Reference Guide for the Opioid Epidemic Simulation Model

An Evidence-Based Tool for What-If Scenario Testing

Model Version 2u*

Prepared by

Jack Homer, PhD
Homer Consulting
Barrytown, New York

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*This guide presents estimates and output for the model's national calibration, based on data for the entire United States. Calibrations of the model for smaller regions and localities are not presented here. Such calibrations would share the same structure and equations as the national model, but some parameter values would differ.

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1. INTRODUCTION

The Opioid Epidemic Model (version 2u) is a deterministic compartmental system dynamics simulation model for exploring the opioid epidemic in the United States from 1990 to 2030. System dynamics methodology was developed in the 1950s and has been used since the 1970s to model drug abuse and other areas of public health and social policy—especially those involving complex causal pathways with intermediate variables, delays, nonlinearities, and feedback loops (Sterman 2000, Homer and Hirsch 2006, Homer 2012, Homer 2017). Previous system dynamics applications to drug abuse include models of heroin in New York City (Levin et al 1975), cocaine nationally (Homer 1993), and prescription opioids (PO) nationally (Wakeland et al 2013, Wakeland et al 2015). The Opioid Epidemic Model adopts the scientific approach and some of the basic elements of these forerunner models, but was developed from the ground up to suit a different purpose and a different set of specifics.

A committee of the National Academies of Sciences/Engineering/Medicine considered the complexities of the opioid epidemic and stated that what was needed for informed decision making was "a true systems model, not just simple statistics", for the reason that "decisions made about complex systems with endogenous feedback can be myopic in the absence of a formal model" (Bonnie et al 2017). As an example of what they meant by a true systems model, they cited the system dynamics model by Wakeland et al (2015).

Much has been written previously about the merits and best uses of system dynamics modeling, as well as best practices in model development, testing, and reporting (Homer 1996, Sterman 2000, Richardson 2011, Rahmandad and Sterman 2012). The emphasis is on endogenous explanation of a dynamic phenomenon, encompassing as many of the interconnected variables as evidence will allow. The endogenous approach permits robust counterfactual and policy testing, because it allows the actors and variables in the system to respond realistically to changing conditions, rather than holding most things constant as a more exogenous approach would do. Because system dynamics models are broadly encompassing, the model building process requires amassing evidence from many different sources. A dynamic structure is built that reproduces historical trends, and as realistically as possible—yet also parsimoniously—explains them. Uncertainties are addressed through sensitivity testing. Multivariate Monte Carlo testing allows results to be reported with confidence intervals and percentiles around their mean values.

Following these principles, the model described in this Guide was developed over several months starting February 2018. The current version of the model, 2u, represents the culmination of more than 25 significant iterations, the result of continual gathering of evidence and improvements in equation formulation. The evidence came from both

published studies and from our own original work extracting information from primary data sources.

Figure 1 presents the model's basic structural logic.

The model was implemented using Vensim Professional™ software (Windows version 7.3.5). The complete list of the model's approximately 340 interacting equations (including about 80 input constants, 17 time series for input and validation, and 240 output variables including 16 stock variables) is presented in Parts 2 (by sector) and 5 (alphabetically). Part 2 also presents Vensim structural diagrams showing how all the variables in each sector are related. It also describes how each model constant and time series was estimated, including data sources. The model is initialized in 1990 and simulates forward by increments of $1/32^{nd}$ of a year (11.4 days) through 2030; all output variables are recalculated at every increment.

Figure 1.   Model overview
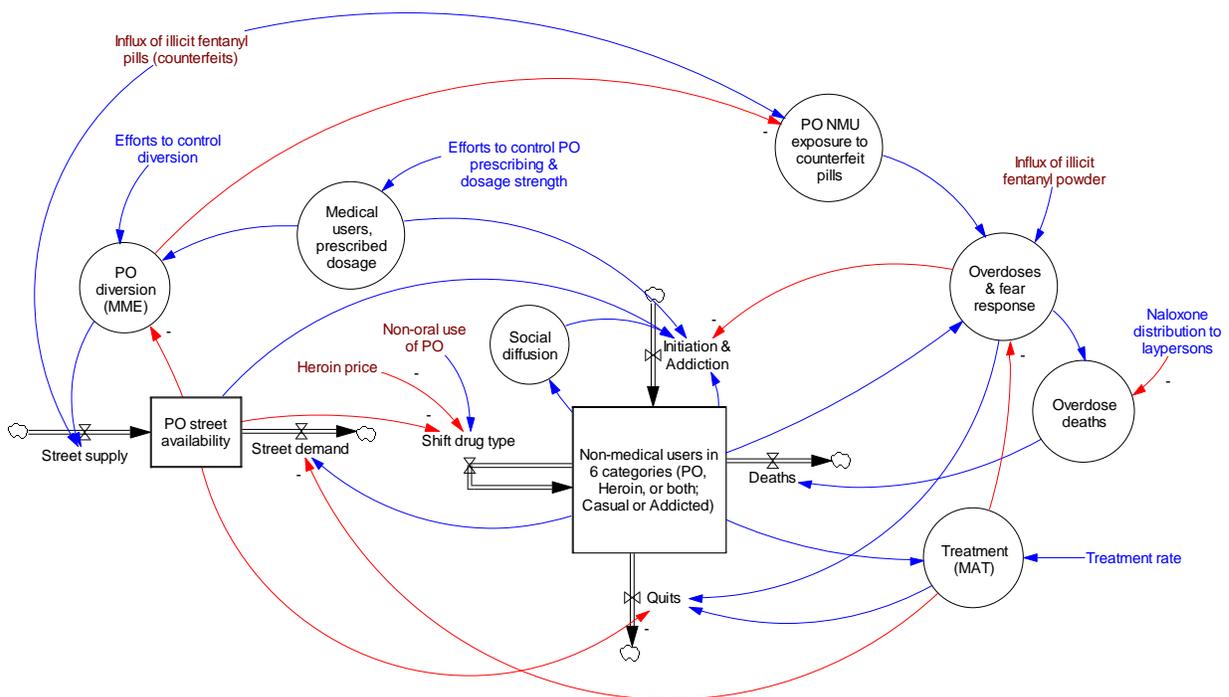
2. MODEL SECTOR DIAGRAMS, EQUATIONS, AND INPUTS

Figure 2.1.   Prescription opioid (PO) medical users and scripts
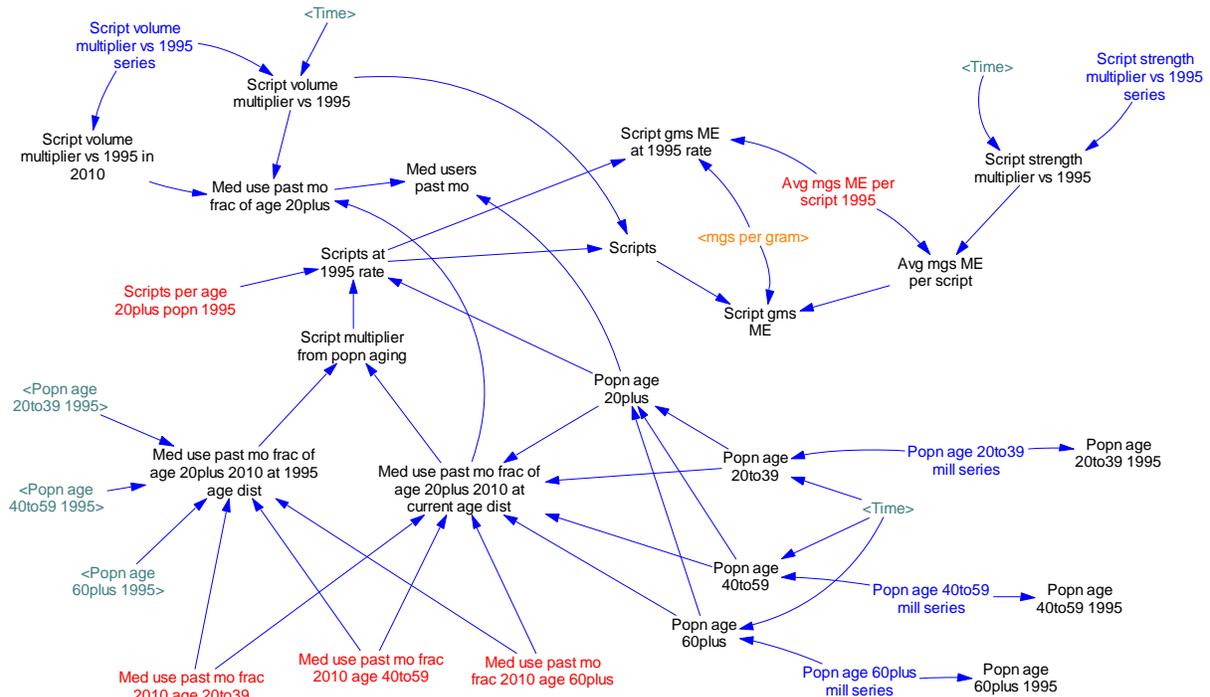
Sector 1 Equations

Med use past mo frac of age 20plus= Med use past mo frac of age 20plus 2010 at current age dist *
    Script volume multiplier vs 1995/Script volume multiplier vs 1995 in 2010

Med use past mo frac of age 20plus 2010 at 1995 age dist= (Med use past mo frac 2010 age 20to39*
    Popn age 20to39 1995 + Med use past mo frac 2010 age 40to59*Popn age 40to59 1995 + Med use
    past mo frac 2010 age 60plus*Popn age 60plus 1995)/(Popn age 20to39 1995+Popn age 40to59
    1995+Popn age 60plus 1995)

Med use past mo frac of age 20plus 2010 at current age dist= (Med use past mo frac 2010 age 20to39*
    Popn age 20to39 + Med use past mo frac 2010 age 40to59*Popn age 40to59 + Med use past mo
    frac 2010 age 60plus*Popn age 60plus)/Popn age 20plus

Med users past mo= Popn age 20plus * Med use past mo frac of age 20plus

Popn age 20plus= Popn age 20to39 + Popn age 40to59 + Popn age 60plus

Popn age 20to39= *Popn age 20to39 mill series(Time)*1e+06

3

Popn age 20to39 1995= *Popn age 20to39 mill series(1995)**1e+06

Popn age 40to59= *Popn age 40to59 mill series(Time)**1e+06

Popn age 40to59 1995= *Popn age 40to59 mill series(1995)**1e+06

Popn age 60plus= *Popn age 60plus mill series(Time)**1e+06

Popn age 60plus 1995= *Popn age 60plus mill series(1995)**1e+06

Script gms ME= Scripts * Avg mgs ME per script/mgs per gram

Script gms ME at 1995 rate= Scripts at 1995 rate * Avg mgs ME per script 1995/mgs per gram

Script multiplier from popn aging= Med use past mo frac of age 20plus 2010 at current age dist/Med use past mo frac of age 20plus 2010 at 1995 age dist

Script strength multiplier vs 1995= *Script strength multiplier vs 1995 series(Time)*

Script volume multiplier vs 1995= *Script volume multiplier vs 1995 series(Time)*

Script volume multiplier vs 1995 in 2010= *Script volume multiplier vs 1995 series(2010)*

Scripts= Scripts at 1995 rate * Script volume multiplier vs 1995

Scripts at 1995 rate= Popn age 20plus * Scripts per age 20plus popn 1995 * Script multiplier from popn aging

Sector 1 Constants

Avg mgs ME per script 1995= 416
(estimation: Divide ARCOS mgs ME 1995 by NPA scripts.)

Med use past mo frac 2010 age 20to39= 0.047
Med use past mo frac 2010 age 40to59= 0.081
Med use past mo frac 2010 age 60plus= 0.079
(estimation: Frenk et al 2015 CDC (NHANES 2007-2012).)

mgs per gram= 1000

Scripts per age 20plus popn 1995= 0.67
(estimation: Divide NPA scripts 1995 by Age 20+ popn 1995.)

Sector 1 Time Series Inputs

Popn age 20to39 mill series([[(1990,0)-(2030,300)],(1990,82.17),(1995,81.01),(2000,81.63),
(2005,82.18),(2010,82.99),(2011,83.58),(2012,84.41),(2013,85.32),(2014,86.28),(2015,87.11),
(2016,87.98),(2017,88.69),(2020,90.31),(2025,92.18),(2030,93.02))

Popn age 40to59 mill series([[(1990,0)-(2030,300)],(1990,53.14),(1995,62.45),(2000,74.08),
(2005,82.7),(2010,85.69),(2011,86.05),(2012,86.11),(2013,85.87),(2014,85.46),(2015,85.06),
(2016,84.54),(2017,84.03),(2020,82.82),(2025,82.43),(2030,85.27))

Popn age 60plus mill series([[(1990,0)-(2030,300)],(1990,41.71),(1995,43.67),(2000,45.94),
(2005,49.79),(2010,57.47),(2011,59.18),(2012,60.98),(2013,62.8),(2014,64.77),(2015,66.77),
(2016,68.76),(2017,70.85),(2020,77.06),(2025,86.52),(2030,91.17))
(estimation: Census historical and projected for 2020-2030.)

Script strength multiplier vs 1995 series([[(1990,0)-(2020,3)],(1990,1.05),(1994,1.048),(1995,1),
(1996,0.977),(1997,1.051),(1998,1.08),(1999,1.169),(2000,1.174),(2001,1.311),(2002,1.45),
(2003,1.597),(2004,1.648),(2005,1.62),(2006,1.73),(2007,1.864),(2008,1.81),(2009,1.882),
(2010,1.976),(2011,2.057),(2012,1.941),(2013,1.895),(2014,1.881),(2015,1.936),(2016,1.854),
(2017,1.85),(2020,1.85))
(estimation: using data from ARCOS and NPA; ratio of estimated avg gms ME per script to its 1995
value; calculate 1994-2016, extrap back to 1990 and forward to 2020 (and adjust to fit NPA kgs ME
data).)

Script volume multiplier vs 1995 series([[(1990,0)-(2020,2)],(1990,0.95),(1994,0.95),(1995,1),
(2000,1.258),(2005,1.526),(2008,1.7),(2010,1.745),(2011,1.728),(2012,1.728),(2013,1.666),
(2014,1.612),(2015,1.487),(2016,1.43),(2017,1.3),(2018,1.2),(2019,1.1),(2020,1.05))
(estimation: using data from NPA and Census; ratio of estimated scripts per adult age 20+ to its 1995
value, and divide by the Aging multiplier (effect of aging on scripts); calculate 1994-2016, extrap
back to 1990 and forward to 2020 (and adjust to fit NPA script data).)

Figure 2.2.   PO-not-heroin abusers (PONHA)
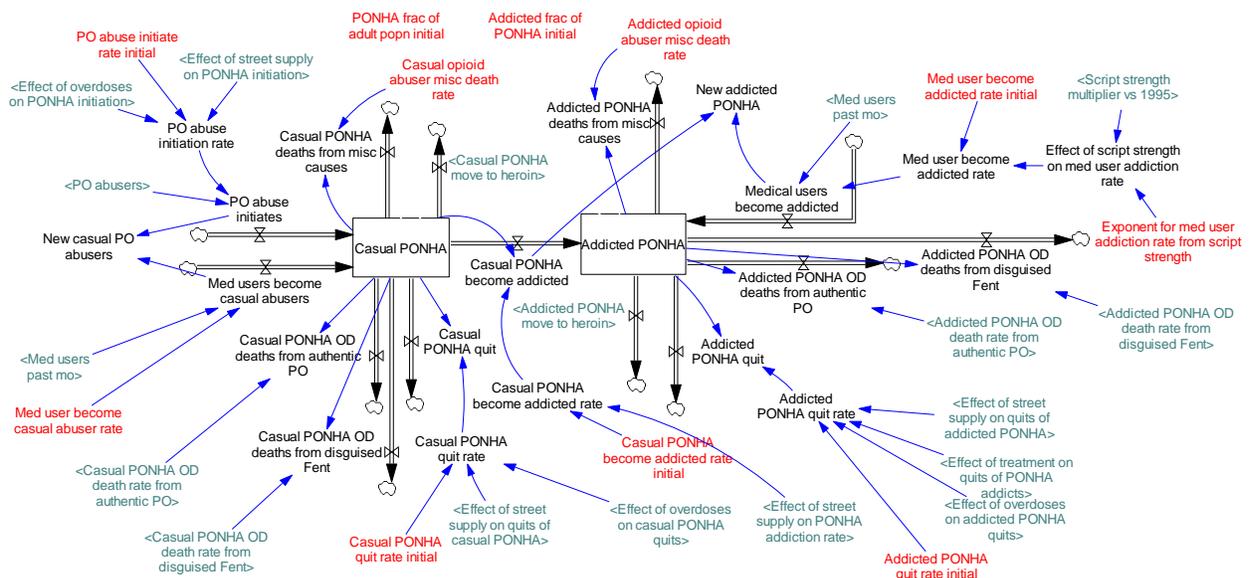
Sector 2 equations

Addicted PONHA= INTEG (Casual PONHA become addicted+Medical users become addicted-Addicted PONHA deaths from misc causes-Addicted PONHA OD deaths from authentic PO-Addicted PONHA OD deaths from disguised Fent-Addicted PONHA quit-Addicted PONHA move to heroin, PONHA frac of adult popn initial * Popn age 20plus * Addicted frac of PONHA initial)

Addicted PONHA deaths from misc causes= Addicted PONHA * Addicted opioid abuser misc death rate

Addicted PONHA move to heroin= Addicted PONHA * Addicted PONHA move to heroin rate

Addicted PONHA OD death rate from authentic PO= Addicted PONHA OD death rate absent Fent * (1-Disguised Fent frac of street pills supply)

Addicted PONHA OD death rate from disguised Fent= Addicted PONHA OD death rate absent Fent * Disguised Fent frac of street pills supply * Reltv PONHA OD risk from disguised Fent pills

Addicted PONHA OD deaths from authentic PO= Addicted PONHA * Addicted PONHA OD death rate from authentic PO

Addicted PONHA OD deaths from disguised Fent= Addicted PONHA * Addicted PONHA OD death rate from disguised Fent

Addicted PONHA quit= Addicted PONHA * Addicted PONHA quit rate

Addicted PONHA quit rate= Addicted PONHA quit rate initial * Effect of treatment on quits of PONHA addicts * Effect of street supply on quits of addicted PONHA * Effect of overdoses on addicted PONHA quits

Casual PONHA= INTEG (Med users become casual abusers+PO abuse initiates-Casual PONHA become addicted-Casual PONHA deaths from misc causes-Casual PONHA move to heroin-Casual PONHA OD deaths from authentic PO-Casual PONHA OD deaths from disguised Fent-Casual PONHA quit, PONHA frac of adult popn initial * Popn age 20plus * (1-Addicted frac of PONHA initial))

Casual PONHA become addicted= Casual PONHA * Casual PONHA become addicted rate

Casual PONHA become addicted rate= Casual PONHA become addicted rate initial * Effect of street supply on PONHA addiction rate

Casual PONHA deaths from misc causes= Casual PONHA * Casual opioid abuser misc death rate

Casual PONHA move to heroin= Casual PONHA * Casual PONHA move to heroin rate

Casual PONHA move to heroin rate= Casual PONHA move to heroin rate initial * Effect of street price on casual PONHA move to heroin * Effect of nonoral use on casual PONHA move to heroin

Casual PONHA OD death rate from authentic PO= Casual PONHA OD death rate absent Fent * (1-Disguised Fent frac of street pills supply)

Casual PONHA OD death rate from disguised Fent= Casual PONHA OD death rate absent Fent * Disguised Fent frac of street pills supply * Reltv PONHA OD risk from disguised Fent pills

Casual PONHA OD deaths from authentic PO= Casual PONHA * Casual PONHA OD death rate from authentic PO

Casual PONHA OD deaths from disguised Fent= Casual PONHA * Casual PONHA OD death rate from disguised Fent

Casual PONHA quit= Casual PONHA * Casual PONHA quit rate

Casual PONHA quit rate= Casual PONHA quit rate initial * Effect of street supply on quits of casual PONHA * Effect of overdoses on casual PONHA quits

Effect of overdoses on addicted PONHA quits= 1 + LN(Recent PONHA overdoses per 10k adult popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for addicted PONHA quits from overdoses

Effect of overdoses on casual PONHA quits= 1 + LN(Recent PONHA overdoses per 10k adult popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for casual PONHA quits from overdoses

Effect of overdoses on PONHA initiation= MAX(0,1 + LN(Recent PONHA overdoses per 10k adult popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for PONHA initiation from overdoses)

Effect of script strength on med user addiction rate= Script strength multiplier vs 1995^Exponent for med user addiction rate from script strength

Effect of street supply on PONHA addiction rate= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for PONHA addiction rate from street supply)

Effect of street supply on PONHA initiation= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for PONHA initiation from street supply)

Effect of street supply on quits of addicted PONHA= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for addicted PONHA quits from street supply)

Effect of street supply on quits of casual PONHA= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for casual PONHA quits from street supply)

Effect of treatment on quits of PONHA addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Quit multiplier for treated PO addicts) / (1-Opioid addiction treatment rate initial +Opioid addiction treatment rate initial*Quit multiplier for treated PO addicts)

Med user become addicted rate= Med user become addicted rate initial * Effect of script strength on
    med user addiction rate

Med users become casual abusers= Med users past mo * Med user become casual abuser rate

Med users past mo= Popn age 20plus * Med use past mo frac of age 20plus

Medical users become addicted= Med users past mo * Med user become addicted rate

New addicted PONHA= Medical users become addicted + Casual PONHA become addicted

New casual PO abusers= PO abuse initiates + Med users become casual abusers

PO abuse initiates= PO abusers * PO abuse initiation rate

PO abuse initiation rate= PO abuse initiate rate initial * Effect of street supply on PONHA initiation *
    Effect of overdoses on PONHA initiation

PO abusers= PONHA + HPPOU

PONHA= Casual PONHA + Addicted PONHA

Sector 2 constants

Addicted frac of PONHA initial= 0.123
    (estimation: optimized [0.1, 0.15]. Our analysis of NSDUH indicates 0.114 for 2000, and 0.142 for
        2005.)

Addicted opioid abuser misc death rate= 0.0045
    (estimation: From NVSR averaging 25-34, 35-44, and 45-54; comes to .0024 in 2000 and .0022 in
        2010. Then multiply by 1.94 per Ray et al 2016 for "high dose users" (>60 mg ME).)

Addicted PONHA quit rate initial= 0.149
    (estimation: optimized [0.08, 0.22].)

Casual opioid abuser misc death rate= 0.0035
    (estimation: From NVSR averaging 25-34, 35-44, and 45-54; comes to .0024 in 2000 and .0022 in
        2010. Then multiply by 1.54 per Ray et al 2016 for "low dose users" (<60 mg ME). Note average of
        1.54 low and 1.94 high (assuming 15% low 85% high) is 1.60, equal to Cottler et al 2016 for NMU
        overall.)

Casual PONHA become addicted rate initial= 0.02
   (estimation: optimized [0.01, 0.03].)

Casual PONHA quit rate initial= 0.209
   (estimation: optimized [0.1, 0.3].)

Exponent for med user addiction rate from script strength= 0.655
   (estimation: optimized [0.3, 0.9]. Edlund et al 2014 indicates that an increase from low dose (1-36
      mg/day) to medium dose (36-120 mg/day) approximately doubles the risk of addiction for chronic
      med users.)

Med user become addicted rate initial= 0.003
   (estimation: Adjust so that med user frac of new addicted PONHA is in the 20% range, per "have
      script" analysis of Jones et al 2014 (NSDUH 2008-11) and our analysis of NSDUH 2005-14.)

Med user become casual abuser rate= 0.018
   (estimation: Adjust so that med user frac of new casual PONHA is in the 12% range, per "have script"
      analysis of Jones et al 2014 (NSDUH 2008-11) and our analysis of NSDUH 2005-14.)

PO abuse initiate rate initial= 0.142
   (estimation: optimized [0.05, 0.25]

PONHA frac of adult popn initial= 0.027
   (estimation: our analysis of NSDUH 1995.)

Figure 2.3.   Former medical user fractions of PONHA
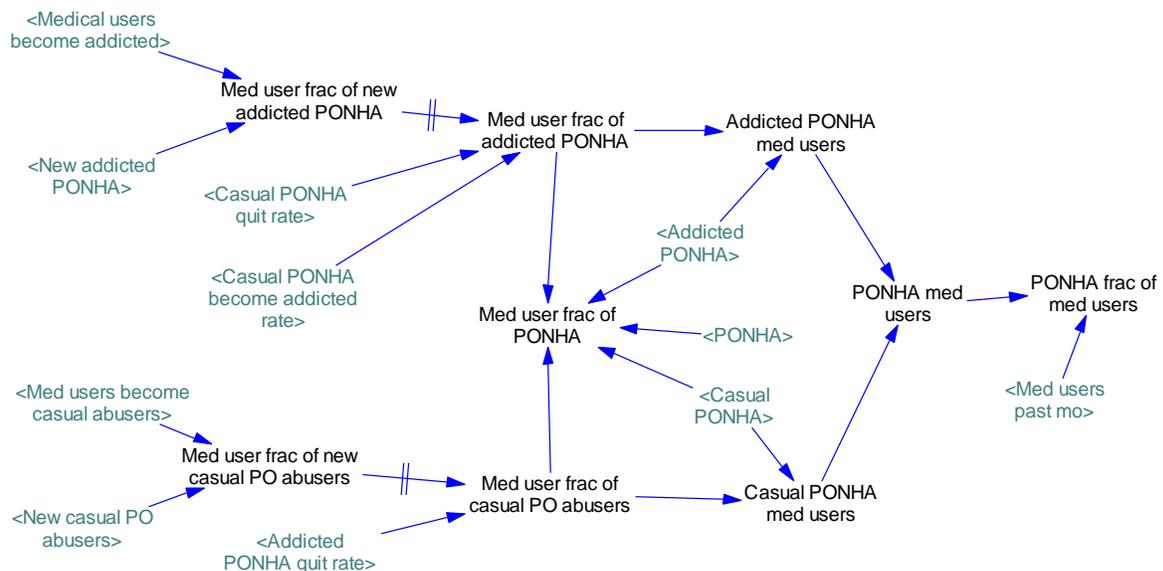
Sector 3 Equations

Addicted PONHA med users= Addicted PONHA * Med user frac of addicted PONHA

Casual PONHA med users= Casual PONHA * Med user frac of casual PO abusers

Med user frac of addicted PONHA= DELAY1(Med user frac of new addicted PONHA, 1/(Casual PONHA
    become addicted rate +Casual PONHA quit rate))

Med user frac of casual PO abusers= DELAY1(Med user frac of new casual PO abusers, 1/Addicted
    PONHA quit rate)

Med user frac of new addicted PONHA= Medical users become addicted/New addicted PONHA

Med user frac of new casual PO abusers= Med users become casual abusers/New casual PO abusers

Med user frac of PONHA= (Med user frac of addicted PONHA*Addicted PONHA + Med user frac of casual
    PO abusers *Casual PONHA)/PONHA

PONHA frac of med users= PONHA med users/Med users past mo

PONHA med users= Casual PONHA med users + Addicted PONHA med users

Figure 2.4.   Heroin-plus-PO users (HPPOU)
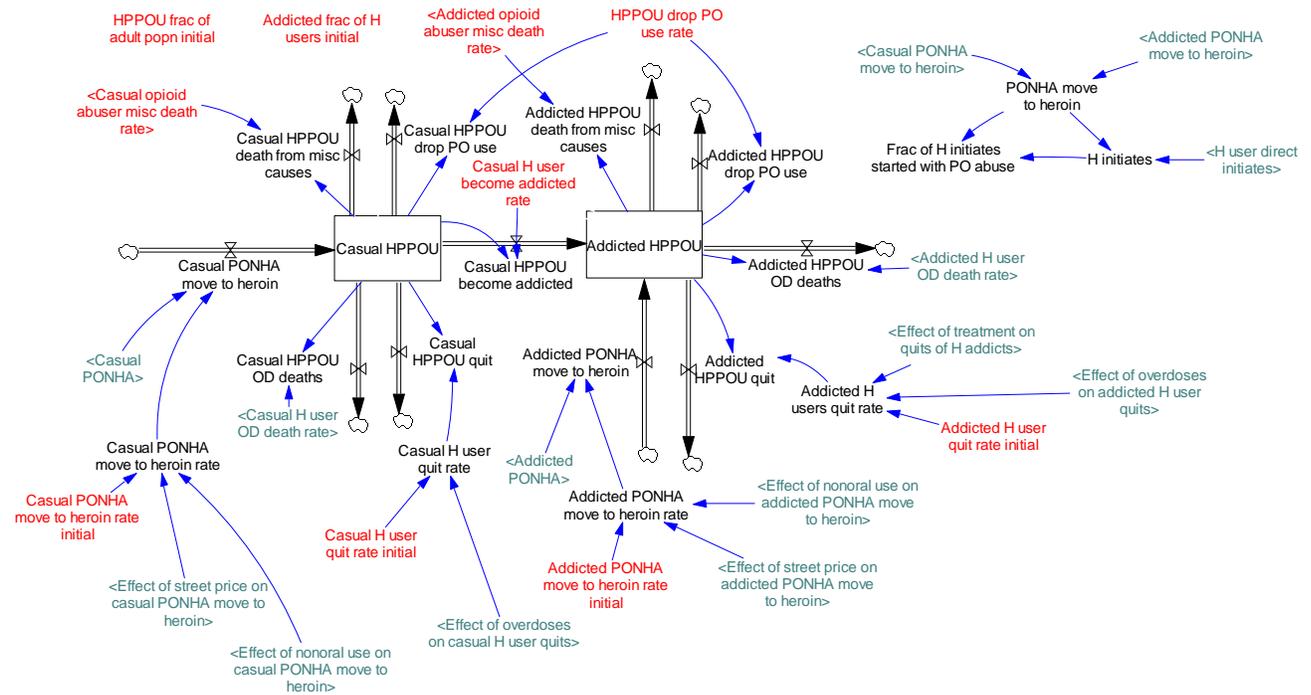
Sector 4 Equations

Addicted H users quit rate= Addicted H user quit rate initial * Effect of treatment on quits of H addicts * Effect of overdoses on addicted H user quits

Addicted HPPOU= INTEG (Addicted PONHA move to heroin+Casual HPPOU become addicted-Addicted HPPOU death from misc causes -Addicted HPPOU drop PO use-Addicted HPPOU OD deaths-Addicted HPPOU quit, HPPOU frac of adult popn initial * Popn age 20plus * Addicted frac of H users initial)

Addicted HPPOU death from misc causes= Addicted HPPOU * Addicted opioid abuser misc death rate

Addicted HPPOU drop PO use= Addicted HPPOU * HPPOU drop PO use rate

Addicted HPPOU OD deaths= Addicted HPPOU * Addicted H user OD death rate

Addicted HPPOU quit= Addicted HPPOU * Addicted H users quit rate

Addicted PONHA move to heroin= Addicted PONHA * Addicted PONHA move to heroin rate

Addicted PONHA move to heroin rate= Addicted PONHA move to heroin rate initial * Effect of nonoral use on addicted PONHA move to heroin * Effect of street price on addicted PONHA move to heroin

Casual H user quit rate= Casual H user quit rate initial * Effect of overdoses on casual H user quits

Casual HPPOU= INTEG (Casual PONHA move to heroin-Casual HPPOU become addicted-Casual HPPOU
       death from misc causes- Casual HPPOU drop PO use-Casual HPPOU OD deaths-Casual HPPOU quit,
       HPPOU frac of adult popn initial * Popn age 20plus * (1-Addicted frac of H users initial))

Casual HPPOU become addicted= Casual HPPOU * Casual H user become addicted rate

Casual HPPOU death from misc causes= Casual HPPOU * Casual opioid abuser misc death rate

Casual HPPOU drop PO use= Casual HPPOU * HPPOU drop PO use rate

Casual HPPOU OD deaths= Casual HPPOU * Casual H user OD death rate

Casual HPPOU quit= Casual HPPOU * Casual H user quit rate

Casual PONHA move to heroin= Casual PONHA * Casual PONHA move to heroin rate

Casual PONHA move to heroin rate= Casual PONHA move to heroin rate initial * Effect of street price on
       casual PONHA move to heroin * Effect of nonoral use on casual PONHA move to heroin

Frac of H initiates started with PO abuse= PONHA move to heroin/H initiates

H initiates= PONHA move to heroin + H user direct initiates

PONHA move to heroin= Casual PONHA move to heroin + Addicted PONHA move to heroin

Sector 4 Constants

Addicted frac of H users initial= 0.65
       (estimation: optimized [0.6, 0.7]. Our NSDUH analysis indicates 60.8% 2000, 61.1% 2005.)

Addicted H user quit rate initial= 0.138
       (estimation: optimized [0.07, 0.21].)

Addicted opioid abuser misc death rate= 0.0045
       (estimation: Ray et al 2016 gives mortality hazard ratio of 1.94 vs general popn for "high dose users"
         (>60 mg ME). Multiply by general popn (2000-2010): average of NVSR death rates for [age 25-34,
         35-44, 45-54] = .0023; x 1.94 = .0045.)

Addicted PONHA move to heroin rate initial= 0.021
       (estimation: optimized [0.01, 0.03].)

Casual H user become addicted rate= 0.096

(estimation: optimized [0.05, 0.15].)

Casual H user quit rate initial= 0.192
     (estimation: optimized [0.13, 0.25].)

Casual PONHA move to heroin rate initial= 0.0038
     (estimation: optimized [0.0025, 0.0050].)

HPPOU drop PO use rate= 0.091
     (estimation: optimized [0.05, 0.13].)

HPPOU frac of adult popn initial= 0.0005
     (estimation: optimized [0.0004, 0.0006]. Our NSDUH analysis indicates 0.0004 for 1995.)

Figure 2.5.   Heroin-not-PO users (HNPOU)
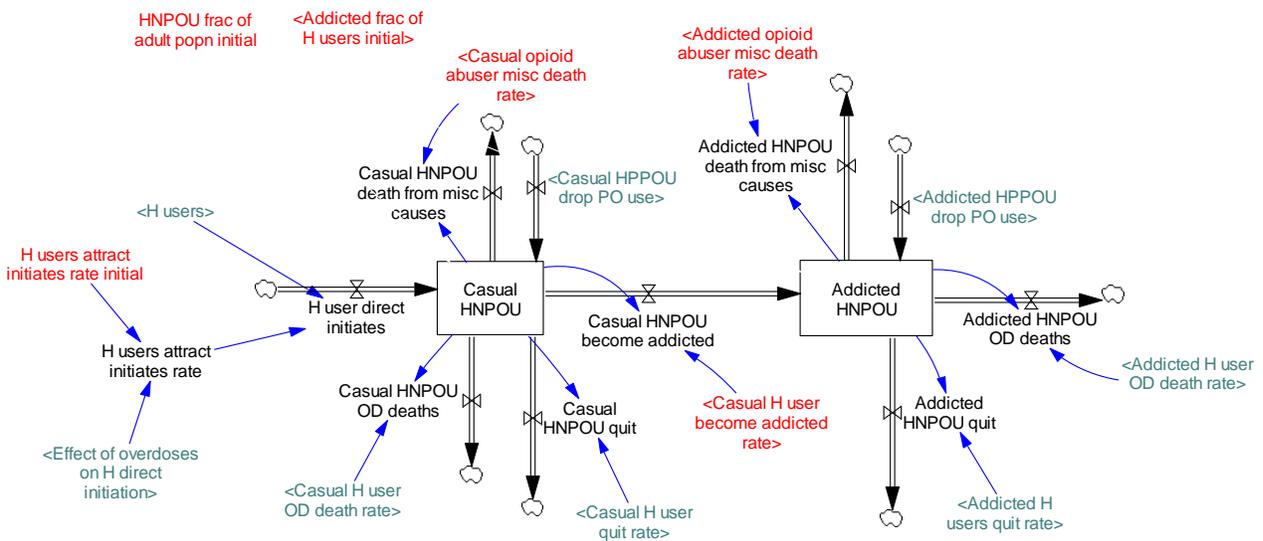
Sector 5 Equations

Addicted HNPOU= INTEG (Addicted HPPOU drop PO use+Casual HNPOU become addicted-Addicted
     HNPOU death from misc causes-Addicted HNPOU OD deaths-Addicted HNPOU quit, HNPOU frac
     of adult popn initial * Popn age 20plus * Addicted frac of H users initial)

Addicted HNPOU death from misc causes= Addicted HNPOU * Addicted opioid abuser misc death rate

Addicted HNPOU OD deaths= Addicted HNPOU * Addicted H user OD death rate

Addicted HNPOU quit= Addicted HNPOU * Addicted H users quit rate

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Casual HNPOU= INTEG (Casual HPPOU drop PO use+H user direct initiates-Casual HNPOU become
    addicted-Casual HNPOU death from misc causes-Casual HNPOU OD deaths-Casual HNPOU quit,
    HNPOU frac of adult popn initial * Popn age 20plus * (1-Addicted frac of H users initial))

Casual HNPOU become addicted= Casual HNPOU * Casual H user become addicted rate

Casual HNPOU death from misc causes= Casual HNPOU * Casual opioid abuser misc death rate

Casual HNPOU OD deaths= Casual HNPOU * Casual H user OD death rate

Casual HNPOU quit= Casual HNPOU*Casual H user quit rate

H user direct initiates= H users * H users attract initiates rate

H users attract initiates rate= H users attract initiates rate initial * Effect of overdoses on H direct
    initiation

Sector 5 Constants

H users attract initiates rate initial= 0.073
    (estimation: optimized [0.04, 0.10].)

HNPOU frac of adult popn initial= 0.0009
    (estimation: optimized [0.0007, 0.0011]. Our NSDUH analysis indicates 0.0010 for 1995.)

Figure 2.6.   Opioid abuser aggregates
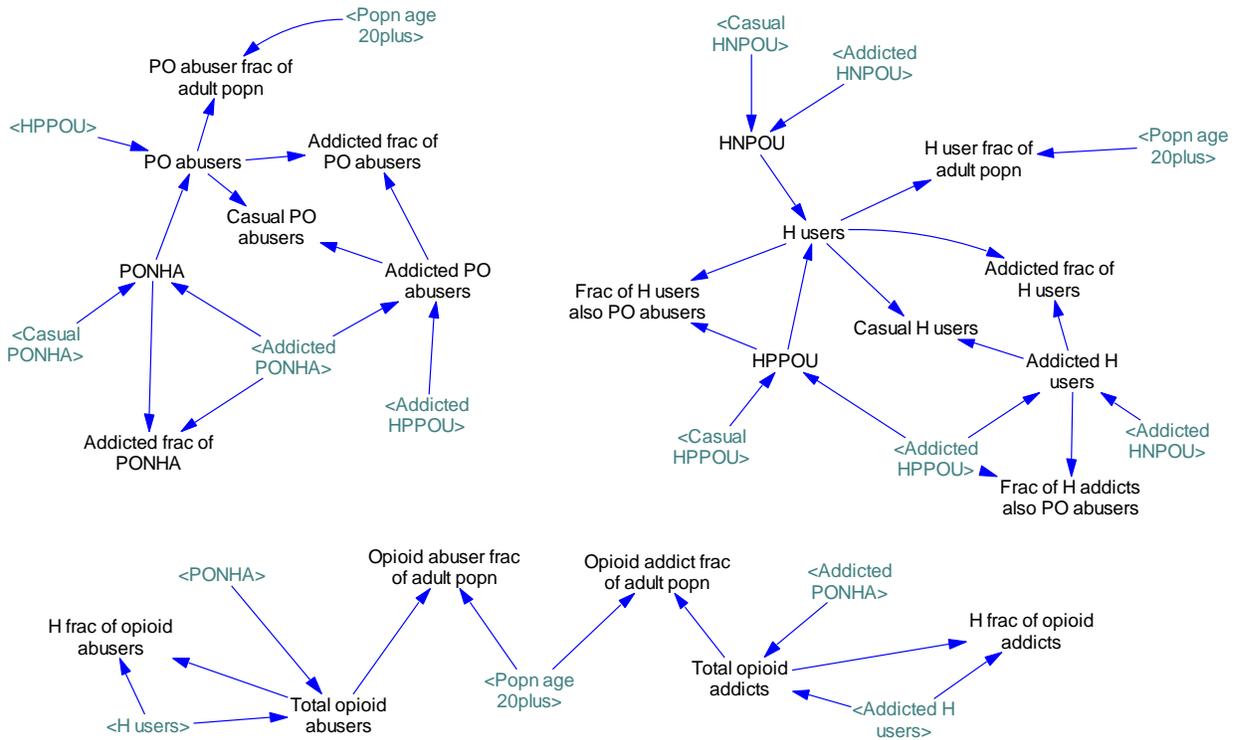
Sector 6 Equations

Addicted frac of H users= Addicted H users/H users

Addicted frac of PO abusers= Addicted PO abusers/PO abusers

Addicted frac of PONHA= Addicted PONHA/PONHA

Addicted H users= Addicted HPPOU + Addicted HNPOU

Addicted PO abusers= Addicted PONHA + Addicted HPPOU

Casual H users= H users - Addicted H users

Casual PO abusers= PO abusers - Addicted PO abusers

Frac of H addicts also PO abusers= Addicted HPPOU/Addicted H users

Frac of H users also PO abusers= HPPOU/H users

H frac of opioid abusers= H users/Total opioid abusers

H frac of opioid addicts= Addicted H users/Total opioid addicts

H user frac of adult popn= H users/Popn age 20plus

H users= HPPOU + HNPOU

HNPOU= Casual HNPOU + Addicted HNPOU

HPPOU= Casual HPPOU + Addicted HPPOU

Opioid abuser frac of adult popn= Total opioid abusers/Popn age 20plus

Opioid addict frac of adult popn= Total opioid addicts/Popn age 20plus

PO abuser frac of adult popn= PO abusers/Popn age 20plus

PO abusers= PONHA + HPPOU

PONHA= Casual PONHA + Addicted PONHA

Total opioid abusers= PONHA + H users

Total opioid addicts= Addicted PONHA + Addicted H users

Figure 2.7. Street pills supply and price
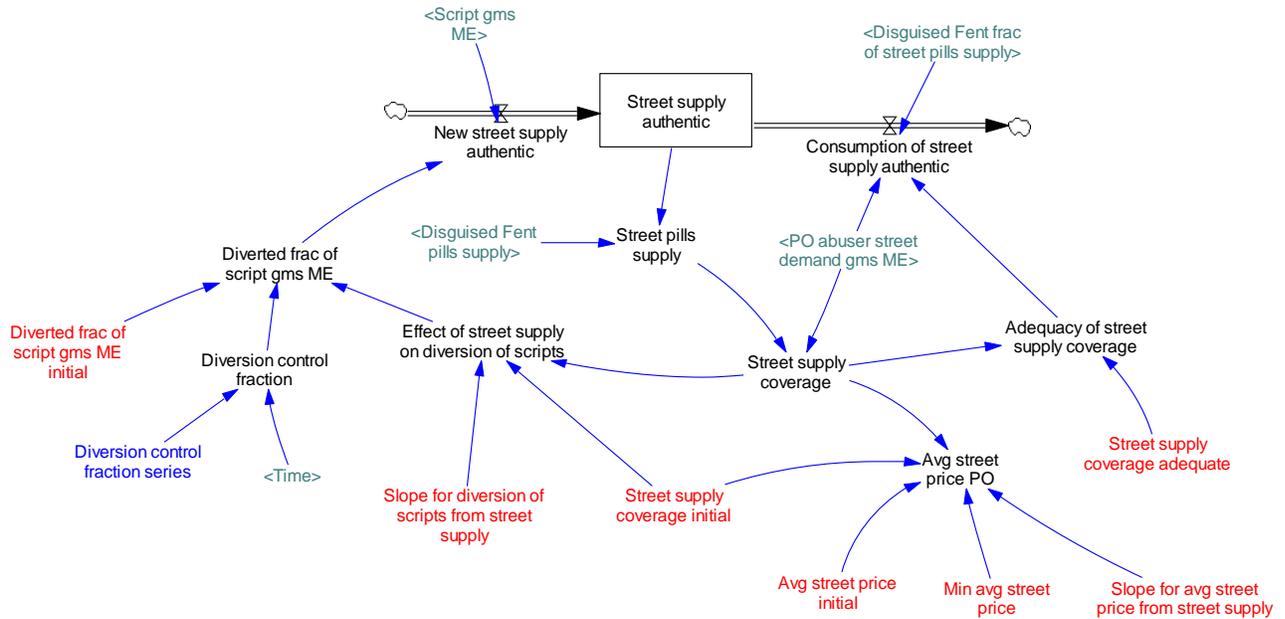
Sector 7 Equations

Adequacy of street supply coverage= MIN(1, Street supply coverage/Street supply coverage adequate)

Avg street price PO= MAX(Min avg street price, Avg street price initial * (1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for avg street price from street supply))

Consumption of street supply authentic= PO abuser street demand gms ME * (1-Disguised Fent frac of street pills supply) * Adequacy of street supply coverage

Diversion control fraction= *Diversion control fraction series(Time)*

Diverted frac of script gms ME= Diverted frac of script gms ME initial * Effect of street supply on diversion of scripts * (1-Diversion control fraction)

Effect of street supply on diversion of scripts = MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for diversion of scripts from street supply)

New street supply authentic= Script gms ME * Diverted frac of script gms ME

Street pills supply= Street supply authentic + Disguised Fent pills supply

Street supply authentic= INTEG (New street supply authentic-Consumption of street supply authentic, PO abuser street demand gms ME * Street supply coverage initial)

Street supply coverage= Street pills supply/PO abuser street demand gms ME

Sector 7 Constants

Avg street price initial= 1.6
  (estimation: optimized [1.4, 1.8]. Historical StreetRx price average per MME goes as low as high as
    $1.88.)

Diverted frac of script gms ME initial= 0.576
  (estimation: optimized [0.4, 0.65].)

Min avg street price= 0.5
  (estimation: Historical StreetRx price average per MME goes as low as $0.62.)

Slope for avg street price from street supply= -0.61
  (estimation: optimized [-0.90, -0.30].)

Slope for diversion of scripts from street supply= -0.38
  (estimation: optimized [-0.60, -0.20].)

Street supply coverage adequate= 0.13
  (estimation: optimized [0.08, 0.18].)

Street supply coverage initial= 0.15
  (estimation: optimized [0.10, 0.20].)

Sector 7 Time Series Inputs

*Diversion control fraction series([(2000,0)-(2020,1)],(2000,0),(2009,0),(2010,0.05),(2011,0.2),
    (2012,0.2),(2013,0.2),(2014,0),(2017,0),(2020,0))*
  (estimation: adjusted for best fit to historical PO price data. Reflects effects of legal crackdowns
    and introduction of tamper-resistant PO (esp. Oxycontin) during 2010 to 2013.)

Figure 2.8. PO street consumption demand
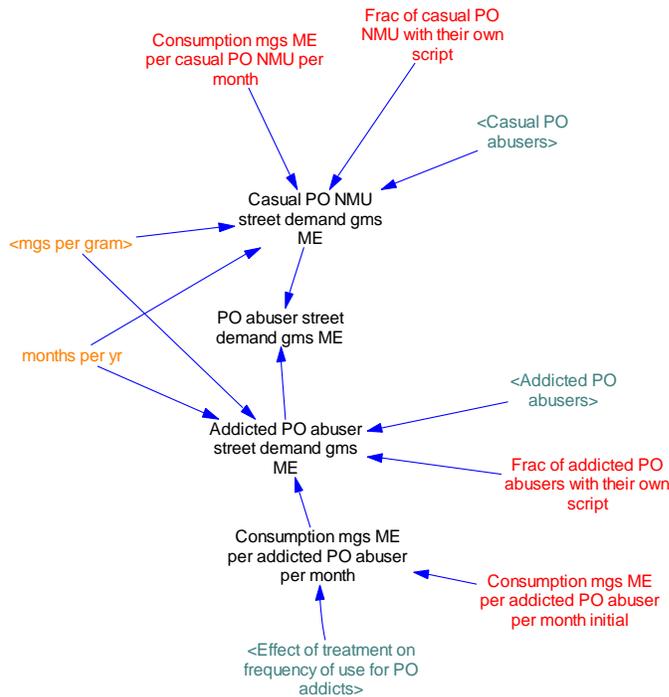
Sector 8 Equations

Addicted PO abuser street demand gms ME= Addicted PO abusers * Consumption mgs ME per addicted PO abuser per month * (1-Frac of addicted PO abusers with their own script) * months per yr/mgs per gram

Casual PO NMU street demand gms ME = Casual PO abusers * Consumption mgs ME per casual PO NMU per month * (1-Frac of casual PO NMU with their own script) * months per yr/mgs per gram

Consumption mgs ME per addicted PO abuser per month = Consumption mgs ME per addicted PO abuser per month initial * Effect of treatment on frequency of use for PO addicts

PO abuser street demand gms ME= Casual PO NMU street demand gms ME + Addicted PO abuser street demand gms ME

Sector 8 Constants

Consumption mgs ME per addicted PO abuser per month initial= 3200 MME/person/month
    (estimated: optimized [2000, 5000].)

Consumption mgs ME per casual PO NMU per month= 200 MME/person/month
    (estimated: optimized [50, 300].)

Frac of addicted PO abusers with their own script= 0.2
    (estimated: Jones et al 2014 (based on NSDUH 2008-11) and our analysis of NSDUH 2005-14.)

Frac of casual PO NMU with their own script= 0.12
    (estimated: Jones et al 2014 (based on NSDUH 2008-11) and our analysis of NSDUH 2005-14.)

months per yr= 12

Figure 2.9. Effects of street supply and price
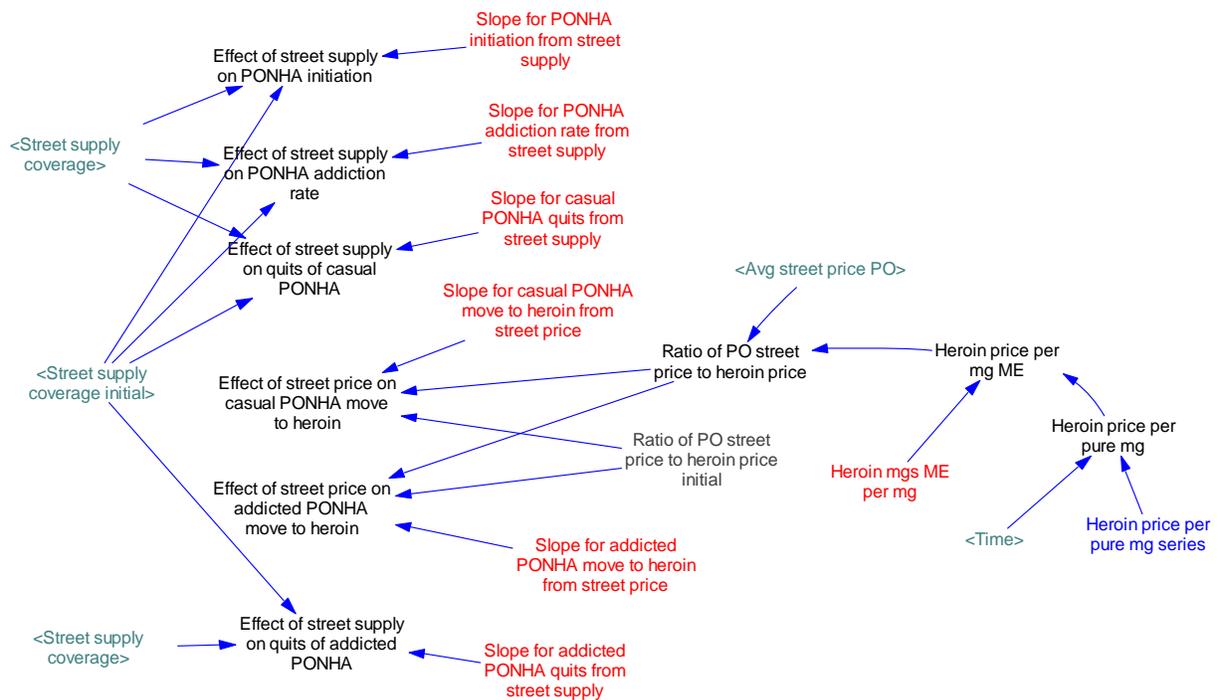
Sector 9 Equations

Effect of street price on addicted PONHA move to heroin= MAX(0, 1 + (Ratio of PO street price to heroin price/Ratio of PO street price to heroin price initial - 1)*Slope for addicted PONHA move to heroin from street price)

Effect of street price on casual PONHA move to heroin= MAX(0, 1 + (Ratio of PO street price to heroin price/Ratio of PO street price to heroin price initial - 1)*Slope for casual PONHA move to heroin from street price)

Effect of street supply on PONHA addiction rate= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for PONHA addiction rate from street supply)

Effect of street supply on PONHA initiation= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for PONHA initiation from street supply)

Effect of street supply on quits of addicted PONHA = MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for addicted PONHA quits from street supply)

Effect of street supply on quits of casual PONHA= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for casual PONHA quits from street supply)

Heroin price per mg ME= Heroin price per pure mg/Heroin mgs ME per mg

Heroin price per pure mg= *Heroin price per pure mg series(Time)*

Ratio of PO street price to heroin price= Avg street price PO/Heroin price per mg ME

Ratio of PO street price to heroin price initial= INITIAL(Ratio of PO street price to heroin price)

Sector 9 Constants

Heroin mgs ME per mg= 3.0 MME
   (estimation: see Deer et al. 2016 (West Virginia SEMP).)

Slope for addicted PONHA move to heroin from street price= 0.92
   (estimation: optimized [0.40, 1.40].)

Slope for addicted PONHA quits from street supply= -0.28
   (estimation: optimized [-0.45, -0.15].)

Slope for casual PONHA move to heroin from street price= 0.78
   (estimation: optimized [0.40, 1.20].)

Slope for casual PONHA quits from street supply= -0.3
   (estimation: optimized [-0.45, -0.15].)

Slope for PONHA addiction rate from street supply= 0.53
   (estimation: optimized [0.25, 0.80].)

Slope for PONHA initiation from street supply= 2.43
   (estimation: optimized [1.20, 3.60].)

Sector 9 Input Time Series

Heroin price per pure mg series([(1990,0)-(2020,1.6)],(1990,1.25),(1993,0.98),(1994,0.95), (1995,1),(1996,0.97),(1997,0.905),(1998,0.68),(1999,0.79),(2000,0.805),(2001,0.8),(2002,0.67), (2003,0.72),(2004,0.69),(2005,0.58),(2006,0.625),(2007,0.595),(2008,0.599),(2009,0.476), (2010,0.553),(2011,0.447),(2013,0.516),(2015,0.41),(2016,0.38),(2017,0.36),(2020,0.36))

(estimation: Unick et al 2014 (STRIDE 1993-2008), and our analysis of DEA STRIDE 2008-2016; use Unick defn of retail<1 gram. 1990 and 2016-2017 values are estimated from our separate learning-curve modeling of heroin price.)

Figure 2.10. Effects of non-oral PO abuse
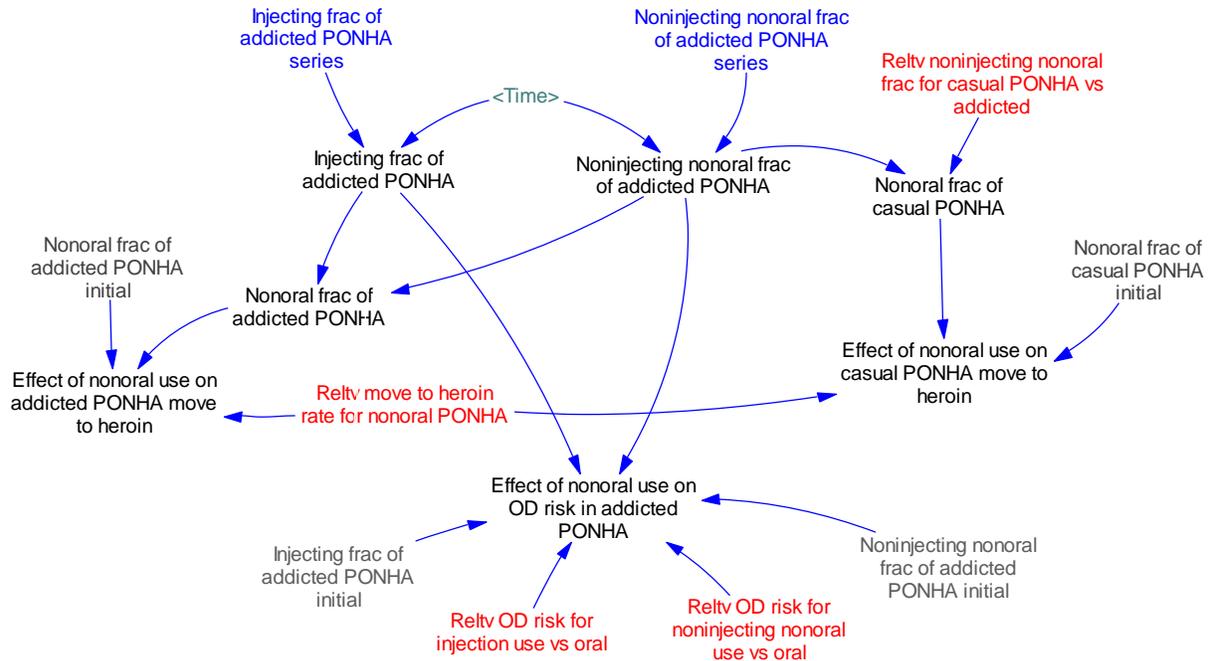
Sector 10 Equations

Effect of nonoral use on addicted PONHA move to heroin= (1-Nonoral frac of addicted PONHA+Nonoral frac of addicted PONHA*Reltv move to heroin rate for nonoral PONHA) / (1-Nonoral frac of addicted PONHA initial+Nonoral frac of addicted PONHA initial*Reltv move to heroin rate for nonoral PONHA)

Effect of nonoral use on casual PONHA move to heroin= (1-Nonoral frac of casual PONHA+Nonoral frac of casual PONHA*Reltv move to heroin rate for nonoral PONHA) / (1-Nonoral frac of casual PONHA initial+Nonoral frac of casual PONHA initial*Reltv move to heroin rate for nonoral PONHA)

Effect of nonoral use on OD risk in addicted PONHA= (1-Noninjecting nonoral frac of addicted PONHA-Injecting frac of addicted PONHA+Noninjecting nonoral frac of addicted PONHA*Reltv OD risk for noninjecting nonoral use vs oral+Injecting frac of addicted PONHA*Reltv OD risk for injection use vs oral) / (1-Noninjecting nonoral frac of addicted PONHA initial-Injecting frac of addicted PONHA initial+Noninjecting nonoral frac of addicted PONHA initial*Reltv OD risk for noninjecting nonoral use vs oral+Injecting frac of addicted PONHA initial *Reltv OD risk for injection use vs oral)

Injecting frac of addicted PONHA= *Injecting frac of addicted PONHA series(Time)*

Injecting frac of addicted PONHA initial= INITIAL(Injecting frac of addicted PONHA)

Noninjecting nonoral frac of addicted PONHA= *Noninjecting nonoral frac of addicted PONHA series(Time)*

Noninjecting nonoral frac of addicted PONHA initial= INITIAL(Noninjecting nonoral frac of addicted PONHA)

Nonoral frac of addicted PONHA= Injecting frac of addicted PONHA + Noninjecting nonoral frac of addicted PONHA

Nonoral frac of addicted PONHA initial= INITIAL(Nonoral frac of addicted PONHA)

Nonoral frac of casual PONHA = Noninjecting nonoral frac of addicted PONHA * Reltv noninjecting nonoral frac for casual PONHA vs addicted

Nonoral frac of casual PONHA initial= INITIAL(Nonoral frac of casual PONHA)

Sector 10 Constants

Reltv move to heroin rate for nonoral PONHA= 10
  (estimation: given by Carlson et al 2016.)

Reltv noninjecting nonoral frac for casual PONHA vs addicted= 0.19
  (estimation: optimized [0.1, 0.3].)

Reltv OD risk for injection use vs oral= 2.7
  (estimation: calculated from Green et al 2017; "death or major effect" from injection.)

Reltv OD risk for noninjecting nonoral use vs oral= 2.3
  (estimation: calculated from Green et al 2017; "death or major effect" from inhalation.)

Sector 10 Time Series Inputs

Injecting frac of addicted PONHA series ([(1990,0)-(2020,0.4)],(1990,0.18),(1994,0.18),(1995,0.175), (1996,0.167),(1997,0.162),(1998,0.148),(1999,0.143),(2000,0.138),(2001,0.132),(2002,0.13), (2003,0.122),(2004,0.117),(2005,0.12),(2006,0.113),(2007,0.102),(2008,0.111),(2009,0.126), (2010,0.144),(2011,0.162),(2012,0.17),(2013,0.181),(2014,0.177),(2015,0.19),(2020,0.19))
  (estimation: Jones 2016 and Jones et al 2017 (using TEDS: injecting) 2004-2013, and our similar analysis of TEDS 1994-2014.)

Noninjecting nonoral frac of addicted PONHA series ([(1990,0)-(2020,0.4)],(1990,0.09),(1994,0.09),
(1995,0.095),(1996,0.094),(1997,0.089),(1998,0.074),(1999,0.074),(2000,0.085),(2001,0.105),
(2002,0.115),(2003,0.142),(2004,0.153),(2005,0.162),(2006,0.178),(2007,0.188),(2008,0.198),
(2009,0.214),(2010,0.238),(2011,0.253),(2012,0.245),(2013,0.23),(2014,0.205),(2015,0.21),
(2020,0.21))

(estimation: Jones 2016 (using TEDS: other non-oral) 2004-2013, and our similar analysis of TEDS 1994-2014.)

Figure 2.11. Effects of perceived overdose risks
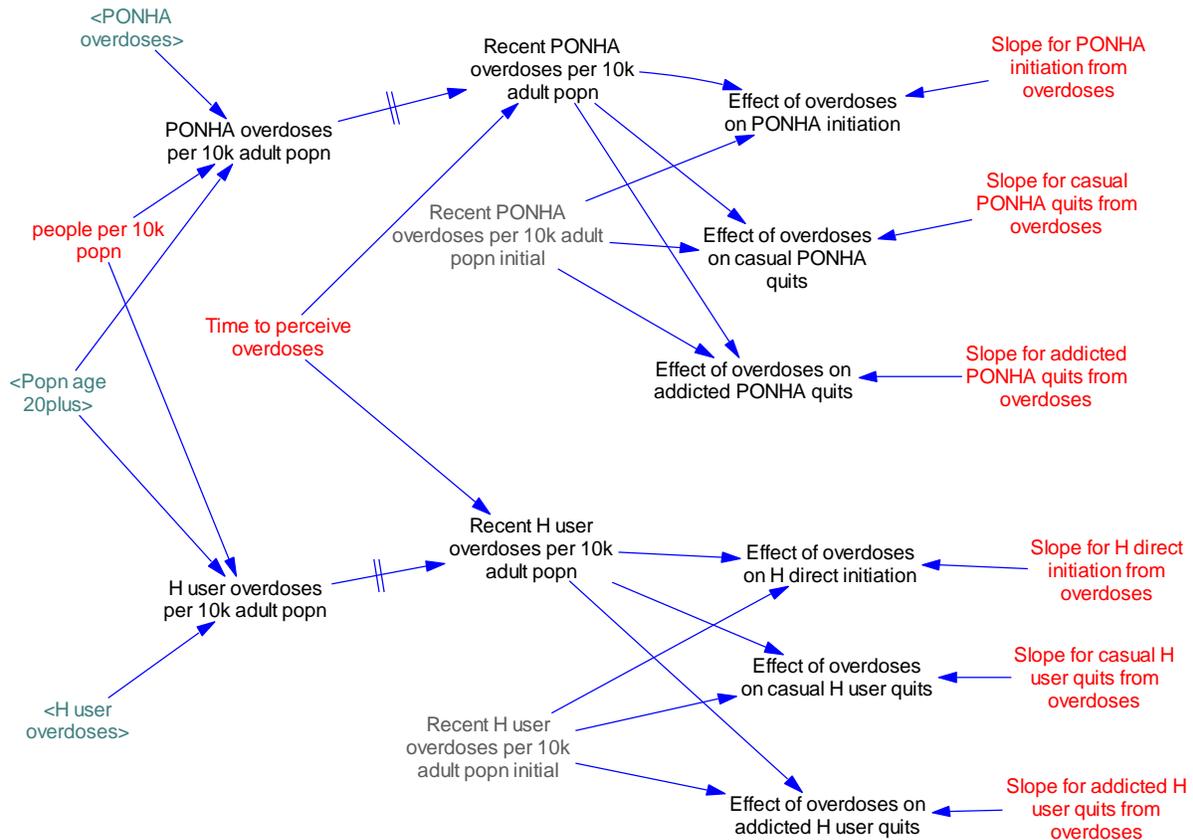
Sector 11 Equations

Effect of overdoses on addicted H user quits= 1 + LN(Recent H user overdoses per 10k adult popn/Recent H user overdoses per 10k adult popn initial)*Slope for addicted H user quits from overdoses

Effect of overdoses on addicted PONHA quits= 1 + LN(Recent PONHA overdoses per 10k adult popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for addicted PONHA quits from overdoses

Effect of overdoses on casual H user quits= 1 + LN(Recent H user overdoses per 10k adult popn/Recent H user overdoses per 10k adult popn initial)*Slope for casual H user quits from overdoses

Effect of overdoses on casual PONHA quits=1 + LN(Recent PONHA overdoses per 10k adult popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for casual PONHA quits from overdoses

Effect of overdoses on H direct initiation= 1 + LN(Recent H user overdoses per 10k adult popn/Recent H user overdoses per 10k adult popn initial)*Slope for H direct initiation from overdoses

Effect of overdoses on PONHA initiation= MAX(0, 1 + LN(Recent PONHA overdoses per 10k adult popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for PONHA initiation from overdoses)

H user overdoses per 10k adult popn= H user overdoses/Popn age 20plus*people per 10k popn

PONHA overdoses per 10k adult popn= PONHA overdoses/Popn age 20plus*people per 10k popn

Recent H user overdoses per 10k adult popn= SMOOTH(H user overdoses per 10k adult popn, Time to perceive overdoses)

Recent H user overdoses per 10k adult popn initial= INITIAL(Recent H user overdoses per 10k adult popn)

Recent PONHA overdoses per 10k adult popn= SMOOTH(PONHA overdoses per 10k adult popn, Time to perceive overdoses)

Recent PONHA overdoses per 10k adult popn initial= INITIAL(Recent PONHA overdoses per 10k adult popn)

Sector 11 Constants

people per 10k popn= 10000

Slope for addicted H user quits from overdoses= 0
    (estimation: optimized [0, 0.2].)

Slope for addicted PONHA quits from overdoses= 0.25
    (estimation: optimized [0.1, 0.4].)

Slope for casual H user quits from overdoses= 0
    (estimation: optimized [0, 0.2].)

Slope for casual PONHA quits from overdoses= 0.35
    (estimation: optimized [0.1, 0.6].)

Slope for H direct initiation from overdoses= -0.2
   (estimation: optimized [-0.4, 0].)

Slope for PONHA initiation from overdoses= -0.75
   (estimation: optimized [-1.2, -0.3].)

Time to perceive overdoses= 0.25
   (estimation: optimized [0.125, 1.0].)

Figure 2.12. Overdose death rates
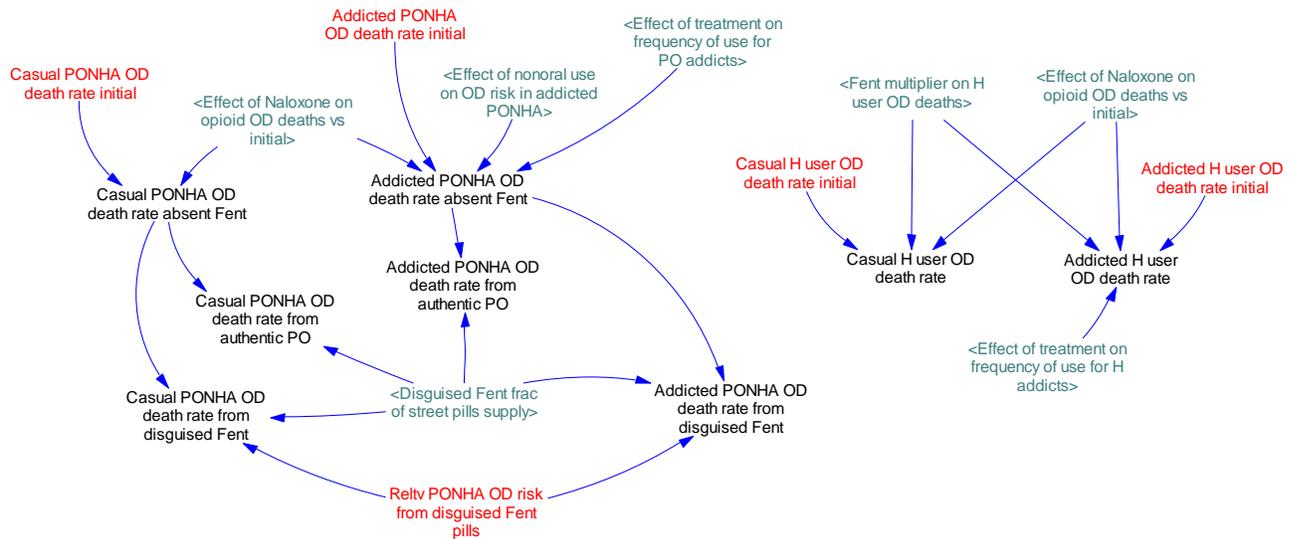
Sector 12 Equations

Addicted H user OD death rate=Addicted H user OD death rate initial * Fent multiplier on H user OD
   deaths * Effect of treatment on frequency of use for H addicts * Effect of Naloxone on opioid OD
   deaths vs initial

Addicted PONHA OD death rate absent Fent= Addicted PONHA OD death rate initial * Effect of nonoral
   use on OD risk in addicted PONHA * Effect of treatment on frequency of use for PO addicts *
   Effect of Naloxone on opioid OD deaths vs initial

Addicted PONHA OD death rate from authentic PO= Addicted PONHA OD death rate absent Fent * (1-
   Disguised Fent frac of street pills supply)

Addicted PONHA OD death rate from disguised Fent= Addicted PONHA OD death rate absent Fent *
   Disguised Fent frac of street pills supply * Reltv PONHA OD risk from disguised Fent pills

Casual H user OD death rate= Casual H user OD death rate initial * Fent multiplier on H user OD deaths * Effect of Naloxone on opioid OD deaths vs initial

Casual PONHA OD death rate absent Fent=Casual PONHA OD death rate initial * Effect of Naloxone on opioid OD deaths vs initial

Casual PONHA OD death rate from authentic PO=Casual PONHA OD death rate absent Fent * (1-Disguised Fent frac of street pills supply)

Casual PONHA OD death rate from disguised Fent= Casual PONHA OD death rate absent Fent * Disguised Fent frac of street pills supply * Reltv PONHA OD risk from disguised Fent pills

Sector 12 Constants

Addicted H user OD death rate initial=0.01
(estimation: optimized [0.005, 0.015].)

Addicted PONHA OD death rate initial=0.0059
(estimation: optimized [0.004, 0.007].)

Casual H user OD death rate initial=0.0081
(estimation: optimized [0.004, 0.012].)

Casual PONHA OD death rate initial= 0.0004
(estimation: optimized [0.0002, 0.0006].)

Reltv PONHA OD risk from disguised Fent pills= 5.19
(estimation: optimized [3.0, 7.0].)

Figure 2.13. Overdose death aggregates
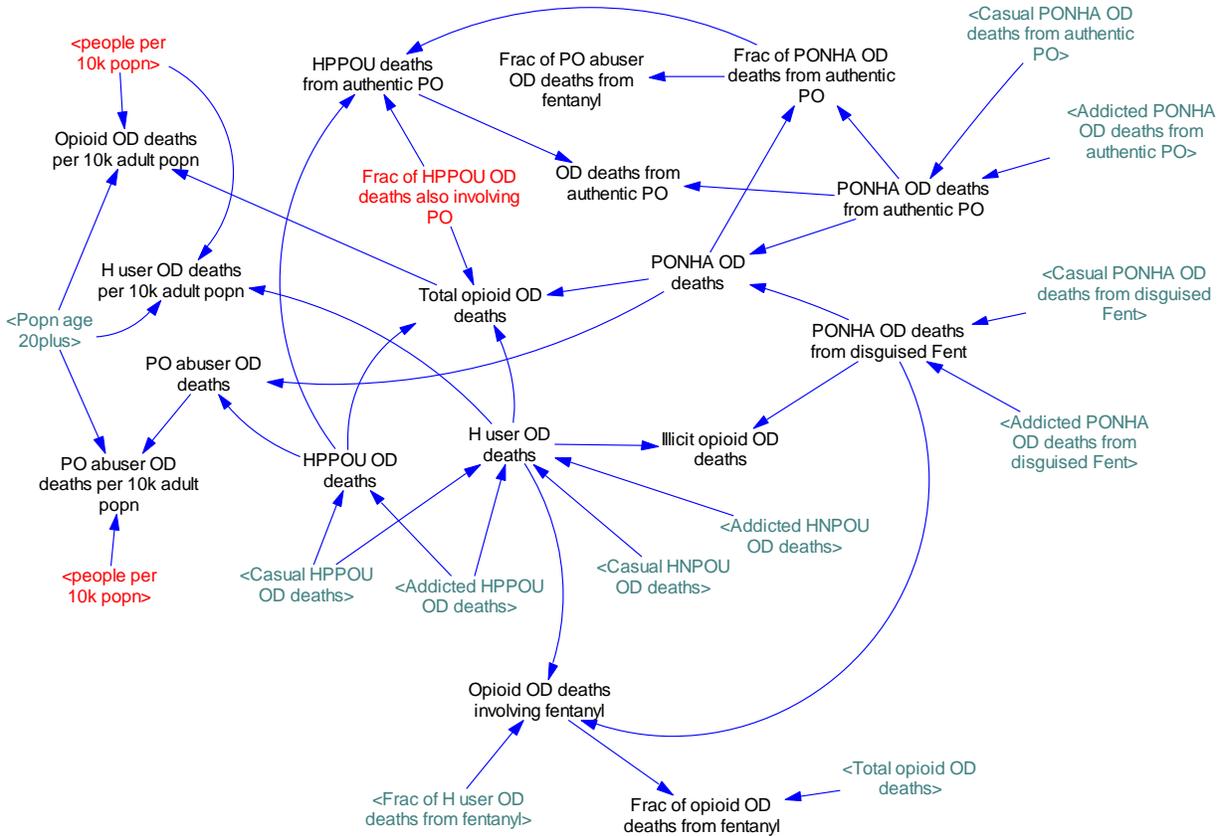
Sector 13 Equations

Frac of opioid OD deaths from fentanyl= Opioid OD deaths involving fentanyl/Total opioid OD deaths

Frac of PO abuser OD deaths from fentanyl= 1 - Frac of PONHA OD deaths from authentic PO

Frac of PONHA OD deaths from authentic PO= PONHA OD deaths from authentic PO/PONHA OD deaths

H user OD deaths = Casual HPPOU OD deaths + Addicted HPPOU OD deaths + Casual HNPOU OD deaths + Addicted HNPOU OD deaths

H user OD deaths per 10k adult popn= H user OD deaths/Popn age 20plus*people per 10k popn

HPPOU deaths from authentic PO = HPPOU OD deaths * Frac of HPPOU OD deaths also involving PO * Frac of PONHA OD deaths from authentic PO

HPPOU OD deaths= Casual HPPOU OD deaths + Addicted HPPOU OD deaths

Illicit opioid OD deaths= H user OD deaths + PONHA OD deaths from disguised Fent

OD deaths from authentic PO= PONHA OD deaths from authentic PO + HPPOU deaths from authentic PO

Opioid OD deaths involving fentanyl= H user OD deaths*Frac of H user OD deaths from fentanyl +
        PONHA OD deaths from disguised Fent

Opioid OD deaths per 10k adult popn= Total opioid OD deaths/Popn age 20plus*people per 10k popn

PO abuser OD deaths= PONHA OD deaths + HPPOU OD deaths

PO abuser OD deaths per 10k adult popn= PO abuser OD deaths/Popn age 20plus*people per 10k popn

PONHA OD deaths= PONHA OD deaths from authentic PO + PONHA OD deaths from disguised Fent

PONHA OD deaths from authentic PO= Casual PONHA OD deaths from authentic PO + Addicted PONHA
        OD deaths from authentic PO

PONHA OD deaths from disguised Fent= Casual PONHA OD deaths from disguised Fent + Addicted
        PONHA OD deaths from disguised Fent

Total opioid OD deaths= PONHA OD deaths + H user OD deaths - HPPOU OD deaths*Frac of HPPOU OD
        deaths also involving PO

Sector 13 Constants

Frac of HPPOU OD deaths also involving PO= 0.25
        (estimation: WONDER data show a close fit (1999-2015) for: Total opioid deaths=(PO deaths + 0.76*
        Illicit opioid deaths). This implies a 24% overlap. We adjusted slightly to improve simulated fit.)

Figure 2.14. Opioid addiction treatment
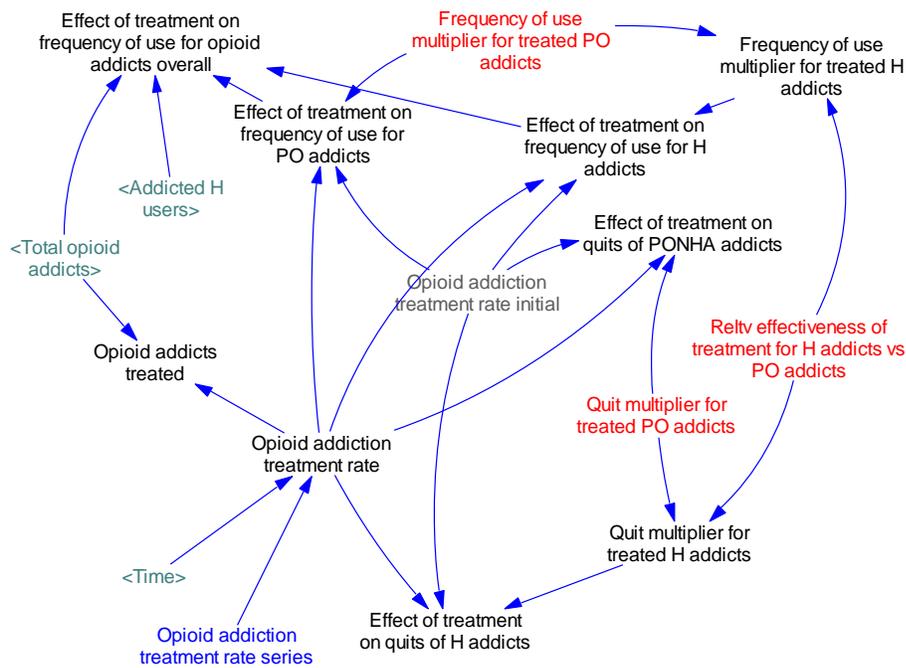
Sector 14 Equations

Effect of treatment on frequency of use for H addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Frequency of use multiplier for treated H addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Frequency of use multiplier for treated H addicts)

Effect of treatment on frequency of use for opioid addicts overall= (Effect of treatment on frequency of use for H addicts*Addicted H users + Effect of treatment on frequency of use for PO addicts*(Total opioid addicts-Addicted H users)) / Total opioid addicts

Effect of treatment on frequency of use for PO addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Frequency of use multiplier for treated PO addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Frequency of use multiplier for treated PO addicts)

Effect of treatment on quits of H addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Quit multiplier for treated H addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Quit multiplier for treated H addicts)

Effect of treatment on quits of PONHA addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Quit multiplier for treated PO addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Quit multiplier for treated PO addicts)

Frequency of use multiplier for treated H addicts= 1 + (Frequency of use multiplier for treated PO addicts-1)*Reltv effectiveness of treatment for H addicts vs PO addicts

Opioid addiction treatment rate= *Opioid addiction treatment rate series(Time)*

Opioid addiction treatment rate initial= INITIAL(Opioid addiction treatment rate)

Opioid addicts treated= Total opioid addicts * Opioid addiction treatment rate

Quit multiplier for treated H addicts= 1 + (Quit multiplier for treated PO addicts-1)*Reltv effectiveness of treatment for H addicts vs PO addicts

Sector 14 Constants

Frequency of use multiplier for treated PO addicts= 0.65
   (Estimation: optimized [0.55, 0.85]. NIDA 2018 suggests a range of .67 (33% reduction: Methadone) to .83 (17% reduction: Buprenorphine) for the effect of treatment on the frequency of opioid-positive drug tests.)

Quit multiplier for treated PO addicts= 2
   (Estimation: optimized [1.5, 3.5]. NIDA 2018 suggests a range of 1.82 (Buprenorphine) to 4.44 (Methadone) for opioids overall. Connery 2015 suggests a range of 2.0 (Meth) to 3.0-8.3 (Bupe).)

Reltv effectiveness of treatment for H addicts vs PO addicts= 0.8
   (Estimation: Potter et al. 2013 (H vs PO); also Gossop et al. 2002 (H), Weiss et al. 2011 (PO), McCarty et al. 2017 (PO).)

Sector 14 Time Series Inputs

Opioid addiction treatment rate series ([(1990,0)-(2020,1)],(1990,0.2),(2000,0.2),(2005,0.165), (2007,0.21),(2010,0.265),(2012,0.305),(2015,0.39),(2016,0.405),(2017,0.415),(2020,0.45))
   (Estimation: treatment volume based on data from Alderks 2017 (N-SSATS 2003-2016; facilities), online ARCOS 2006-2016; office-based Buprenorphine). Rate calculated by dividing treatment volume by total opioid addicts from Jones et al 2015.)

Figure 2.15. Naloxone use for overdoses
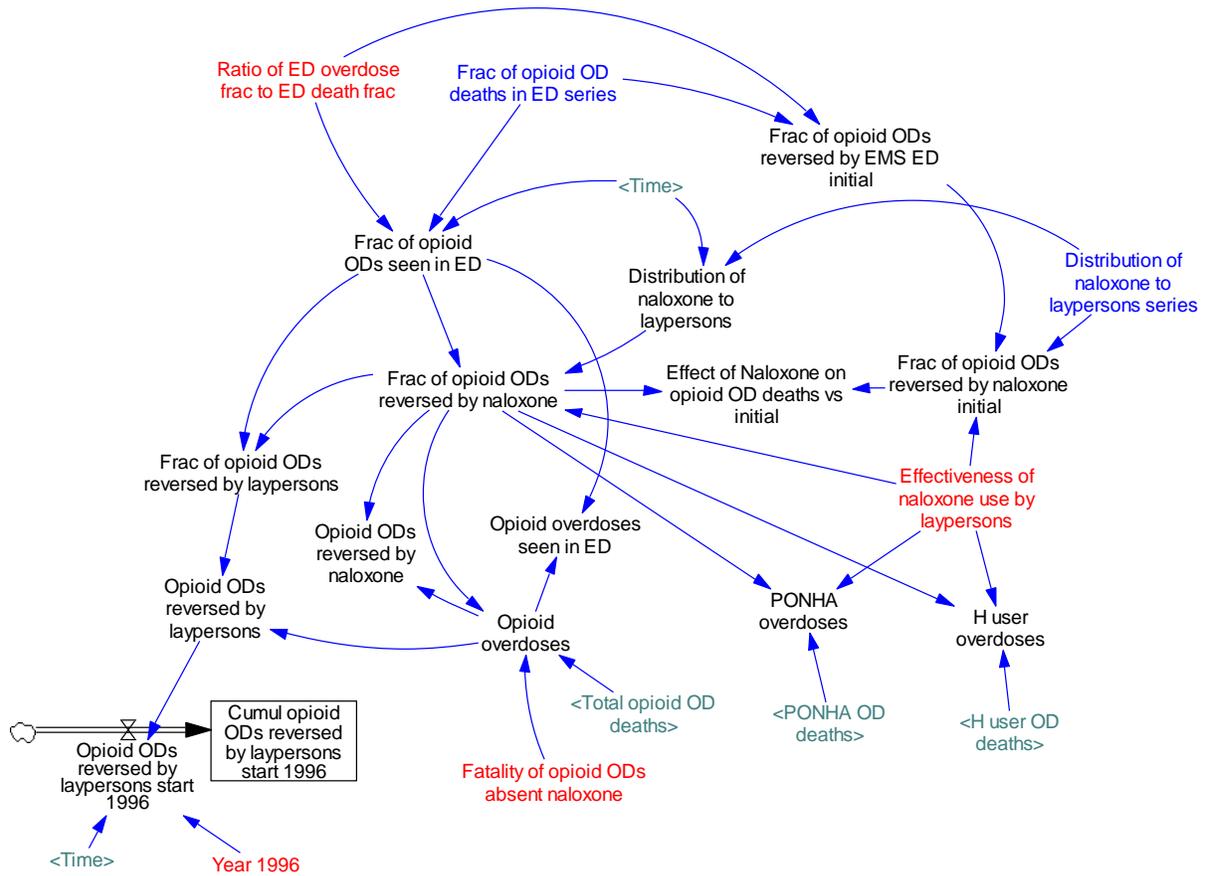
Sector 15 Equations

Cumul opioid ODs reversed by laypersons start 1996= INTEG(Opioid ODs reversed by laypersons start 1996,0)

Distribution of naloxone to laypersons= *Distribution of naloxone to laypersons series(Time)*

Effect of Naloxone on opioid OD deaths vs initial= (1-Frac of opioid ODs reversed by naloxone) / (1-Frac of opioid ODs reversed by naloxone initial)

Frac of opioid ODs reversed by EMS ED initial= *Frac of opioid OD deaths in ED series(1990)* * Ratio of ED overdose frac to ED death frac

Frac of opioid ODs reversed by laypersons= Frac of opioid ODs reversed by naloxone - Frac of opioid ODs seen in ED

Frac of opioid ODs reversed by naloxone= Frac of opioid ODs seen in ED + (1-Frac of opioid ODs seen in ED)*Distribution of naloxone to laypersons*Effectiveness of naloxone use by laypersons

Frac of opioid ODs reversed by naloxone initial= Frac of opioid ODs reversed by EMS ED initial + (1-Frac of opioid ODs reversed by EMS ED initial)*_Distribution of naloxone to laypersons series(1990)_*Effectiveness of naloxone use by laypersons

Frac of opioid ODs seen in ED= _Frac of opioid OD deaths in ED series(Time)_ * Ratio of ED overdose frac to ED death frac

H user overdoses= ZIDZ(H user OD deaths, 1 - Frac of opioid ODs reversed by naloxone*Effectiveness of naloxone use by laypersons)

Opioid ODs reversed by laypersons= Opioid overdoses * Frac of opioid ODs reversed by laypersons

Opioid ODs reversed by laypersons start 1996= IF THEN ELSE(Time>=Year 1996, Opioid ODs reversed by laypersons, 0)

Opioid ODs reversed by naloxone= Opioid overdoses * Frac of opioid ODs reversed by naloxone

Opioid overdoses= ZIDZ(Total opioid OD deaths, Fatality of opioid ODs absent naloxone*(1-Frac of opioid ODs reversed by naloxone))

Opioid overdoses seen in ED= Opioid overdoses * Frac of opioid ODs seen in ED

PONHA overdoses= ZIDZ(PONHA OD deaths, 1 - Frac of opioid ODs reversed by naloxone*Effectiveness of naloxone use by laypersons)

Sector 15 Constants

Effectiveness of naloxone use by laypersons= 0.9
(estimation: Lynn & Galinkin 2018 (75-100%), see also Clark et al 2014, McDonald & Strang 2016, and Kounang 2017 (93%).)

Fatality of opioid ODs absent naloxone= 0.1
(estimation: adjust to fit Hasegawa et al. 2014 data on ODs in ED, and Wheeler et al. 2015 data on ODs reversed by laypersons.)

Ratio of ED overdose frac to ED death frac=1
(estimation: assumes ED's see the same fraction of nonfatal overdoses as they of fatal overdoses; the latter from Mack et al. 2017.)

Year 1996= 1996

Sector 15 Time Series Inputs

Distribution of naloxone to laypersons series ([(1990,0)-(2020,0.1)],(1990,0),(2000,0),(2005,0.0005), (2010,0.006),(2013,0.03),(2015,0.037),(2017,0.04),(2020,0.04))

(estimation: Wheeler et al. 2015. Calibrated to fit table of opioid OD reversals by laypersons, 2013 and 1996-2014 cumulative.)

Frac of opioid OD deaths in ED series ([(1990,0.2)-(2020,1)],(1990,0.345),(1999,0.347),(2000,0.346), (2001,0.34),(2002,0.326),(2003,0.316),(2004,0.305),(2005,0.3),(2006,0.301),(2007,0.286), (2008,0.27),(2009,0.265),(2010,0.274),(2011,0.28),(2012,0.271),(2013,0.27),(2014,0.266), (2015,0.268),(2020,0.27))
(estimation: based on Mack et al 2017, Table 3 (NVSS 1999-2015), combining Metro and Nonmetro, fraction of OD deaths in medical facility as opposed to home or other. Note also Adams 2018 cites WONDER: "77% of opioid overdose deaths occur outside of a medical setting".)

Figure 2.16. Effects of illicit fentanyl
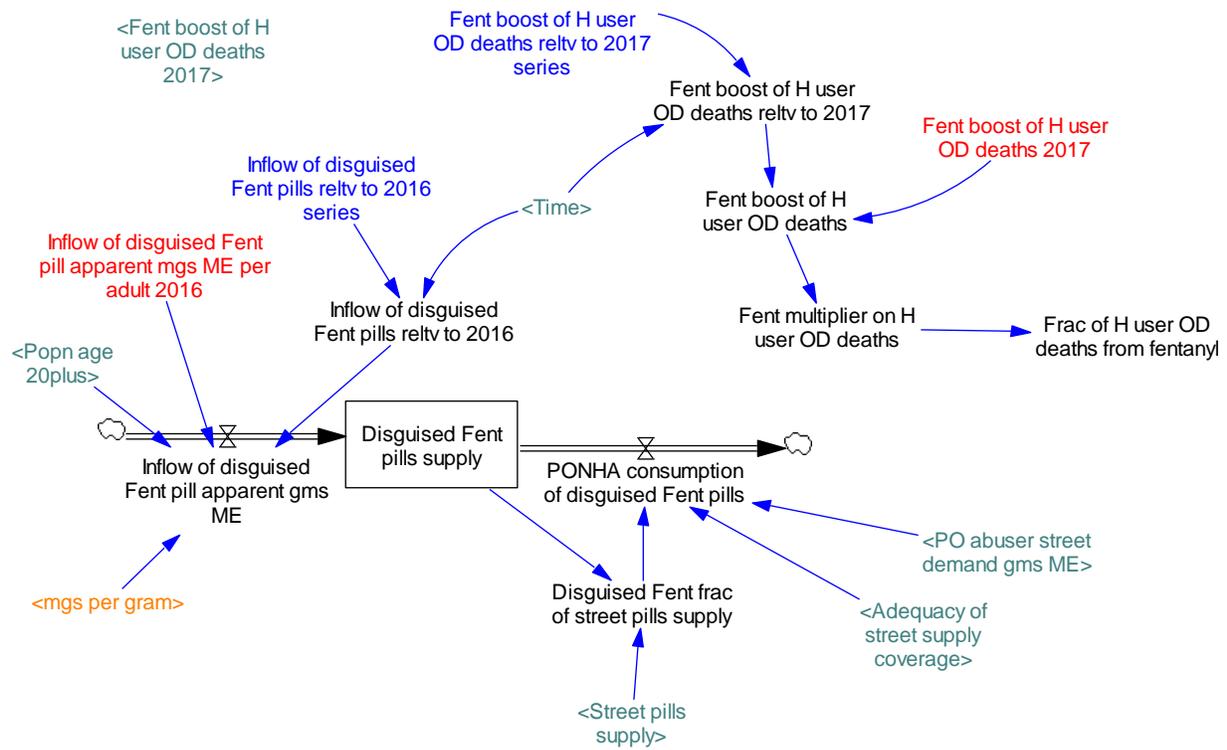
Sector 16 Equations

Disguised Fent frac of street pills supply= Disguised Fent pills supply/Street pills supply

Disguised Fent pills supply= INTEG (Inflow of disguised Fent pill apparent gms ME-PONHA consumption of disguised Fent pills, 0)

Fent boost of H user OD deaths= Fent boost of H user OD deaths 2017 * Fent boost of H user OD deaths reltv to 2017

Fent boost of H user OD deaths reltv to 2017= *Fent boost of H user OD deaths reltv to 2017 series(Time)*

Fent multiplier on H user OD deaths= 1 + Fent boost of H user OD deaths

Frac of H user OD deaths from fentanyl= (Fent multiplier on H user OD deaths-1)/Fent multiplier on H user OD deaths

Inflow of disguised Fent pill apparent gms ME= Inflow of disguised Fent pill apparent mgs ME per adult 2016/mgs per gram * Popn age 20plus * Inflow of disguised Fent pills reltv to 2016

Inflow of disguised Fent pills reltv to 2016= *Inflow of disguised Fent pills reltv to 2016 series(Time)*

PONHA consumption of disguised Fent pills= PO abuser street demand gms ME * Disguised Fent frac of street pills supply*Adequacy of street supply coverage

Sector 16 Constants

Fent boost of H user OD deaths 2017= 3.1
 (estimation: optimized [2.0, 4.0].)

Inflow of disguised Fent pill apparent mgs ME per adult 2016= 25
 (estimation: optimized [10, 40].)

Sector 16 Time Series Inputs

Fent boost of H user OD deaths reltv to 2017 series ([(1990,0)-(2020,4)],(2000,0),(2010,0),(2012,0.05), (2015,0.45),(2017,1),(2020,1.25))
 (estimation: based on ratio of historical illicit (heroin or synthetic) overdoses from WONDER to historical heroin users from Muhuri et al. 2013 and Jones 2016; similar pattern seen for heroin deaths specifically and synthetic deaths specifically. See also patterns of fentanyl growth from NFLIS 2017a, NFLIS 2017b, and Springer et al. 2019.)

Inflow of disguised Fent pills reltv to 2016 series ([(1990,0)-(2020,4)],(2000,0),(2010,0),(2012,0), (2013,0.01),(2014,0.12),(2015,0.41),(2016,1),(2017,1.3),(2018,1.5),(2020,1.6))
 (estimation: based on NFLIS 2017a, 2017b, and Springer et al. 2019.)

Figure 2.17. Cumulative outcome measures over time
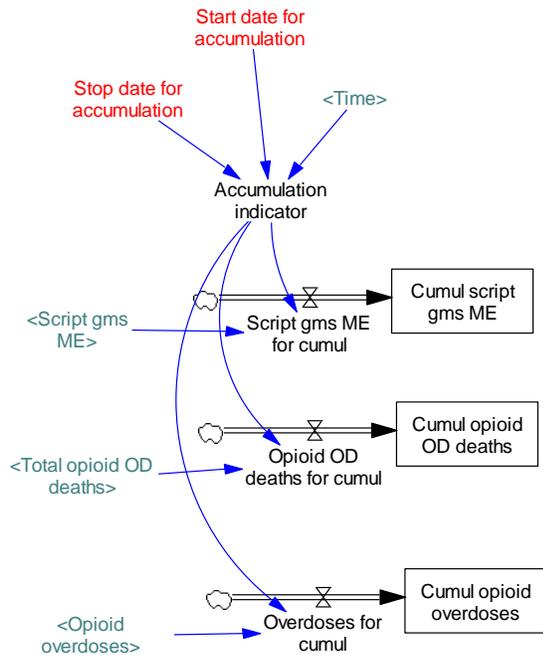
Sector 17 Equations

Accumulation indicator = IF THEN ELSE(Time<Start date for accumulation, 0, IF THEN ELSE(Time>=Stop date for accumulation, 0, 1))

Cumul opioid OD deaths= INTEG (Opioid OD deaths for cumul, 0)

Cumul opioid overdoses= INTEG (Overdoses for cumul, 0)

Cumul script gms ME= INTEG (Script gms ME for cumul, 0)

Opioid OD deaths for cumul= Accumulation indicator*Total opioid OD deaths

Overdoses for cumul= Accumulation indicator*Opioid overdoses

Script gms ME for cumul= Accumulation indicator*Script gms ME

Sector 17 Equations

Start date for accumulation= 2020

Stop date for accumulation= 2030

Figure 2.18. Historical data
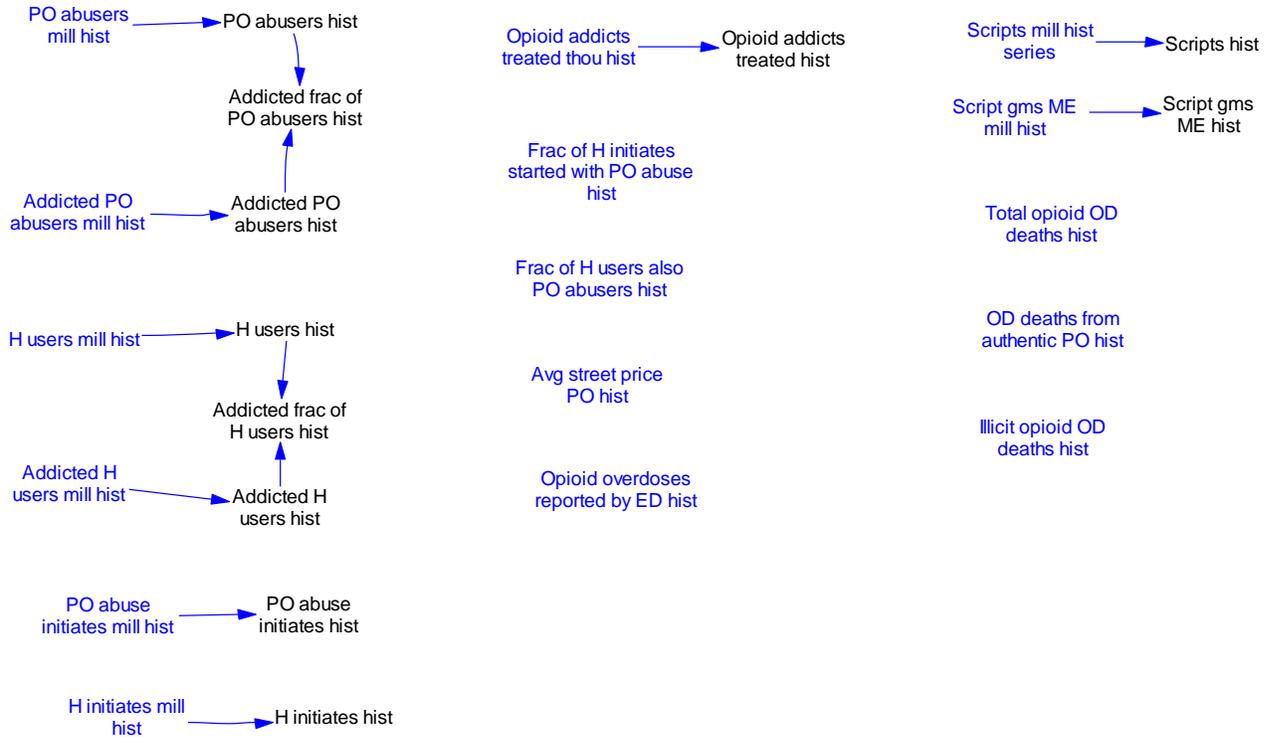
Sector 18 Equations

Addicted frac of H users hist:RAW::= X IF MISSING(Addicted H users hist/H users hist,:NA:)

Addicted frac of PO abusers hist:RAW::= X IF MISSING(Addicted PO abusers hist/PO abusers hist,:NA:)

Addicted H users hist:RAW::= X IF MISSING(Addicted H users mill hist*1e+06,:NA:)

Addicted PO abusers hist:RAW::= X IF MISSING(Addicted PO abusers mill hist*1e+06,:NA:)

H initiates hist:RAW::= X IF MISSING(H initiates mill hist*1e+06,:NA:)

H users hist:RAW::= X IF MISSING(H users mill hist series*1e+06,:NA:)

Opioid addicts treated hist:RAW::= X IF MISSING(Opioid addicts treated thou hist*1000,:NA:)

PO abuse initiates hist:RAW::= X IF MISSING(PO abuse initiates mill hist*1e+06,:NA:)

PO abusers hist:RAW::= X IF MISSING(PO abusers mill hist*1e+06,:NA:)

Script gms ME hist:RAW::= X IF MISSING(Script gms ME mill hist*1e+06,:NA:)

Scripts hist:RAW::= X IF MISSING(Scripts mill hist series*1e+06,:NA:)

Sector 18 Time Series Data (Linked from Excel Spreadsheet)

Addicted H users mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B2')

(2000,0.187),(2002,0.198),(2003,0.169),(2004,0.226),(2005,0.199),(2006,0.298),(2007,0.179), (2008,0.254),(2009,0.324),(2010,0.321),(2011,0.369),(2012,0.39),(2013,0.43),(2014,0.5)

Sources: our NSDUH analysis for 2000, Muhuri et al. 2013 (NSDUH 2002-11), Jones 2016 (NSDUH 2012-14).

Addicted PO abusers mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B5')

(2000,0.7),(2001,1),(2002,1.5),(2003,1.338),(2004,1.435),(2005,1.491),(2006,1.544),(2007,1.676), (2008,1.633),(2009,1.73),(2010,1.785),(2011,1.728),(2012,2.1),(2013,1.9),(2014,1.8),(2015,1.98), (2016,1.9),(2017,1.59)

Sources: Wakeland et al. 2015 (NSDUH 2000-02), Jones et al. 2015 (NSDUH 2003-11), Muhuri et al. 2013 (NSDUH 2002-11), Jones 2016 (NSDUH 2012-14); and our NSDUH analysis for 2015-17.

Avg street price PO hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B44')

(2007,0.873),(2008,0.784),(2009,0.761),(2010,0.699),(2011,1.87),(2012,1.37),(2013,1.39),(2014,0.7), (2015,0.68),(2016,0.71),(2017,0.69),(2018,0.7)

Sources: our analysis of StreetRx.com for 2008 and 2011-18; Bluelight.org for 2007 and 2009-10.

Frac of H initiates started with PO abuse hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B8')

(2000,0.635),(2003,0.668),(2005,0.822),(2009,0.774),(2010,0.934),(2013,0.762),(2014,0.844), (2016,0.654)

Sources: Jones 2013 (NSDUH 2002-04 pooled for 2003 and 2008-10 pooled for 2009); our NSDUH analysis for other years.

Frac of H users also PO abusers hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B41')

(2000,0.496),(2005,0.562),(2010,0.626),(2014,0.616),(2016,0.562)

Source: our NSDUH analysis.

H initiates mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B11')

(2002,0.117),(2003,0.092),(2004,0.118),(2005,0.108),(2006,0.09),(2007,0.106),(2008,0.116), (2009,0.187),(2010,0.142),(2011,0.178),(2012,0.156),(2013,0.169),(2014,0.212),(2015,0.135), (2016,0.17),(2017,0.081),(2018,0.118)

Source: SAMHSA 2019 (NSDUH 2002-2018; Fig 29).

H users mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B14')

(1990,0.187),(1995,0.428),(2000,0.308),(2002,0.404),(2003,0.314),(2004,0.398),(2005,0.379), (2006,0.56),(2007,0.373),(2008,0.455),(2009,0.582),(2010,0.621),(2011,0.62),(2012,0.67), (2013,0.68),(2014,0.91),(2015,0.841),(2016,0.942),(2018,0.808)

Sources: Muhuri et al. 2013 (NSDUH 2002-11), Jones 2016 (NSDUH 2012-14), our NSDUH analysis for 1990-2000 and 2015-2016; and SAMHSA 2019 (Fig 24).

Illicit opioid OD deaths hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B17')

(1999,2675),(2000,2606),(2001,2721),(2002,3369),(2003,3464),(2004,3529),(2005,3717), (2006,4682),(2007,4599),(2008,5319),(2009,6195),(2010,5998),(2011,7019),(2012,8484), (2013,11153),(2014,15091),(2015,19884),(2016,29101)

Source: CDC WONDER (heroin and illicit Fentanyl and other synthetics [ICD T40.1, T40.4]). Table download from https://www.drugabuse.gov/related-topics/trends-statistics/overdose-death-rates

OD deaths from authentic PO hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B29')

(1999,6158),(2000,6462),(2001,7389),(2002,9349),(2003,10266),(2004,11000),(2005,12068), (2006,13989),(2007,15046),(2008,15560),(2009,15800),(2010,16655),(2011,17552),(2012,16652), (2013,16443),(2014,16941),(2015,17536),(2016,19354)

Source: CDC WONDER (Opioid pain relievers [ICD T40.2, T40.3, T40.6]). Table download from https://www.drugabuse.gov/related-topics/trends-statistics/overdose-death-rates

Opioid addicts treated thou hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B20')

(2003,227),(2004,241),(2005,235.8),(2006,308.3),(2007,349.7),(2008,419.6),(2009,495.6), (2010,555.2),(2011,600.5),(2012,656),(2013,722.8),(2014,774.4),(2015,831.9),(2016,865.6)

Sources: based on Alderks 2017 (facility treatments, N-SSATS 2003-15) and our analysis of ARCOS (non-facility Buprenorphine treatment 2006-16).

Opioid overdoses reported by ED hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B64')

(1993,18307),(1995,13392),(1997,28796),(1999,42090),(2001,50103),(2003,34975),(2005,31180), (2007,63559),(2009,84715)

Source: Hasegawa et al 2014 (NHAMCS 1993-2010).

PO abuse initiates mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B23')

(1990,0.65),(1991,0.75),(1992,0.7),(1993,0.9),(1994,0.85),(1995,0.9),(1996,1.1),(1997,1.25), (1998,1.5),(1999,1.75),(2000,2.25),(2001,2.4),(2002,2.7),(2003,2.6),(2004,2.4),(2005,2.2), (2006,2.2),(2007,2.2),(2008,2.2),(2009,2.2),(2010,2),(2011,1.8),(2012,1.75),(2015,2.126), (2016,2.139),(2017,2.01),(2018,1.908)

Sources: Compton & Volkow 2006 (NSDUH 1990-2001); Wakeland et al. 2015 (NSDUH 1995-2011); Kolodny et al 2015 (NSDUH 1991-2012); SAMHSA 2019 (2015-18; Fig 31).

PO abusers mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B26')

(1995,4.8),(1996,5),(1997,4.35),(1998,4.25),(1999,7),(2000,6.8),(2001,8.8),(2002,10.99), (2003,11.67),(2004,11.26),(2005,11.82),(2006,12.65),(2007,12.52),(2008,11.92),(2009,12.45), (2010,12.24),(2011,11.14),(2012,12.49),(2013,11.08),(2014,10.34),(2015,12.71),(2016,11.87), (2017,11.06), (2018,9.9)

Sources: Wakeland et al. 2015 (NSDUH 1995-2001); Jones 2016 (NSDUH 2002+); SAMHSA 2019 (Fig 24); and our NSDUH analysis for 2015-17.

Script gms ME mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B32')

(1994,50.9),(1995,52.1),(1996,54.1),(1997,60.7),(1998,66.9),(1999,78.2),(2000,84.2),(2001,102.7), (2002,116.9),(2003,134.9),(2004,147),(2005,151.7),(2006,171.9),(2007,194.3),(2008,197.1), (2009,208.9),(2010,224.5),(2011,234.4),(2012,223.7),(2013,212.7),(2014,206.4),(2015,198.1), (2016,184.2)

Sources: our analysis of ARCOS 2001-16, using conversion factors from CMS 2015; Dasgupta et al. 2006 (ARCOS 1994-2002); and Iqvia Institute 2018.

Scripts mill hist series:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B35')

(1992,107.3),(1993,113.1),(1994,117),(1995,125.4),(1996,133.4),(1997,138.9),(1998,148.9), (1999,160.9),(2000,172.5),(2001,188.6),(2002,193.9),(2003,203.3),(2004,214.6),(2005,225.3), (2006,239),(2007,250.8),(2008,262),(2009,267),(2010,273.3),(2011,274.1),(2012,277.3), (2013,270.1),(2014,264.1),(2015,246.2),(2016,239),(2017,209.4)

Source: Pezalla 2017 (Iqvia NPA 1992-2016); https://www.cdc.gov/drugoverdose/maps/rxrate-maps.html (Iqvia Xponent 2006-17).

Total opioid OD deaths hist:RAW::=GET XLS DATA('Opioid model inputs and data series 2u.xlsx','Validation data series','1','B38')

(1999,8048),(2000,8407),(2001,9492),(2002,11917),(2003,12939),(2004,13755),(2005,14917), (2006,17545),(2007,18515),(2008,19582),(2009,20422),(2010,21088),(2011,22784),(2012,23164), (2013,25050),(2014,28647),(2015,33091),(2016,42249),(2017,49068)

Source: CDC WONDER ([ICD T40.1, T40.2, T40.3, T40.4, T40.6]). Table download from https://www.drugabuse.gov/related-topics/trends-statistics/overdose-death-rates

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4. PRIMARY DATA SOURCES

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5. COMPLETE EQUATION LISTING

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*******************************
   .Active
*******************************
```
         Active equations

(001)   Accumulation indicator= IF THEN ELSE(Time<Start date for accumulation, 0, IF THEN
           ELSE(Time>=Stop date for accumulation, 0, 1))
         Units: dmnl

(002)   Addicted frac of H users= Addicted H users/H users
         Units: dmnl

(003)   Addicted frac of H users initial= 0.65
         Units: dmnl

(004)   Addicted frac of PO abusers= Addicted PO abusers/PO abusers
         Units: dmnl

(005)   Addicted frac of PONHA= Addicted PONHA/PONHA
         Units: dmnl

(006)   Addicted frac of PONHA initial= 0.123
         Units: dmnl

(007)   Addicted H user OD death rate= Addicted H user OD death rate initial * Fent multiplier on H user
           OD deaths * Effect of treatment on frequency of use for H addicts * Effect of Naloxone on
           opioid OD deaths vs initial
         Units: 1/Year

(008)   Addicted H user OD death rate initial=
             0.01
         Units: 1/Year

(009)   Addicted H user quit rate initial=
             0.138
         Units: 1/Year

(010)   Addicted H users=
             Addicted HPPOU + Addicted HNPOU
         Units: popn

(011)   Addicted H users quit rate= Addicted H user quit rate initial * Effect of treatment on quits of H
           addicts * Effect of overdoses on addicted H user quits
         Units: 1/Year

(012)   Addicted HNPOU= INTEG (Addicted HPPOU drop PO use+Casual HNPOU become addicted-
        Addicted HNPOU death from misc causes-Addicted HNPOU OD deaths-Addicted HNPOU quit,
        HNPOU frac of adult popn initial * Popn age 20plus * Addicted frac of H users initial)
        Units: popn

(013)   Addicted HNPOU death from misc causes= Addicted HNPOU * Addicted opioid abuser misc
        death rate
        Units: popn/Year

(014)   Addicted HNPOU OD deaths= Addicted HNPOU * Addicted H user OD death rate
        Units: popn/Year

(015)   Addicted HNPOU quit= Addicted HNPOU * Addicted H users quit rate
        Units: popn/Year

(016)   Addicted HPPOU= INTEG (Addicted PONHA move to heroin+Casual HPPOU become addicted-
        Addicted HPPOU death from misc causes -Addicted HPPOU drop PO use-Addicted HPPOU OD
        deaths-Addicted HPPOU quit, HPPOU frac of adult popn initial * Popn age 20plus * Addicted
        frac of H users initial)
        Units: popn

(017)   Addicted HPPOU death from misc causes= Addicted HPPOU * Addicted opioid abuser misc death
        rate
        Units: popn/Year

(018)   Addicted HPPOU drop PO use= Addicted HPPOU * HPPOU drop PO use rate
        Units: popn/Year

(019)   Addicted HPPOU OD deaths= Addicted HPPOU * Addicted H user OD death rate
        Units: popn/Year

(020)   Addicted HPPOU quit= Addicted HPPOU * Addicted H users quit rate
        Units: popn/Year

(021)   Addicted opioid abuser misc death rate= 0.0045
        Units: 1/Year

(022)   Addicted PO abuser street demand gms ME= Addicted PO abusers * Consumption mgs ME per
        addicted PO abuser per month * (1-Frac of addicted PO abusers with their own script) *
        months per yr/mgs per gram
        Units: gramsME/Year

(023)   Addicted PO abusers= Addicted PONHA + Addicted HPPOU
        Units: popn

(024)   Addicted PONHA= INTEG (Casual PONHA become addicted+Medical users become addicted-
        Addicted PONHA deaths from misc causes -Addicted PONHA OD deaths from authentic PO-
        Addicted PONHA OD deaths from disguised Fent -Addicted PONHA quit-Addicted PONHA

move to heroin, PONHA frac of adult popn initial * Popn age 20plus * Addicted frac of PONHA initial)
Units: popn

(025)   Addicted PONHA deaths from misc causes= Addicted PONHA * Addicted opioid abuser misc death rate
Units: popn/Year

(026)   Addicted PONHA med users= Addicted PONHA * Med user frac of addicted PONHA
Units: popn

(027)   Addicted PONHA move to heroin= Addicted PONHA * Addicted PONHA move to heroin rate
Units: popn/Year

(028)   Addicted PONHA move to heroin rate= Addicted PONHA move to heroin rate initial * Effect of nonoral use on addicted PONHA move to heroin * Effect of street price on addicted PONHA move to heroin
Units: 1/Year

(029)   Addicted PONHA move to heroin rate initial= 0.021
Units: 1/Year

(030)   Addicted PONHA OD death rate absent Fent= Addicted PONHA OD death rate initial * Effect of nonoral use on OD risk in addicted PONHA * Effect of treatment on frequency of use for PO addicts * Effect of Naloxone on opioid OD deaths vs initial
Units: 1/Year

(031)   Addicted PONHA OD death rate from authentic PO= Addicted PONHA OD death rate absent Fent * (1-Disguised Fent frac of street pills supply)
Units: 1/Year

(032)   Addicted PONHA OD death rate from disguised Fent= Addicted PONHA OD death rate absent Fent * Disguised Fent frac of street pills supply * Reltv PONHA OD risk from disguised Fent pills
Units: 1/Year

(033)   Addicted PONHA OD death rate initial= 0.0059
Units: 1/Year

(034)   Addicted PONHA OD deaths from authentic PO= Addicted PONHA * Addicted PONHA OD death rate from authentic PO
Units: popn/Year

(035)   Addicted PONHA OD deaths from disguised Fent= Addicted PONHA * Addicted PONHA OD death rate from disguised Fent
Units: popn/Year

(036)   Addicted PONHA quit= Addicted PONHA * Addicted PONHA quit rate
Units: popn/Year

(037) Addicted PONHA quit rate= Addicted PONHA quit rate initial * Effect of treatment on quits of
        PONHA addicts * Effect of street supply on quits of addicted PONHA * Effect of overdoses on
        addicted PONHA quits
        Units: 1/Year

(038) Addicted PONHA quit rate initial= 0.149
        Units: 1/Year

(039) Adequacy of street supply coverage= MIN(1, Street supply coverage/Street supply coverage
        adequate)
        Units: dmnl

(040) Avg mgs ME per script= Avg mgs ME per script 1995 * Script strength multiplier vs 1995
        Units: mgsME/scripts

(041) Avg mgs ME per script 1995= 416
        Units: mgsME/scripts

(042) Avg street price initial= 1.6
        Units: dollars/mgME

(043) Avg street price PO= MAX(Min avg street price, Avg street price initial * (1 + (Street supply
        coverage/Street supply coverage initial - 1)*Slope for avg street price from street supply))
        Units: dollars/mgME

(044) Casual H user become addicted rate= 0.096
        Units: 1/Year

(045) Casual H user OD death rate= Casual H user OD death rate initial * Fent multiplier on H user OD
        deaths * Effect of Naloxone on opioid OD deaths vs initial
        Units: 1/Year

(046) Casual H user OD death rate initial= 0.0081
        Units: 1/Year

(047) Casual H user quit rate= Casual H user quit rate initial * Effect of overdoses on casual H user
        quits
        Units: 1/Year

(048) Casual H user quit rate initial= 0.192
        Units: 1/Year

(049) Casual H users= H users - Addicted H users
        Units: popn

(050) Casual HNPOU= INTEG (Casual HPPOU drop PO use+H user direct initiates-Casual HNPOU
        become addicted -Casual HNPOU death from misc causes-Casual HNPOU OD deaths-Casual

HNPOU quit, HNPOU frac of adult popn initial * Popn age 20plus * (1-Addicted frac of H users initial))
Units: popn

(051)   Casual HNPOU become addicted= Casual HNPOU * Casual H user become addicted rate
Units: popn/Year

(052)   Casual HNPOU death from misc causes= Casual HNPOU * Casual opioid abuser misc death rate
Units: popn/Year

(053)   Casual HNPOU OD deaths= Casual HNPOU * Casual H user OD death rate
Units: popn/Year

(054)   Casual HNPOU quit= Casual HNPOU*Casual H user quit rate
Units: popn/Year

(055)   Casual HPPOU= INTEG (Casual PONHA move to heroin-Casual HPPOU become addicted-Casual HPPOU death from misc causes-Casual HPPOU drop PO use-Casual HPPOU OD deaths-Casual HPPOU quit, HPPOU frac of adult popn initial * Popn age 20plus * (1-Addicted frac of H users initial))
Units: popn

(056)   Casual HPPOU become addicted= Casual HPPOU * Casual H user become addicted rate
Units: popn/Year

(057)   Casual HPPOU death from misc causes= Casual HPPOU * Casual opioid abuser misc death rate
Units: popn/Year

(058)   Casual HPPOU drop PO use= Casual HPPOU * HPPOU drop PO use rate
Units: popn/Year

(059)   Casual HPPOU OD deaths= Casual HPPOU * Casual H user OD death rate
Units: popn/Year

(060)   Casual HPPOU quit= Casual HPPOU * Casual H user quit rate
Units: popn/Year

(061)   Casual opioid abuser misc death rate= 0.0035
Units: 1/Year

(062)   Casual PO abusers= PO abusers - Addicted PO abusers
Units: popn

(063)   Casual PO NMU street demand gms ME= Casual PO abusers * Consumption mgs ME per casual PO NMU per month * (1-Frac of casual PO NMU with their own script) * months per yr /mgs per gram
Units: gramsME/Year

(064)   Casual PONHA= INTEG (Med users become casual abusers+PO abuse initiates-Casual PONHA
         become addicted -Casual PONHA deaths from misc causes-Casual PONHA move to heroin-
         Casual PONHA OD deaths from authentic PO -Casual PONHA OD deaths from disguised Fent-
         Casual PONHA quit, PONHA frac of adult popn initial * Popn age 20plus * (1-Addicted frac of
         PONHA initial))
         Units: popn

(065)   Casual PONHA become addicted= Casual PONHA * Casual PONHA become addicted rate
         Units: popn/Year

(066)   Casual PONHA become addicted rate= Casual PONHA become addicted rate initial * Effect of
         street supply on PONHA addiction rate
         Units: 1/Year

(067)   Casual PONHA become addicted rate initial= 0.02
         Units: 1/Year

(068)   Casual PONHA deaths from misc causes= Casual PONHA * Casual opioid abuser misc death rate
         Units: popn/Year

(069)   Casual PONHA med users= Casual PONHA * Med user frac of casual PO abusers
         Units: popn

(070)   Casual PONHA move to heroin= Casual PONHA * Casual PONHA move to heroin rate
         Units: popn/Year

(071)   Casual PONHA move to heroin rate= Casual PONHA move to heroin rate initial * Effect of street
         price on casual PONHA move to heroin * Effect of nonoral use on casual PONHA move to
         heroin
         Units: 1/Year

(072)   Casual PONHA move to heroin rate initial= 0.0038
         Units: 1/Year

(073)   Casual PONHA OD death rate absent Fent= Casual PONHA OD death rate initial * Effect of
         Naloxone on opioid OD deaths vs initial
         Units: 1/Year

(074)   Casual PONHA OD death rate from authentic PO= Casual PONHA OD death rate absent Fent * (1-
         Disguised Fent frac of street pills supply)
         Units: 1/Year

(075)   Casual PONHA OD death rate from disguised Fent= Casual PONHA OD death rate absent Fent *
         Disguised Fent frac of street pills supply * Reltv PONHA OD risk from disguised Fent pills
         Units: 1/Year

(076)   Casual PONHA OD death rate initial= 0.0004
         Units: 1/Year

(077) Casual PONHA OD deaths from authentic PO= Casual PONHA * Casual PONHA OD death rate
       from authentic PO
       Units: popn/Year

(078) Casual PONHA OD deaths from disguised Fent= Casual PONHA * Casual PONHA OD death rate
       from disguised Fent
       Units: popn/Year

(079) Casual PONHA quit= Casual PONHA * Casual PONHA quit rate
       Units: popn/Year

(080) Casual PONHA quit rate= Casual PONHA quit rate initial * Effect of street supply on quits of
       casual PONHA * Effect of overdoses on casual PONHA quits
       Units: 1/Year

(081) Casual PONHA quit rate initial= 0.209
       Units: 1/Year

(082) Consumption mgs ME per addicted PO abuser per month= Consumption mgs ME per addicted
       PO abuser per month initial * Effect of treatment on frequency of use for PO addicts
       Units: mgsME/(popn*month)

(083) Consumption mgs ME per addicted PO abuser per month initial= 3200
       Units: mgsME/(popn*month)

(084) Consumption mgs ME per casual PO NMU per month= 200
       Units: mgsME/popn/month

(085) Consumption of street supply authentic= PO abuser street demand gms ME * (1-Disguised Fent
       frac of street pills supply) * Adequacy of street supply coverage
       Units: gramsME/Year

(086) Cumul opioid OD deaths= INTEG (Opioid OD deaths for cumul, 0)
       Units: popn

(087) Cumul opioid ODs reversed by laypersons start 1996= INTEG (Opioid ODs reversed by laypersons
       start 1996, 0)
       Units: popn

(088) Cumul opioid overdoses= INTEG (Overdoses for cumul, 0)
       Units: popn

(089) Cumul script gms ME= INTEG (Script gms ME for cumul, 0)
       Units: gramsME

(090) Disguised Fent frac of street pills supply= Disguised Fent pills supply/Street pills supply
       Units: dmnl

(091) Disguised Fent pills supply= INTEG (Inflow of disguised Fent pill apparent gms ME-PONHA consumption of disguised Fent pills, 0)
Units: gramsME

(092) Distribution of naloxone to laypersons= Distribution of naloxone to laypersons series(Time)
Units: dmnl

(093) Distribution of naloxone to laypersons series([(1990,0)-(2020,0.1)],(1990,0),(2000,0),(2005,0.0005),(2010,0.006),(2013,0.03),(2015,0.037),(2017,0.04),(2020,0.04))
Units: dmnl

(094) Diversion control fraction= Diversion control fraction series(Time)
Units: dmnl

(095) Diversion control fraction series([(2000,0)-(2020,1)],(2000,0),(2009,0),(2010,0.05),(2011,0.2),(2012,0.2),(2013,0.2),(2014,0),(2017,0),(2020,0))
Units: dmnl

(096) Diverted frac of script gms ME= Diverted frac of script gms ME initial * Effect of street supply on diversion of scripts * (1-Diversion control fraction)
Units: dmnl

(097) Diverted frac of script gms ME initial= 0.576
Units: dmnl

(098) Effect of Naloxone on opioid OD deaths vs initial= (1-Frac of opioid ODs reversed by naloxone) / (1-Frac of opioid ODs reversed by naloxone initial)
Units: dmnl

(099) Effect of nonoral use on addicted PONHA move to heroin= (1-Nonoral frac of addicted PONHA+Nonoral frac of addicted PONHA*Reltv move to heroin rate for nonoral PONHA) / (1-Nonoral frac of addicted PONHA initial +Nonoral frac of addicted PONHA initial*Reltv move to heroin rate for nonoral PONHA)
Units: dmnl

(100) Effect of nonoral use on casual PONHA move to heroin= (1-Nonoral frac of casual PONHA+Nonoral frac of casual PONHA*Reltv move to heroin rate for nonoral PONHA) / (1-Nonoral frac of casual PONHA initial +Nonoral frac of casual PONHA initial*Reltv move to heroin rate for nonoral PONHA)
Units: dmnl

(101) Effect of nonoral use on OD risk in addicted PONHA= (1-Noninjecting nonoral frac of addicted PONHA-Injecting frac of addicted PONHA +Noninjecting nonoral frac of addicted PONHA*

Reltv OD risk for noninjecting nonoral use vs oral+Injecting frac of addicted PONHA*Reltv OD
risk for injection use vs oral) / (1-Noninjecting nonoral frac of addicted PONHA initial-Injecting
frac of addicted PONHA initial +Noninjecting nonoral frac of addicted PONHA initial
*Reltv OD risk for noninjecting nonoral use vs oral+Injecting frac of addicted PONHA
initial*Reltv OD risk for injection use vs oral)
Units: dmnl

(102)   Effect of overdoses on addicted H user quits= 1 + LN(Recent H user overdoses per 10k adult
        popn/Recent H user overdoses per 10k adult popn initial)*Slope for addicted H user quits from
        overdoses
        Units: dmnl

(103)   Effect of overdoses on addicted PONHA quits= 1 + LN(Recent PONHA overdoses per 10k adult
        popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for addicted PONHA quits
        from overdoses
        Units: dmnl

(104)   Effect of overdoses on casual H user quits= 1 + LN(Recent H user overdoses per 10k adult
        popn/Recent H user overdoses per 10k adult popn initial)*Slope for casual H user quits from
        overdoses
        Units: dmnl

(105)   Effect of overdoses on casual PONHA quits= 1 + LN(Recent PONHA overdoses per 10k adult
        popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for casual PONHA quits from
        overdoses
        Units: dmnl

(106)   Effect of overdoses on H direct initiation= 1 + LN(Recent H user overdoses per 10k adult
        popn/Recent H user overdoses per 10k adult popn initial)*Slope for H direct initiation from
        overdoses
        Units: dmnl

(107)   Effect of overdoses on PONHA initiation= MAX(0,1 + LN(Recent PONHA overdoses per 10k adult
        popn/Recent PONHA overdoses per 10k adult popn initial)*Slope for PONHA initiation from
        overdoses)
        Units: dmnl

(108)   Effect of script strength on med user addiction rate= Script strength multiplier vs
        1995^Exponent for med user addiction rate from script strength
        Units: dmnl

(109)   Effect of street price on addicted PONHA move to heroin= MAX(0, 1 + (Ratio of PO street price
        to heroin price/Ratio of PO street price to heroin price initial - 1)*Slope for addicted PONHA
        move to heroin from street price)
        Units: dmnl

(110) Effect of street price on casual PONHA move to heroin= MAX(0, 1 + (Ratio of PO street price to heroin price/Ratio of PO street price to heroin price initial - 1)*Slope for casual PONHA move to heroin from street price)
Units: dmnl

(111) Effect of street supply on diversion of scripts=MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for diversion of scripts from street supply)
Units: dmnl

(112) Effect of street supply on PONHA addiction rate= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for PONHA addiction rate from street supply)
Units: dmnl

(113) Effect of street supply on PONHA initiation= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for PONHA initiation from street supply)
Units: dmnl

(114) Effect of street supply on quits of addicted PONHA= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for addicted PONHA quits from street supply)
Units: dmnl

(115) Effect of street supply on quits of casual PONHA= MAX(0, 1 + (Street supply coverage/Street supply coverage initial - 1)*Slope for casual PONHA quits from street supply)
Units: dmnl

(116) Effect of treatment on frequency of use for H addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Frequency of use multiplier for treated H addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Frequency of use multiplier for treated H addicts)
Units: dmnl

(117) Effect of treatment on frequency of use for opioid addicts overall= (Effect of treatment on frequency of use for H addicts*Addicted H users + Effect of treatment on frequency of use for PO addicts*(Total opioid addicts-Addicted H users)) / Total opioid addicts
Units: dmnl

(118) Effect of treatment on frequency of use for PO addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Frequency of use multiplier for treated PO addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Frequency of use multiplier for treated PO addicts)
Units: dmnl

(119) Effect of treatment on quits of H addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Quit multiplier for treated H addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Quit multiplier for treated H addicts)
Units: dmnl

(120) Effect of treatment on quits of PONHA addicts= (1-Opioid addiction treatment rate+Opioid addiction treatment rate*Quit multiplier for treated PO addicts) / (1-Opioid addiction treatment rate initial+Opioid addiction treatment rate initial*Quit multiplier for treated PO addicts)
Units: dmnl

(121) Effectiveness of naloxone use by laypersons= 0.9
Units: dmnl

(122) Exponent for med user addiction rate from script strength= 0.655
Units: dmnl

(123) Fatality of opioid ODs absent naloxone= 0.1
Units: dmnl

(124) Fent boost of H user OD deaths= Fent boost of H user OD deaths 2017 * Fent boost of H user OD deaths reltv to 2017
Units: dmnl

(125) Fent boost of H user OD deaths 2017= 3.1
Units: dmnl

(126) Fent boost of H user OD deaths reltv to 2017= Fent boost of H user OD deaths reltv to 2017 series(Time)
Units: dmnl

(127) Fent boost of H user OD deaths reltv to 2017 series([(1990,0)-(2020,4)],(2000,0),(2010,0),(2012,0.05),(2015,0.45),(2017,1),(2020,1.25))
Units: dmnl

(128) Fent multiplier on H user OD deaths= 1 + Fent boost of H user OD deaths
Units: dmnl

(129) Frac of addicted PO abusers with their own script= 0.2
Units: dmnl

(130) Frac of casual PO NMU with their own script= 0.12
Units: dmnl

(131) Frac of H addicts also PO abusers= Addicted HPPOU/Addicted H users
Units: dmnl

(132) Frac of H initiates started with PO abuse= PONHA move to heroin/H initiates
Units: dmnl

(133) Frac of H user OD deaths from fentanyl= (Fent multiplier on H user OD deaths-1)/Fent multiplier on H user OD deaths
Units: dmnl

(134)   Frac of H users also PO abusers= HPPOU/H users
         Units: dmnl

(135)   Frac of HPPOU OD deaths also involving PO= 0.25
         Units: dmnl

(136)   Frac of opioid OD deaths from fentanyl= Opioid OD deaths involving fentanyl/Total opioid OD
         deaths
         Units: dmnl

(137)   Frac of opioid OD deaths in ED series([(1990,0.2)-
         (2020,1)],(1990,0.345),(1999,0.347),(2000,0.346),(2001,0.34), (2002,0.326),(2003,0.316),
         (2004,0.305),(2005,0.3),(2006,0.301),(2007,0.286),(2008,0.27),(2009,0.265),(2010,0.274),
         (2011,0.28),(2012,0.271),(2013,0.27),(2014,0.266),(2015,0.268),(2020,0.27))
         Units: dmnl

(138)   Frac of opioid ODs reversed by EMS ED initial= Frac of opioid OD deaths in ED series(1990) *
         Ratio of ED overdose frac to ED death frac
         Units: dmnl

(139)   Frac of opioid ODs reversed by laypersons= Frac of opioid ODs reversed by naloxone - Frac of
         opioid ODs seen in ED
         Units: dmnl

(140)   Frac of opioid ODs reversed by naloxone= Frac of opioid ODs seen in ED + (1-Frac of opioid ODs
         seen in ED)*Distribution of naloxone to laypersons*Effectiveness of naloxone use by
         laypersons
         Units: dmnl

(141)   Frac of opioid ODs reversed by naloxone initial= Frac of opioid ODs reversed by EMS ED initial +
         (1-Frac of opioid ODs reversed by EMS ED initial)*Distribution of naloxone to laypersons
         series(1990)*Effectiveness of naloxone use by laypersons
         Units: dmnl

(142)   Frac of opioid ODs seen in ED= Frac of opioid OD deaths in ED series(Time) * Ratio of ED
         overdose frac to ED death frac
         Units: dmnl

(143)   Frac of PO abuser OD deaths from fentanyl= 1 - Frac of PONHA OD deaths from authentic PO
         Units: dmnl

(144)   Frac of PONHA OD deaths from authentic PO= PONHA OD deaths from authentic PO/PONHA OD
         deaths
         Units: dmnl

(145)   Frequency of use multiplier for treated H addicts= 1 + (Frequency of use multiplier for treated
         PO addicts-1)*Reltv effectiveness of treatment for H addicts vs PO addicts

Units: dmnl

(146) Frequency of use multiplier for treated PO addicts= 0.65
Units: dmnl

(147) H frac of opioid abusers= H users/Total opioid abusers
Units: dmnl

(148) H frac of opioid addicts= Addicted H users/Total opioid addicts
Units: dmnl

(149) H initiates= PONHA move to heroin + H user direct initiates
Units: popn/Year

(150) H user direct initiates= H users * H users attract initiates rate
Units: popn/Year

(151) H user frac of adult popn= H users/Popn age 20plus
Units: dmnl

(152) H user OD deaths= Casual HPPOU OD deaths + Addicted HPPOU OD deaths + Casual HNPOU OD
deaths + Addicted HNPOU OD deaths
Units: popn/Year

(153) H user OD deaths per 10k adult popn= H user OD deaths/Popn age 20plus*people per 10k popn
Units: 1/Year

(154) H user overdoses= ZIDZ(H user OD deaths, 1 - Frac of opioid ODs reversed by
naloxone*Effectiveness of naloxone use by laypersons)
Units: popn/Year

(155) H user overdoses per 10k adult popn= H user overdoses/Popn age 20plus*people per 10k popn
Units: 1/Year

(156) H users= HPPOU + HNPOU
Units: popn

(157) H users attract initiates rate= H users attract initiates rate initial * Effect of overdoses on H
direct initiation
Units: 1/Year

(158) H users attract initiates rate initial= 0.073
Units: 1/Year

(159) Heroin mgs ME per mg= 3
Units: mgME/mg

(160) Heroin price per mg ME= Heroin price per pure mg/Heroin mgs ME per mg

Units: dollars/mgME

(161) Heroin price per pure mg= Heroin price per pure mg series(Time)
Units: dollars/mg

(162) Heroin price per pure mg series([(1990,0)-
(2020,1.6)],(1990,1.25),(1993,0.98),(1994,0.95),(1995,1),(1996,0.97),(1997,0.905),
(1998,0.68),(1999,0.79),(2000,0.805),(2001,0.8),(2002,0.67),(2003,0.72),(2004,0.69),
(2005,0.58),(2006,0.625),(2007,0.595),(2008,0.599),(2009,0.476),(2010,0.553),(2011,0.447),
(2013,0.516),(2015,0.41),(2016,0.38),(2017,0.36),(2020,0.36))
Units: dollars/mg

(163) HNPOU= Casual HNPOU + Addicted HNPOU
Units: popn

(164) HNPOU frac of adult popn initial= 0.0009
Units: dmnl

(165) HPPOU= Casual HPPOU + Addicted HPPOU
Units: popn

(166) HPPOU deaths from authentic PO= HPPOU OD deaths * Frac of HPPOU OD deaths also involving
PO * Frac of PONHA OD deaths from authentic PO
Units: popn/Year

(167) HPPOU drop PO use rate= 0.091
Units: 1/Year

(168) HPPOU frac of adult popn initial= 0.0005
Units: dmnl

(169) HPPOU OD deaths= Casual HPPOU OD deaths + Addicted HPPOU OD deaths
Units: popn/Year

(170) Illicit opioid OD deaths= H user OD deaths + PONHA OD deaths from disguised Fent
Units: popn/Year

(171) Illicit opioid OD deaths per H user= Illicit opioid OD deaths/HPPOU
Units: 1/Year

(172) Inflow of disguised Fent pill apparent gms ME= Inflow of disguised Fent pill apparent mgs ME
per adult 2016/mgs per gram* Popn age 20plus * Inflow of disguised Fent pills reltv to 2016
Units: gramsME/Year

(173) Inflow of disguised Fent pill apparent mgs ME per adult 2016= 25
Units: mgsME/(popn*Year)

(174)   Inflow of disguised Fent pills reltv to 2016= Inflow of disguised Fent pills reltv to 2016
        series(Time)
        Units: dmnl

(175)   Inflow of disguised Fent pills reltv to 2016 series([(1990,0)-
        (2020,4)],(2000,0),(2010,0),(2012,0),(2013,0.01),(2014,0.12),(2015,0.41),(2016,1),(2017,1.3),(2
        018,1.5),(2020,1.6))
        Units: dmnl

(176)   Injecting frac of addicted PONHA= Injecting frac of addicted PONHA series(Time)
        Units: dmnl

(177)   Injecting frac of addicted PONHA initial= INITIAL(Injecting frac of addicted PONHA)
        Units: dmnl

(178)   Injecting frac of addicted PONHA series([(1990,0)-
        (2020,0.4)],(1990,0.18),(1994,0.18),(1995,0.175),(1996,0.167), (1997,0.162),(1998,0.148),
        (1999,0.143),(2000,0.138),(2001,0.132),(2002,0.13),(2003,0.122),(2004,0.117),(2005,0.12),
        (2006,0.113),(2007,0.102),(2008,0.111),(2009,0.126),(2010,0.144),(2011,0.162),(2012,0.17),
        (2013,0.181),(2014,0.177),(2015,0.19),(2020,0.19))
        Units: dmnl

(179)   Med use past mo frac 2010 age 20to39= 0.047
        Units: dmnl

(180)   Med use past mo frac 2010 age 40to59= 0.081
        Units: dmnl

(181)   Med use past mo frac 2010 age 60plus= 0.079
        Units: dmnl

(182)   Med use past mo frac of age 20plus= Med use past mo frac of age 20plus 2010 at current age
        dist * Script volume multiplier vs 1995/Script volume multiplier vs 1995 in 2010
        Units: dmnl

(183)   Med use past mo frac of age 20plus 2010 at 1995 age dist= (Med use past mo frac 2010 age
        20to39*Popn age 20to39 1995 + Med use past mo frac 2010 age 40to59*Popn age 40to59
        1995 + Med use past mo frac 2010 age 60plus*Popn age 60plus 1995)/(Popn age 20to39
        1995+Popn age 40to59 1995+Popn age 60plus 1995)
        Units: dmnl

(184)   Med use past mo frac of age 20plus 2010 at current age dist= (Med use past mo frac 2010 age
        20to39*Popn age 20to39 + Med use past mo frac 2010 age 40to59*Popn age 40to59 + Med
        use past mo frac 2010 age 60plus*Popn age 60plus)/Popn age 20plus
        Units: dmnl

(185)   Med user become addicted rate= Med user become addicted rate initial * Effect of script
        strength on med user addiction rate

Units: 1/Year

(186)   Med user become addicted rate initial= 0.003
         Units: 1/Year

(187)   Med user become casual abuser rate= 0.018
         Units: 1/Year

(188)   Med user frac of addicted PONHA= DELAY1(Med user frac of new addicted PONHA, 1/(Casual
           PONHA become addicted rate +Casual PONHA quit rate))
         Units: dmnl

(189)   Med user frac of casual PO abusers= DELAY1(Med user frac of new casual PO abusers,
           1/Addicted PONHA quit rate)
         Units: dmnl

(190)   Med user frac of new addicted PONHA= Medical users become addicted/New addicted PONHA
         Units: dmnl

(191)   Med user frac of new casual PO abusers= Med users become casual abusers/New casual PO
           abusers
         Units: dmnl

(192)   Med user frac of PONHA= (Med user frac of addicted PONHA*Addicted PONHA + Med user frac
           of casual PO abusers*Casual PONHA)/PONHA
         Units: dmnl

(193)   Med users become casual abusers= Med users past mo * Med user become casual abuser rate
         Units: popn/Year

(194)   Med users past mo= Popn age 20plus * Med use past mo frac of age 20plus
         Units: popn

(195)   Medical users become addicted= Med users past mo * Med user become addicted rate
         Units: popn/Year

(196)   mgs per gram= 1000
         Units: mgsME/gramsME

(197)   Min avg street price= 0.5
         Units: dollars/mgME

(198)   months per yr= 12
         Units: months/Year

(199)   New addicted PONHA= Medical users become addicted + Casual PONHA become addicted
         Units: popn/Year

(200)   New casual PO abusers= PO abuse initiates + Med users become casual abusers
         Units: popn/Year

(201)   New street supply authentic= Script gms ME * Diverted frac of script gms ME
         Units: gramsME/Year

(202)   Noninjecting nonoral frac of addicted PONHA= Noninjecting nonoral frac of addicted PONHA
             series(Time)
         Units: dmnl

(203)   Noninjecting nonoral frac of addicted PONHA initial= INITIAL(Noninjecting nonoral frac of
             addicted PONHA)
         Units: dmnl

(204)   Noninjecting nonoral frac of addicted PONHA series(
             [(1990,0)-(2020,0.4)],(1990,0.09),(1994,0.09),(1995,0.095),(1996,0.094),
             (1997,0.089),(1998,0.074),(1999,0.074),(2000,0.085),(2001,0.105),(2002,0.115),(2003,0.142),(
             2004,0.153),(2005,0.162),(2006,0.178),(2007,0.188),(2008,0.198),(2009,0.214),(2010,0.238),(2
             011,0.253),(2012,0.245),(2013,0.23),(2014,0.205),(2015,0.21),(2020,0.21))
         Units: dmnl

(205)   Nonoral frac of addicted PONHA= Injecting frac of addicted PONHA + Noninjecting nonoral frac
             of addicted PONHA
         Units: dmnl

(206)   Nonoral frac of addicted PONHA initial= INITIAL(Nonoral frac of addicted PONHA)
         Units: dmnl

(207)   Nonoral frac of casual PONHA= Noninjecting nonoral frac of addicted PONHA * Reltv
             noninjecting nonoral frac for casual PONHA vs addicted
         Units: dmnl

(208)   Nonoral frac of casual PONHA initial= INITIAL(Nonoral frac of casual PONHA)
         Units: dmnl

(209)   OD deaths from authentic PO= PONHA OD deaths from authentic PO + HPPOU deaths from
             authentic PO
         Units: popn/Year

(210)   Opioid abuser frac of adult popn= Total opioid abusers/Popn age 20plus
         Units: dmnl

(211)   Opioid addict frac of adult popn= Total opioid addicts/Popn age 20plus
         Units: dmnl

(212)   Opioid addiction treatment rate= Opioid addiction treatment rate series(Time)
         Units: 1/Year

(213)   Opioid addiction treatment rate initial= INITIAL(Opioid addiction treatment rate)
        Units: 1/Year

(214)   Opioid addiction treatment rate series([(1990,0)-
        (2020,1)],(1990,0.2),(2000,0.2),(2005,0.165),(2007,0.21),(2010,0.265),(2012,0.305),
        (2015,0.39),(2016,0.405),(2017,0.415),(2020,0.45))
        Units: 1/Year

(215)   Opioid addicts treated= Total opioid addicts * Opioid addiction treatment rate
        Units: popn/Year

(216)   Opioid OD deaths for cumul= Accumulation indicator*Total opioid OD deaths
        Units: popn/Year

(217)   Opioid OD deaths involving fentanyl= H user OD deaths*Frac of H user OD deaths from fentanyl
        + PONHA OD deaths from disguised Fent
        Units: popn/Year

(218)   Opioid OD deaths per 10k adult popn= Total opioid OD deaths/Popn age 20plus*people per 10k
        popn
        Units: 1/Year

(219)   Opioid ODs reversed by laypersons= Opioid overdoses * Frac of opioid ODs reversed by
        laypersons
        Units: popn/Year

(220)   Opioid ODs reversed by laypersons start 1996= IF THEN ELSE(Time>=Year 1996, Opioid ODs
        reversed by laypersons, 0)
        Units: popn/Year

(221)   Opioid ODs reversed by naloxone= Opioid overdoses * Frac of opioid ODs reversed by naloxone
        Units: popn/Year

(222)   Opioid overdoses= ZIDZ(Total opioid OD deaths, Fatality of opioid ODs absent naloxone*(1-Frac
        of opioid ODs reversed by naloxone))
        Units: popn/Year

(223)   Opioid overdoses seen in ED= Opioid overdoses * Frac of opioid ODs seen in ED
        Units: popn/Year

(224)   Overdoses for cumul= Accumulation indicator*Opioid overdoses
        Units: popn/Year

(225)   people per 10k popn= 10000
        Units: dmnl

(226)   PO abuse initiate rate initial= 0.142
        Units: 1/Year

(227) PO abuse initiates= PO abusers * PO abuse initiation rate
       Units: popn/Year

(228) PO abuse initiation rate= PO abuse initiate rate initial * Effect of street supply on PONHA
       initiation * Effect of overdoses on PONHA initiation
       Units: 1/Year

(229) PO abuser frac of adult popn= PO abusers/Popn age 20plus
       Units: dmnl

(230) PO abuser OD deaths= PONHA OD deaths + HPPOU OD deaths
       Units: popn/Year

(231) PO abuser OD deaths per 10k adult popn= PO abuser OD deaths/Popn age 20plus*people per
       10k popn
       Units: 1/Year

(232) PO abuser street demand gms ME= Casual PO NMU street demand gms ME + Addicted PO
       abuser street demand gms ME
       Units: gramsME/Year

(233) PO abusers= PONHA + HPPOU
       Units: popn

(234) PONHA= Casual PONHA + Addicted PONHA
       Units: popn

(235) PONHA consumption of disguised Fent pills= PO abuser street demand gms ME * Disguised Fent
       frac of street pills supply * Adequacy of street supply coverage
       Units: gramsME/Year

(236) PONHA frac of adult popn initial= 0.027
       Units: dmnl

(237) PONHA frac of med users= PONHA med users/Med users past mo
       Units: dmnl

(238) PONHA med users= Casual PONHA med users + Addicted PONHA med users
       Units: popn

(239) PONHA move to heroin= Casual PONHA move to heroin + Addicted PONHA move to heroin
       Units: popn/Year

(240) PONHA OD deaths= PONHA OD deaths from authentic PO + PONHA OD deaths from disguised
       Fent
       Units: popn/Year

(241)   PONHA OD deaths from authentic PO= Casual PONHA OD deaths from authentic PO + Addicted
          PONHA OD deaths from authentic PO
          Units: popn/Year

(242)   PONHA OD deaths from disguised Fent= Casual PONHA OD deaths from disguised Fent +
          Addicted PONHA OD deaths from disguised Fent
          Units: popn/Year

(243)   PONHA overdoses= ZIDZ(PONHA OD deaths, 1 - Frac of opioid ODs reversed by
          naloxone*Effectiveness of naloxone use by laypersons)
          Units: popn/Year

(244)   PONHA overdoses per 10k adult popn= PONHA overdoses/Popn age 20plus*people per 10k
          popn
          Units: 1/Year

(245)   Popn age 20plus= Popn age 20to39 + Popn age 40to59 + Popn age 60plus
          Units: popn

(246)   Popn age 20to39= Popn age 20to39 mill series(Time)*1e+06
          Units: popn

(247)   Popn age 20to39 1995= Popn age 20to39 mill series(1995)*1e+06
          Units: popn

(248)   Popn age 20to39 mill series([(1990,0)-
          (2030,300)],(1990,82.17),(1995,81.01),(2000,81.63),(2005,82.18),
          (2010,82.99),(2011,83.58),(2012,84.41),(2013,85.32),(2014,86.28),(2015,87.11),(2016,87.98),(
          2017,88.69),(2020,90.31),(2025,92.18),(2030,93.02))
          Units: popn

(249)   Popn age 40to59= Popn age 40to59 mill series(Time)*1e+06
          Units: popn

(250)   Popn age 40to59 1995= Popn age 40to59 mill series(1995)*1e+06
          Units: popn

(251)   Popn age 40to59 mill series([(1990,0)-(2030,300)],(1990,53.14),(1995,62.45),(2000,74.08),
          (2005,82.7),(2010,85.69),(2011,86.05),(2012,86.11),(2013,85.87),(2014,85.46),(2015,85.06),
          (2016,84.54),(2017,84.03),(2020,82.82),(2025,82.43),(2030,85.27))
          Units: popn

(252)   Popn age 60plus= Popn age 60plus mill series(Time)*1e+06
          Units: popn

(253)   Popn age 60plus 1995= Popn age 60plus mill series(1995)*1e+06
          Units: popn

(254) Popn age 60plus mill series([(1990,0)-(2030,300)],(1990,41.71),(1995,43.67),(2000,45.94),
(2005,49.79),(2010,57.47),(2011,59.18),(2012,60.98),(2013,62.8),(2014,64.77),(2015,66.77),
(2016,68.76),(2017,70.85),(2020,77.06),(2025,86.52),(2030,91.17))
Units: popn

(255) Quit multiplier for treated H addicts= 1 + (Quit multiplier for treated PO addicts-1)*Reltv
effectiveness of treatment for H addicts vs PO addicts
Units: dmnl

(256) Quit multiplier for treated PO addicts= 2
Units: dmnl

(257) Ratio of ED overdose frac to ED death frac= 1
Units: dmnl

(258) Ratio of PO street price to heroin price= Avg street price PO/Heroin price per mg ME
Units: dmnl

(259) Ratio of PO street price to heroin price initial= INITIAL(Ratio of PO street price to heroin price)
Units: dmnl

(260) Recent H user overdoses per 10k adult popn= SMOOTH(H user overdoses per 10k adult
popn,Time to perceive overdoses)
Units: 1/Year

(261) Recent H user overdoses per 10k adult popn initial= INITIAL(Recent H user overdoses per 10k
adult popn)
Units: 1/Year

(262) Recent PONHA overdoses per 10k adult popn= SMOOTH(PONHA overdoses per 10k adult
popn,Time to perceive overdoses)
Units: 1/Year

(263) Recent PONHA overdoses per 10k adult popn initial= INITIAL(Recent PONHA overdoses per 10k
adult popn)
Units: 1/Year

(264) Reltv effectiveness of treatment for H addicts vs PO addicts= 0.8
Units: dmnl

(265) Reltv move to heroin rate for nonoral PONHA= 10
Units: dmnl

(266) Reltv noninjecting nonoral frac for casual PONHA vs addicted= 0.19
Units: dmnl

(267) Reltv OD risk for injection use vs oral= 2.7
Units: dmnl

(268)   Reltv OD risk for noninjecting nonoral use vs oral= 2.3
        Units: dmnl

(269)   Reltv PONHA OD risk from disguised Fent pills= 5.19
        Units: dmnl

(270)   Script gms ME= Scripts * Avg mgs ME per script/mgs per gram
        Units: gramsME/Year

(271)   Script gms ME at 1995 rate= Scripts at 1995 rate * Avg mgs ME per script 1995/mgs per gram
        Units: gramsME/Year

(272)   Script gms ME for cumul= Accumulation indicator*Script gms ME
        Units: gramsME/Year

(273)   Script multiplier from popn aging= Med use past mo frac of age 20plus 2010 at current age dist/
          Med use past mo frac of age 20plus 2010 at 1995 age dist
        Units: dmnl

(274)   Script strength multiplier vs 1995= Script strength multiplier vs 1995 series(Time)
        Units: dmnl

(275)   Script strength multiplier vs 1995 series([(1990,0)-(2020,3)],(1990,1.05),(1994,1.048),(1995,1),
          (1996,0.977),(1997,1.051),(1998,1.08),(1999,1.169),(2000,1.174),(2001,1.311),(2002,1.45),
          (2003,1.597),(2004,1.648),(2005,1.62),(2006,1.73),(2007,1.864),(2008,1.81),(2009,1.882),
          (2010,1.976),(2011,2.057),(2012,1.941),(2013,1.895),(2014,1.881),(2015,1.936),(2016,1.854),(
          2017,1.85),(2020,1.85))
        Units: dmnl

(276)   Script volume multiplier vs 1995= Script volume multiplier vs 1995 series(Time)
        Units: dmnl

(277)   Script volume multiplier vs 1995 in 2010= Script volume multiplier vs 1995 series(2010)
        Units: dmnl

(278)   Script volume multiplier vs 1995 series([(1990,0)-(2020,2)],(1990,0.95),(1994,0.95),(1995,1),
          (2000,1.258),(2005,1.526),(2008,1.7),(2010,1.745),(2011,1.728),(2012,1.728),(2013,1.666),
          (2014,1.612),(2015,1.487),(2016,1.43),(2017,1.3),(2018,1.2),(2019,1.1),(2020,1.05))
        Units: dmnl

(279)   Scripts= Scripts at 1995 rate * Script volume multiplier vs 1995
        Units: scripts/Year

(280)   Scripts at 1995 rate= Popn age 20plus * Scripts per age 20plus popn 1995 * Script multiplier
          from popn aging
        Units: scripts/Year

(281)   Scripts per age 20plus popn 1995= 0.67
         Units: scripts/popn/Year

(282)   Slope for addicted H user quits from overdoses= 0
         Units: dmnl

(283)   Slope for addicted PONHA move to heroin from street price= 0.92
         Units: dmnl

(284)   Slope for addicted PONHA quits from overdoses= 0.25
         Units: dmnl

(285)   Slope for addicted PONHA quits from street supply= -0.28
         Units: dmnl

(286)   Slope for avg street price from street supply= -0.61
         Units: dmnl

(287)   Slope for casual H user quits from overdoses= 0
         Units: dmnl

(288)   Slope for casual PONHA move to heroin from street price= 0.78
         Units: dmnl

(289)   Slope for casual PONHA quits from overdoses= 0.35
         Units: dmnl

(290)   Slope for casual PONHA quits from street supply= -0.3
         Units: dmnl

(291)   Slope for diversion of scripts from street supply= -0.38
         Units: dmnl

(292)   Slope for H direct initiation from overdoses= -0.2
         Units: dmnl

(293)   Slope for PONHA addiction rate from street supply= 0.53
         Units: dmnl

(294)   Slope for PONHA initiation from overdoses= -0.75
         Units: dmnl

(295)   Slope for PONHA initiation from street supply= 2.43
         Units: dmnl

(296)   Start date for accumulation= 2020
         Units: Year

(297) Stop date for accumulation= 2030
Units: Year

(298) Street pills supply= Street supply authentic + Disguised Fent pills supply
Units: gramsME

(299) Street supply authentic= INTEG (New street supply authentic-Consumption of street supply
authentic, PO abuser street demand gms ME * Street supply coverage initial)
Units: gramsME

(300) Street supply coverage= Street pills supply/PO abuser street demand gms ME
Units: years

(301) Street supply coverage adequate= 0.13
Units: years

(302) Street supply coverage initial= 0.15
Units: years

(303) Time to perceive overdoses= 0.25
Units: Year

(304) Total opioid abusers= PONHA + H users
Units: popn

(305) Total opioid addicts= Addicted PONHA + Addicted H users
Units: popn

(306) Total opioid OD deaths= PONHA OD deaths + H user OD deaths - HPPOU OD deaths*Frac of
HPPOU OD deaths also involving PO
Units: popn/Year

(307) Year 1996= 1996
Units: Year

****
.Control
****
        Simulation Control Parameters

(308) FINAL TIME = 2030
Units: Year

(309) INITIAL TIME = 1990
Units: Year

(310) SAVEPER = TIME STEP
Units: Year

(311)   TIME STEP = 0.03125
         Units: Year

****
   .Hist
****
           Historical data

(312)   Addicted frac of H users hist:RAW::= X IF MISSING(Addicted H users hist/H users hist,:NA:)
         Units: dmnl

(313)   Addicted frac of PO abusers hist:RAW::= X IF MISSING(Addicted PO abusers hist/PO abusers
           hist,:NA:)
         Units: dmnl

(314)   Addicted H users hist:RAW::= X IF MISSING(Addicted H users mill hist*1e+06,:NA:)
         Units: popn

(315)   Addicted H users mill hist:RAW::= GET XLS DATA('Opioid model inputs and data series
           2u.xlsx','Validation data series','1','B2')
         Units: popn

(316)   Addicted PO abusers hist:RAW::= X IF MISSING(Addicted PO abusers mill hist*1e+06,:NA:)
         Units: popn

(317)   Addicted PO abusers mill hist:RAW::= GET XLS DATA('Opioid model inputs and data series
           2u.xlsx','Validation data series','1','B5')
         Units: popn

(318)   Avg street price PO hist:RAW::= GET XLS DATA('Opioid model inputs and data series
           2u.xlsx','Validation data series','1','B44')
         Units: dollars/mgME

(319)   Frac of H initiates started with PO abuse hist:RAW::= GET XLS DATA('Opioid model inputs and
           data series 2u.xlsx','Validation data series','1','B8')
         Units: dmnl

(320)   Frac of H users also PO abusers hist:RAW::= GET XLS DATA('Opioid model inputs and data series
           2u.xlsx','Validation data series','1','B41')
         Units: dmnl

(321)   H initiates hist:RAW::= X IF MISSING(H initiates mill hist*1e+06,:NA:)
         Units: popn/Year

(322)   H initiates mill hist:RAW::= GET XLS DATA('Opioid model inputs and data series
           2u.xlsx','Validation data series','1','B11')
         Units: popn/Year

(323)   H users hist:RAW::= X IF MISSING(H users mill hist series*1e+06,:NA:)
         Units: popn

(324)   H users mill hist series:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B14')
         Units: popn

(325)   Heroin price per mg hist:RAW::=GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B47')
         Units: dollars/mg

(326)   Illicit opioid OD deaths hist:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B17')
         Units: popn/Year

(327)   OD deaths from authentic PO hist:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B29')
         Units: popn/Year

(328)   Opioid addicts treated hist:RAW::= X IF MISSING(Opioid addicts treated thou hist*1000,:NA:)
         Units: popn/Year

(329)   Opioid addicts treated thou hist:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B20')
         Units: popn/Year

(330)   Opioid overdoses reported by ED hist:RAW::= GET XLS DATA('Opioid model inputs and data
         series 2u.xlsx','Validation data series','1','B64')
         Units: popn/Year

(331)   PO abuse initiates hist:RAW::=X IF MISSING(PO abuse initiates mill hist*1e+06,:NA:)
         Units: popn/Year

(332)   PO abuse initiates mill hist:RAW::=GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B23')
         Units: popn/Year

(333)   PO abusers hist:RAW::= X IF MISSING(PO abusers mill hist*1e+06,:NA:)
         Units: popn

(334)   PO abusers mill hist:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B26')
         Units: popn

(335)   Script gms ME hist:RAW::= X IF MISSING(Script gms ME mill hist*1e+06,:NA:)
         Units: gramsME/Year

(336)   Script gms ME mill hist:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B32')
         Units: gramsME/Year

(337)   Scripts hist:RAW::= X IF MISSING(Scripts mill hist series*1e+06,:NA:)
         Units: scripts/Year

(338)   Scripts mill hist series:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B35')
         Units: scripts/Year

(339)   Total opioid OD deaths hist:RAW::= GET XLS DATA('Opioid model inputs and data series
         2u.xlsx','Validation data series','1','B38')
         Units: popn/Year