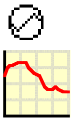
NetFlow = IRAdu+MRAdo+RRAdu-CRAdu-DR1
Units: people/Years

Perceived_BenefitsFromSm = 1
Units: Dimensionless

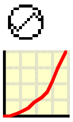
Perceived_HealthCons = FractionSmAdu_Actual/TimeToManifest_HealthCons
Units: 1/Years



PercEver_SmAdoData = GRAPH(TIME)
(1992, 43.4), (1993, 42.4), (1994, 41.7), (1995, 41.1), (1996, 42.2), (1997, 42.6), (1998, 41.8), (1999, 42.0 (2000, 40.9), (2001, 40.1), (2002, 36.9), (2003, 33.4), (2004, 34.0), (2005, 35.7), (2006, 32.5), (2007, 30.3 (2008, 31.5), (2009, 32.7), (2010, 31.8), (2011, 31.0), (2012, 29.0), (2013, 28.0)
Units: Dimensionless



PercSm__AdoData = GRAPH(TIME)
(1992, 32.0), (1993, 36.7), (1994, 38.1), (1995, 39.6), (1996, 40.5), (1997, 41.5), (1998, 41.0), (1999, 40.6 (2000, 38.0), (2001, 35.3), (2002, 32.8), (2003, 30.2), (2004, 26.1), (2005, 22.1), (2006, 21.6), (2007, 21.1 (2008, 21.8), (2009, 22.4), (2010, 20.9), (2011, 19.4), (2012, 19.2), (2013, 19.0)
Units: Dimensionless



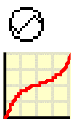
Price_Elasticity = GRAPH(FractionSmAdu_Actual)
(0.00, 0.3), (0.1, 0.315), (0.2, 0.333), (0.3, 0.359), (0.4, 0.389), (0.5, 0.422), (0.6, 0.472), (0.7, 0.535), (0.8, 0.618), (0.9, 0.746), (1.00, 0.9) Units: Dimensionless

Price__Effect = If .SWPrice=0 then 1 else (.Price_AdjustedTo_Wages/INIT(.Price_AdjustedTo_Wages))^(Price_Elasticity) Units: Dimensionless
Quitting_Ratio = If .Base_Mode=0 then BasicQR else Resistance_Effect*BasicQR
Units: 1/Years

RelapseRatio = If .Base_Mode=0 then 0.44096 else RRData
Units: 1/Years

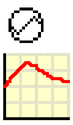
RelRisk_ExSmokers = 1.2
Units: Dimensionless

Resistance_Effect = GRAPH(FractionSmAdu_Actual)

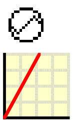


(0.01, 0.5), (0.02, 0.54), (0.03, 0.589), (0.04, 0.649), (0.05, 0.703), (0.06, 0.738), (0.07, 0.777), (0.08, 0.802), (0.09, 0.822), (0.1, 0.842), (0.11, 0.866), (0.12, 0.876), (0.13, 0.901), (0.14, 0.911), (0.15, 0.926), (0.16, 0.936), (0.17, 0.95), (0.18, 0.97), (0.19, 0.975), (0.2, 0.985), (0.21, 0.995), (0.22, 1.00), (0.23, 1.00), (0.24, 1.01), (0.25, 1.01), (0.26, 1.02), (0.27, 1.02), (0.28, 1.03), (0.29, 1.04), (0.3, 1.05), (0.31, 1.06), (0.32, 1.07), (0.33, 1.07), (0.34, 1.08), (0.35, 1.09), (0.36, 1.10), (0.37, 1.12), (0.38, 1.13), (0.39, 1.14), (0.4, 1.15), (0.41, 1.16), (0.42, 1.18), (0.43, 1.19), (0.44, 1.22), (0.45, 1.25), (0.46, 1.27), (0.47, 1.31), (0.48, 1.37), (0.49, 1.41), (0.5, 1.50)
Units: Dimensionless

RRData = GRAPH(TIME)



(1992, 0.454), (1993, 0.47), (1993, 0.484), (1994, 0.492), (1994, 0.514), (1995, 0.528), (1995, 0.545), (1996, 0.558), (1996, 0.562), (1997, 0.578), (1998, 0.595), (1998, 0.609), (1999, 0.619), (1999, 0.622), (2000, 0.622), (2000, 0.622), (2001, 0.619), (2001, 0.612), (2002, 0.605), (2002, 0.602), (2003, 0.592), (2004, 0.578), (2004, 0.568), (2005, 0.562), (2005, 0.551), (2006, 0.548), (2006, 0.541), (2007, 0.528), (2007, 0.524), (2008, 0.518), (2009, 0.514), (2009, 0.511), (2010, 0.507), (2010, 0.504), (2011, 0.504), (2011, 0.501), (2012, 0.497), (2012, 0.494), (2013, 0.49), (2013, 0.487), (2014, 0.484)
Units: 1/Years



SmokingRelated__DeathRatio = GRAPH(FractionSmAdu_Actual) (0.00, 1.06), (1.00, 4.00)
Units: Unitless

SuccessQuit_Ratio = 0.454545
Units: Dimensionless

TimeToForget = 45
Units: Years
TimeToManifest_HealthCons = 25
Units: Years