Basics of Causal Loop Diagrams

CMPT 858

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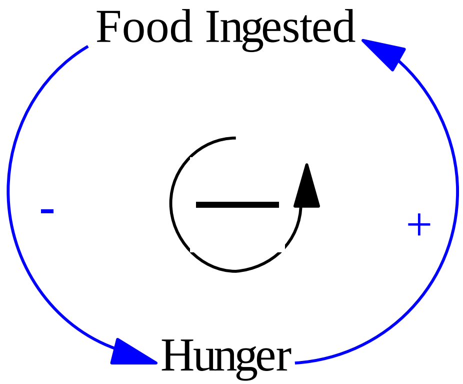
1/25/2011

Causal Loop Diagram



- Focuses on capturing causality – and especially *feedback* effects
- Indicates sign of causal impact (+ vs. –)
  - $x \rightarrow^{+} y$ indicates $\frac{\partial y}{\partial x} > 0$
  - $x \rightarrow^{-} y$ indicates $\frac{\partial y}{\partial x} < 0$

Causal Loop Diagram

- An arrow with a positive sign (+): "all else remaining equal, an increase (decrease) in the first variable increases (decreases) the second variable above (below) what it would otherwise have been."
- An arrow with a negative sign (-): "all else remaining equal, an increase (decrease) in the first variable decreases (increases) the second variable below (above) what it otherwise would have been."

Reasoning about Link Polarity

- Easy to get confused regarding link polarity in the context of a causal pathway
- Tips for reasoning about X→Y link polarity
  - Reason about this link in isolation
    - Do not be concerned about links preceding X or following Y
  - Ask "if X were to INCREASE, would Y increase or decrease *compared to what it would otherwise have been*"?
    - Increase in Y implies "+",decrease in Y implies "-"
    - If answer is not clear or depends on value of X, need to think about representing several paths between X and Y

Consider A → B

- We are reasoning here about <u>*causal*</u> influences
– The changes on B *caused by* changes in A
  - This is not merely an associational relationship
  - This should not merely be a matter of definition
- Notion of "Increase"
  - Must Clearly Distinguish
    - "if X were to INCREASE, would Y increase or decrease *compared to what it would have otherwise been* "?
  - "if X were to INCREASE, would Y increase or decrease *over time*"?
    - i.e. "if X were to INCREASE, would Y rise or fall *over time*"?

Reminder

- An arrow with a positive sign (+): "all else remaining equal, an increase (decrease) in the first variable increases (decreases) the second variable above (below) what it would otherwise have been."
- An arrow with a negative sign (-): "all else remaining equal, an increase (decrease) in the first variable decreases (increases) the second variable below (above) what it otherwise would have been."

Polarity

- $A \rightarrow^{+} B$ Does *not* mean that if A rises then B will rise *over time*
  - – Just says that B will be higher than it would otherwise have been
  - – B may still be declining over time – but is higher than it otherwise would have been
- $A \rightarrow^{-} B$ Does *not* mean that if A rises then B will decline *over time*
  - – Just says that B will be lower than it would otherwise have been
  - – B may still be risingover time – but is higher than it otherwise would have been

Critical: Notion of "Increase"

- Must Clearly Distinguish
  - Correct Interpretation: "if X were to INCREASE, would Y increase or decrease *compared to what it would have otherwise been*"?
  - Different notion: "if X were to INCREASE, would Y increase or decrease*over time*"?

    i.e. "if X were to INCREASE, would Y rise or fall *over time*"?

Causal Pathways

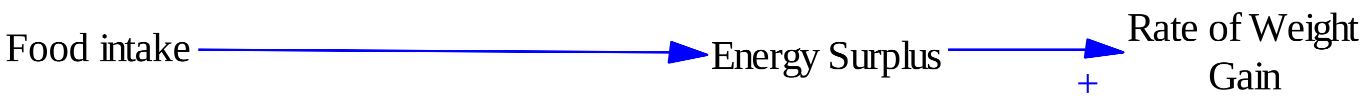
- We can reason about the influence of one variable and another variable by examining the signs along their causal pathway
- Two negatives (whether adjacent or not) will act to reverse each other
  - Consider A $\rightarrow^{-}$ B $\rightarrow^{-}$ C
    - An increase to A leads B to be less than it otherwise would have been
    - B being lower than it otherwise would have been causes C to be higher than it otherwise would have been
- (compared to what it otherwise would have been)

Tips

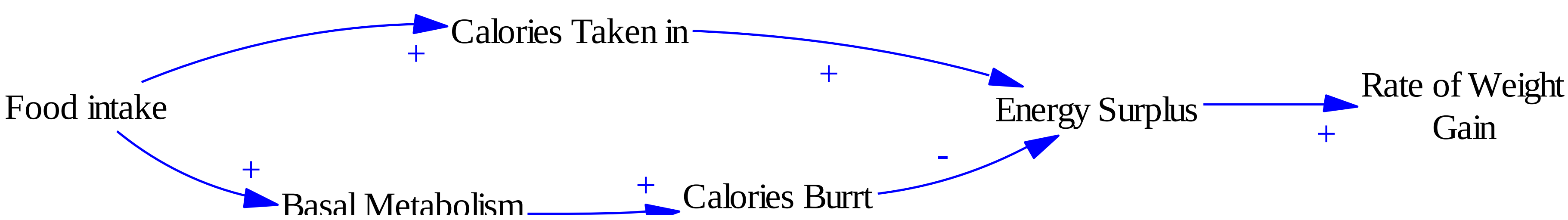
- Variables will often be noun phrases
- Variables should be at least ordinal
- Links should have unambiguous polarity
- Indicate pronounced delays
- Avoid mega-diagrams
- Label loops
- Distinguish perceived and actual situation
- Incorporate targets of balancing loops
- Try to stick to planar graphs
- Diagrams describe causal not casual factors!

Ambiguous Link

- Ambiguous Link: Sometimes +, sometimes -

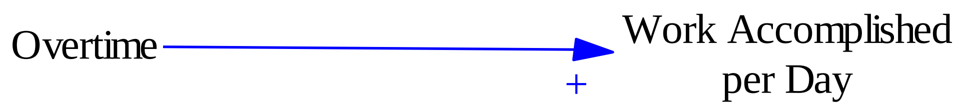


- Replace this by disaggregating causal pathways by showing multiple links



Example 2

- Ambiguous Link: Sometimes +, sometimes –



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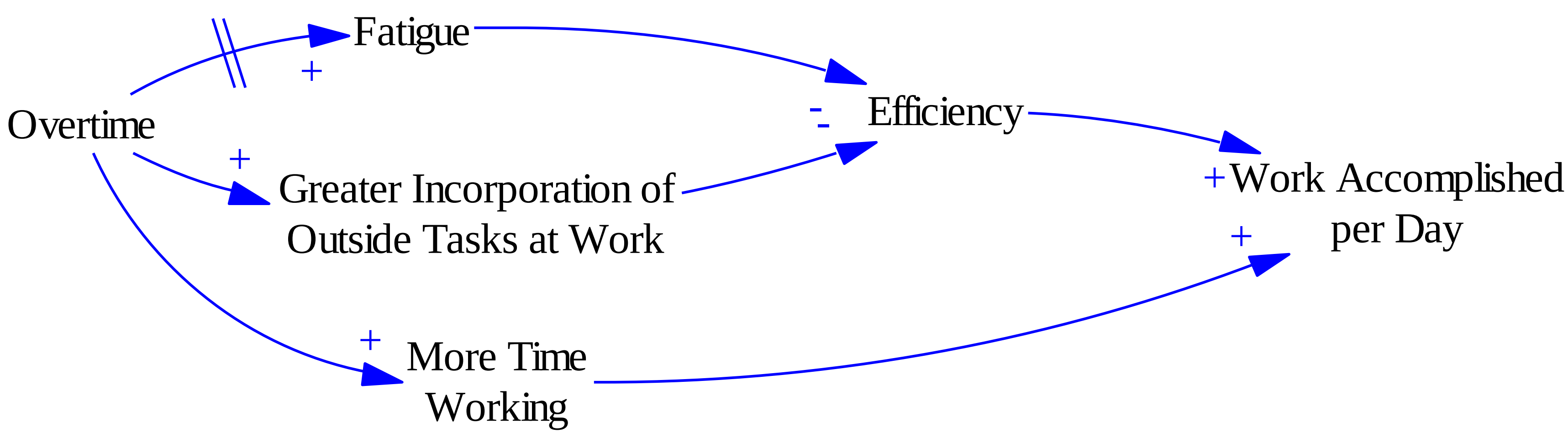
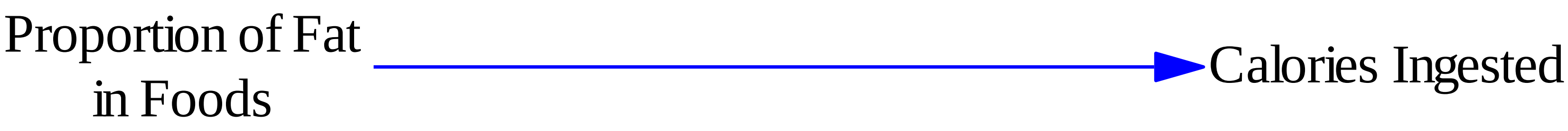


Example 3

- Ambiguous Link: Sometimes +, sometimes -



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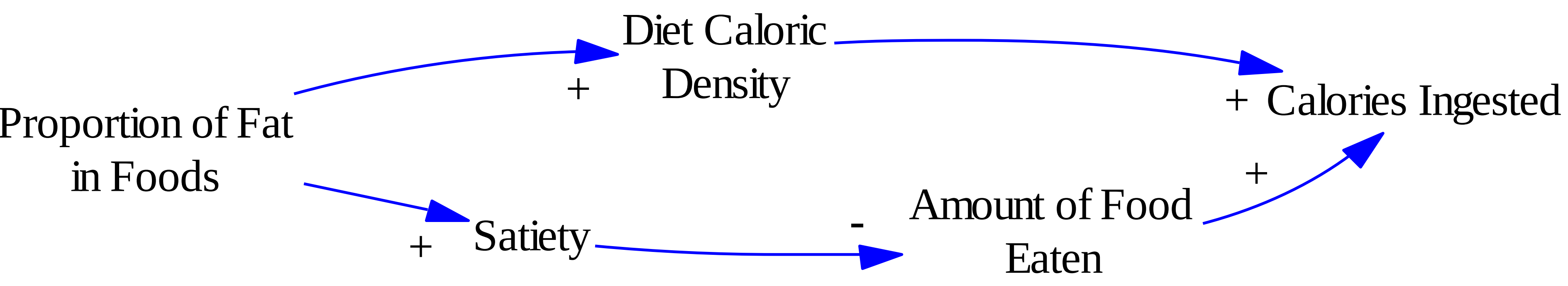
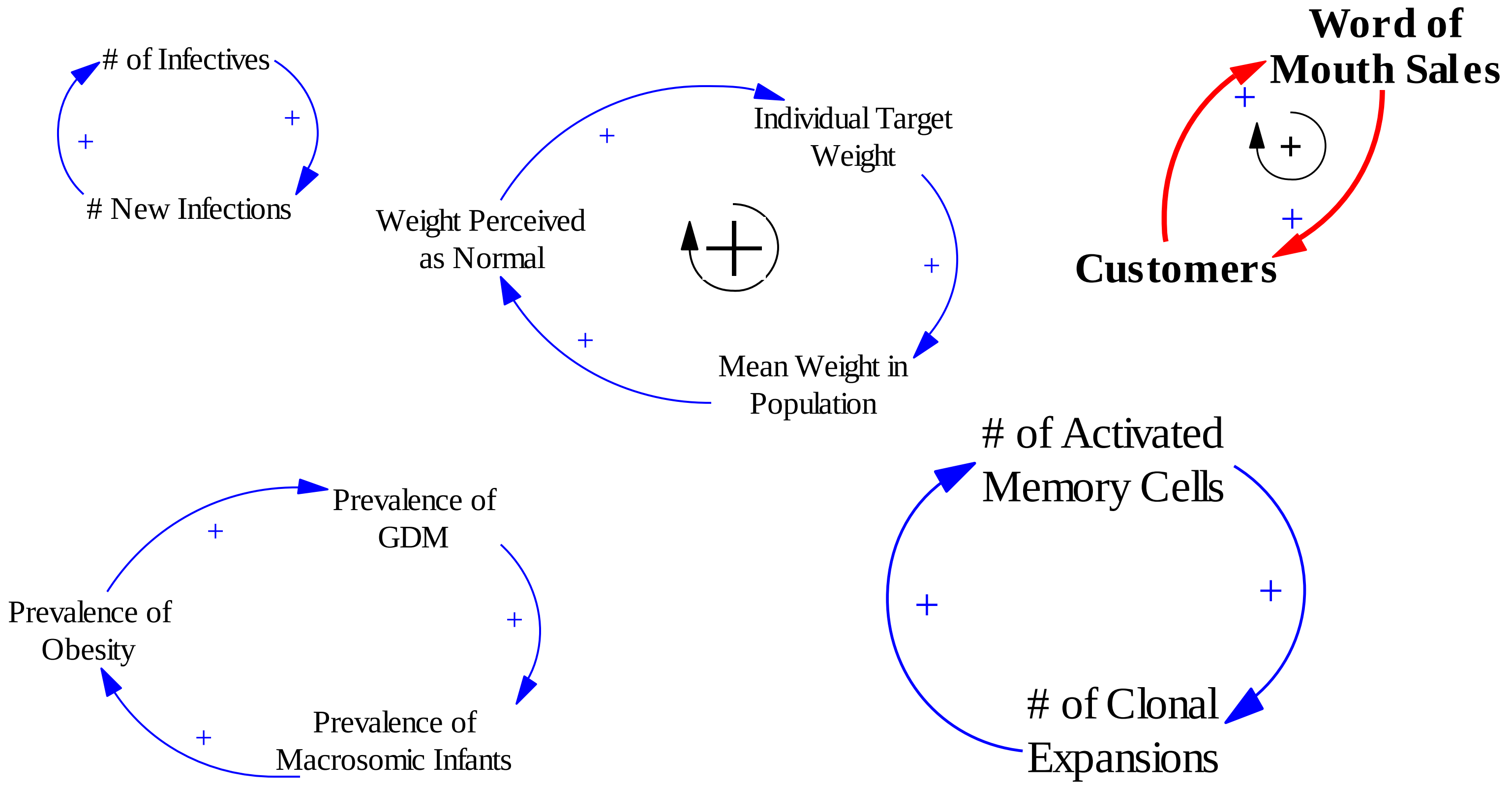


Feedback Loops

- Loops in a causal loop diagram indicate *feedback* in the system being represented
  - Qualitatively speaking, this indicates that a given change kicks off a set of changes that cascade through other factors so as to either amplify (“reinforce”) or push back against (“damp”, “balance”) the original change
- Loop classification: product of signs in loop (best to trace through conceptually)
  - Balancing loop: Product of signs negative
  - Reinforcing loop: Product of signs positive

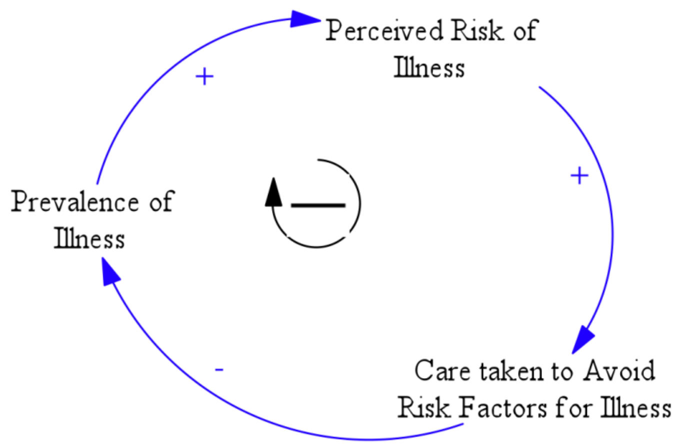
Example Vicious/Virtuous Cycles

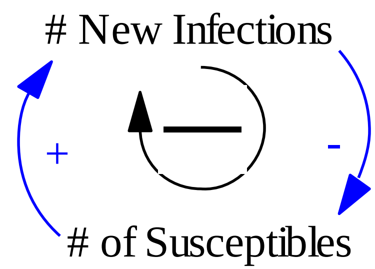
- Positive (reinforcing) feedback can lead to extremely rapid changes in situation

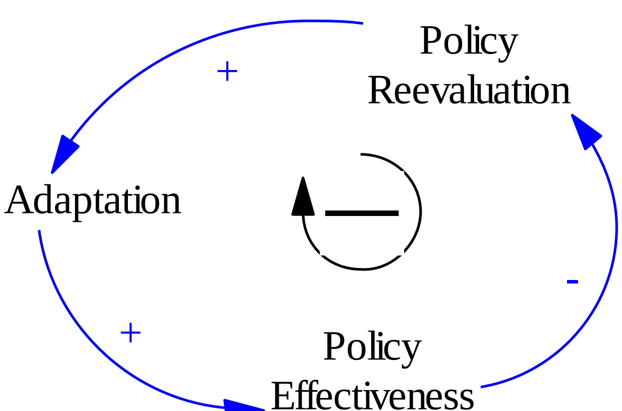


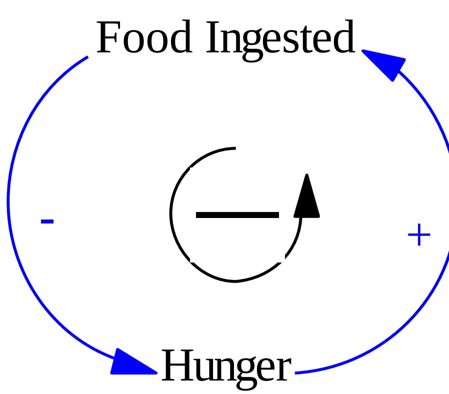
Example “Balancing Loops”

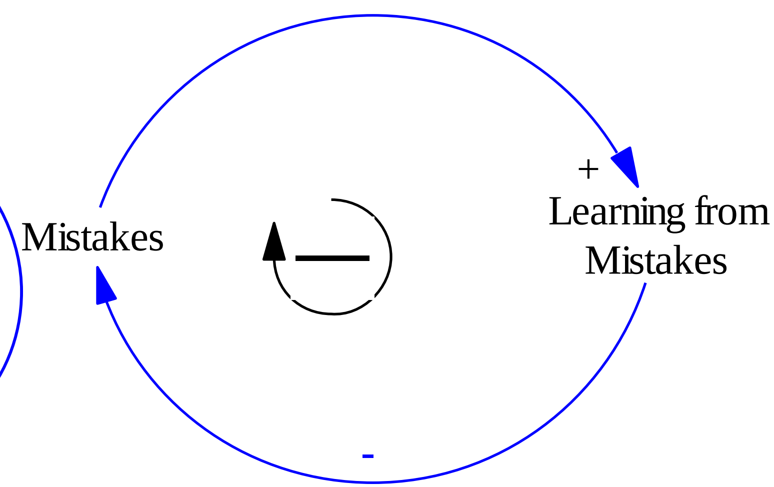
- Balancing loops tend to be self-regulating





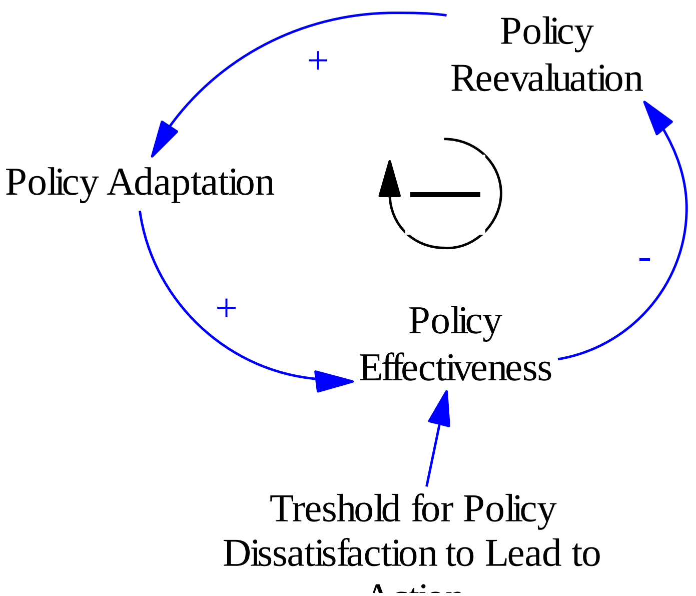


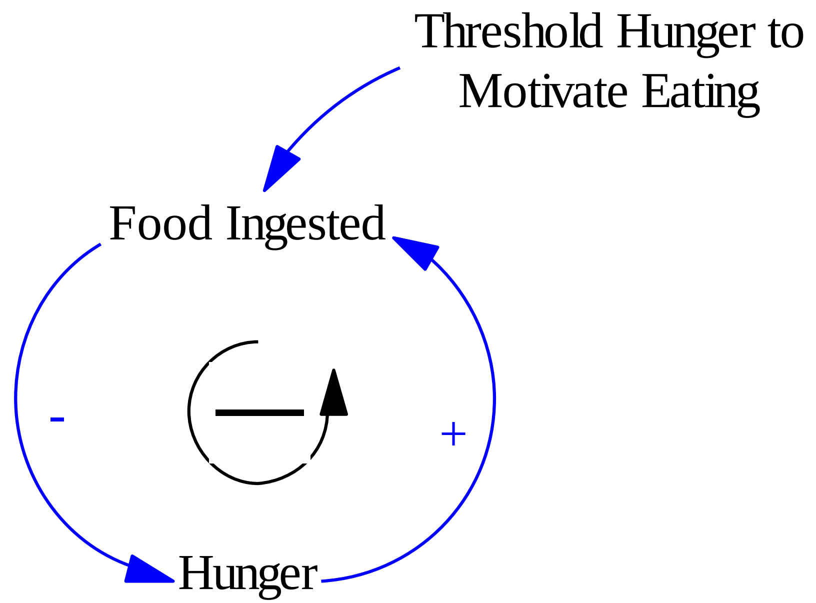




Best Practice: Incorporating Thresholds

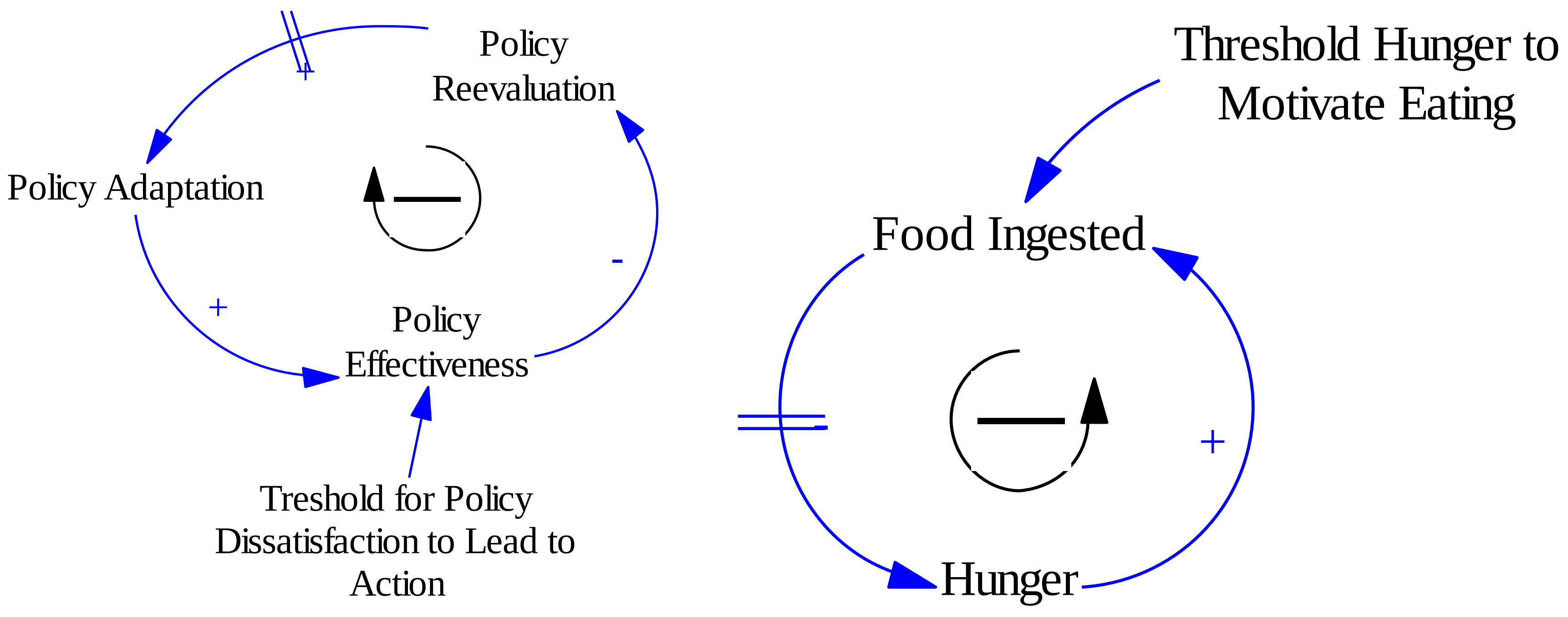
- Balancing loops tend to be self-regulating



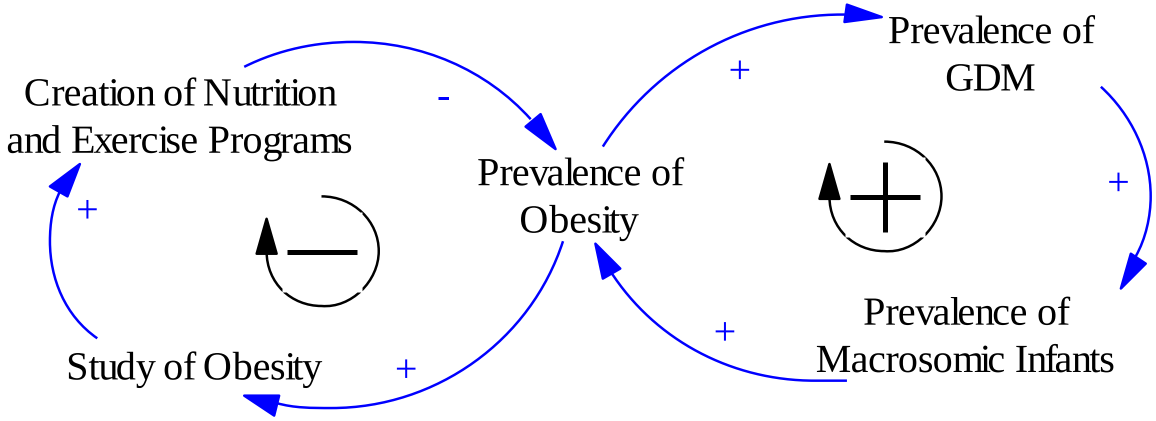


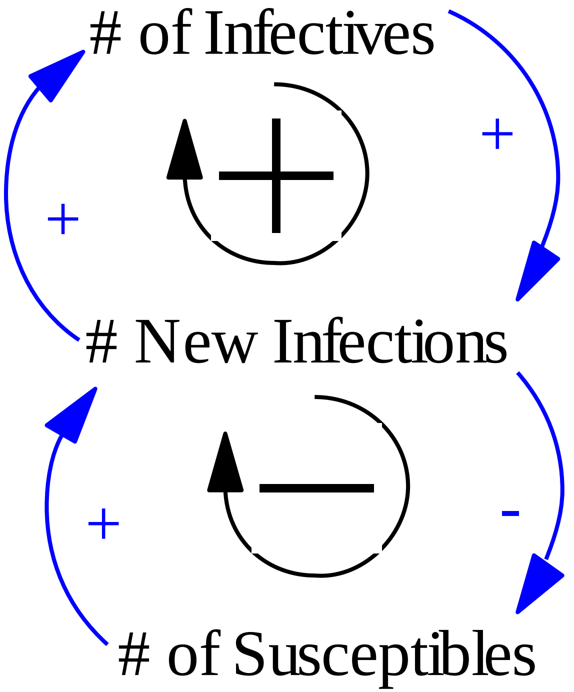
Best Practice: Indicating (Pronounced) Delays

- Balancing loops tend to be self-regulating

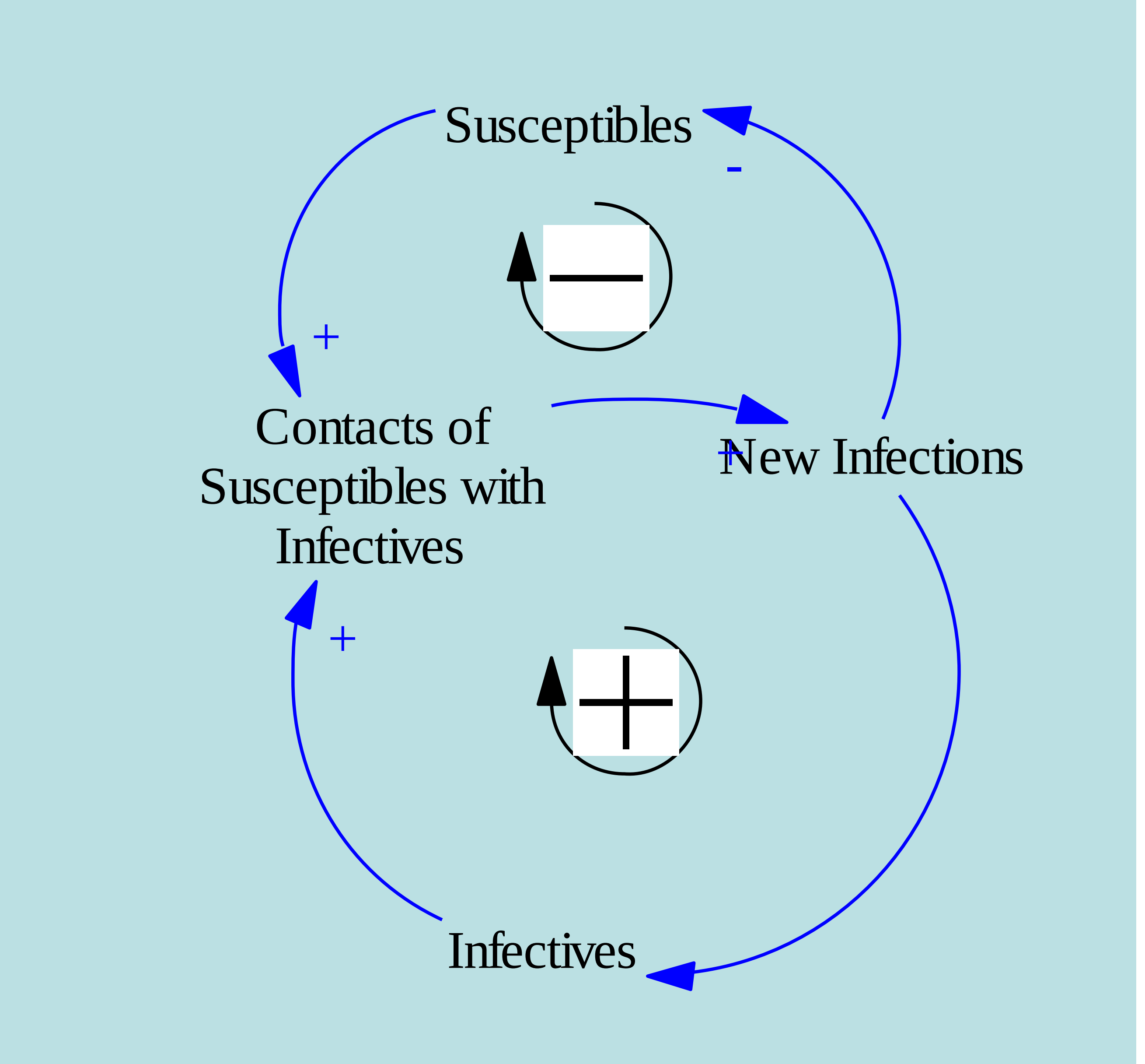


Elaborating Causal Loops

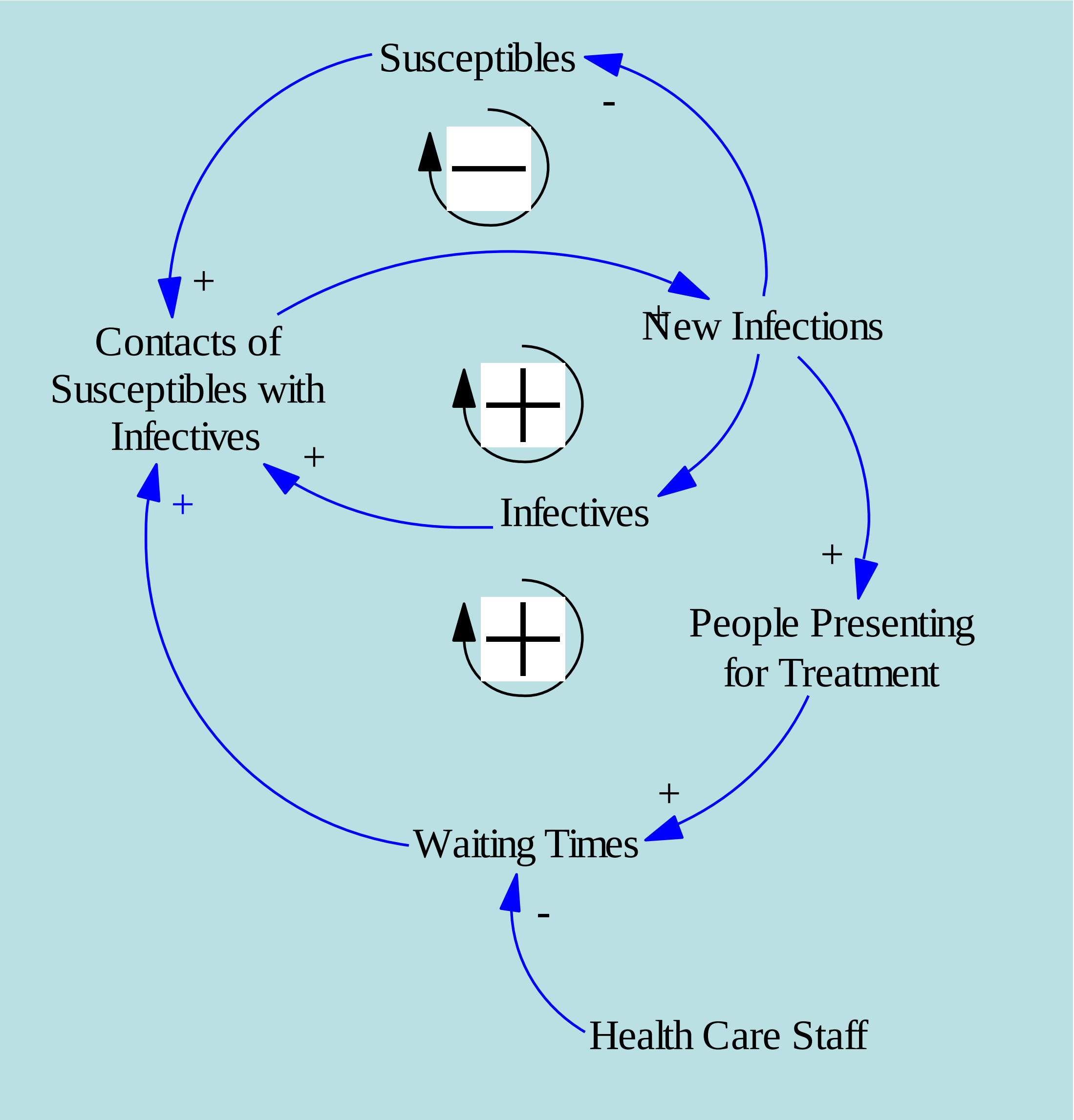




Classic Feedbacks

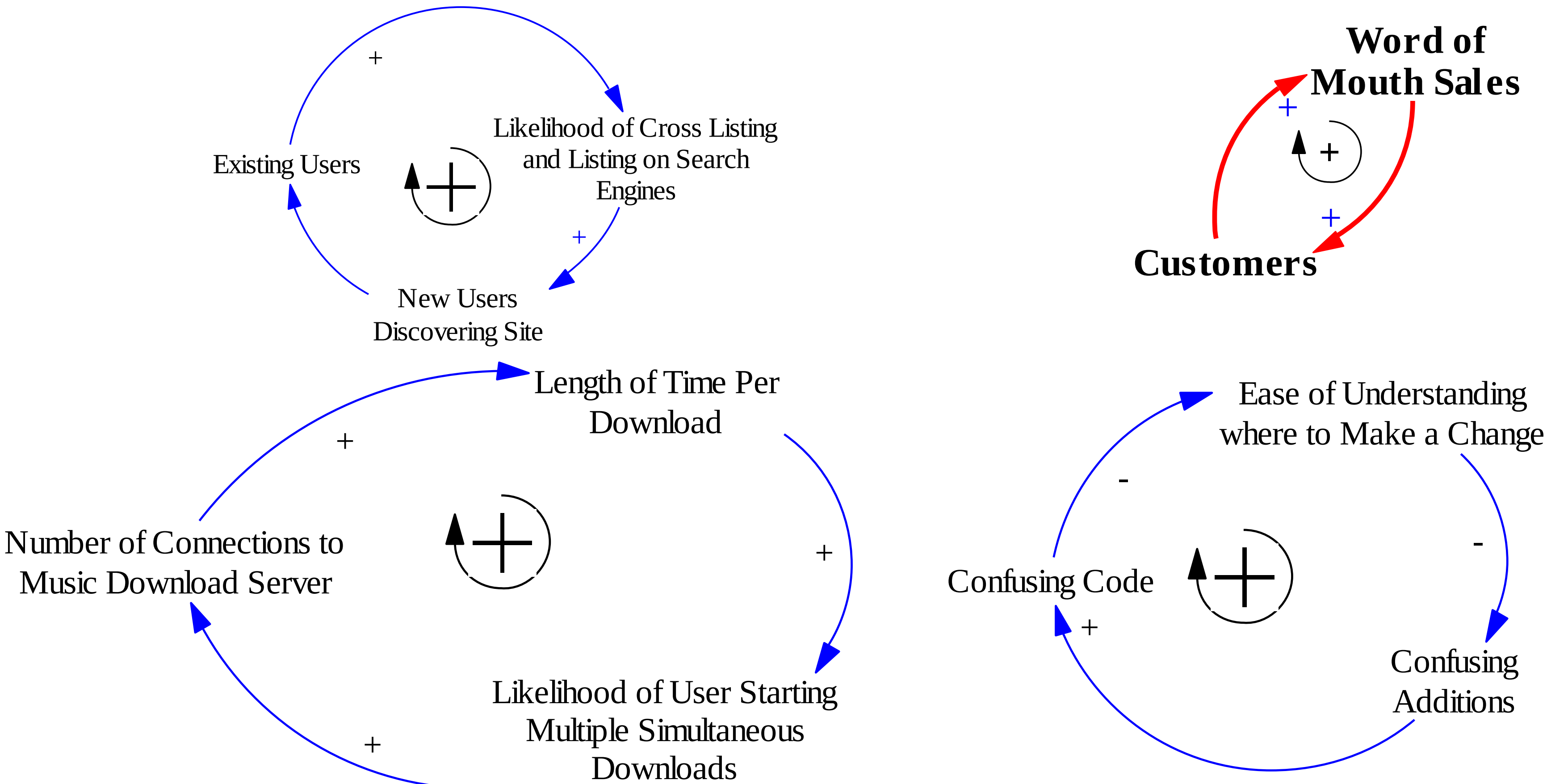


Broadening the Model Boundaries

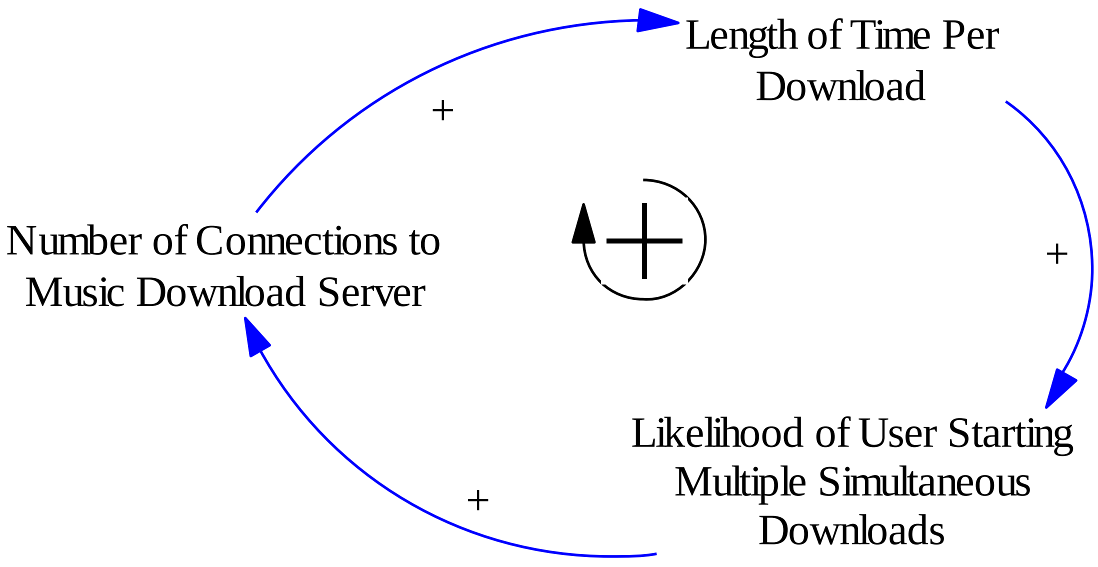


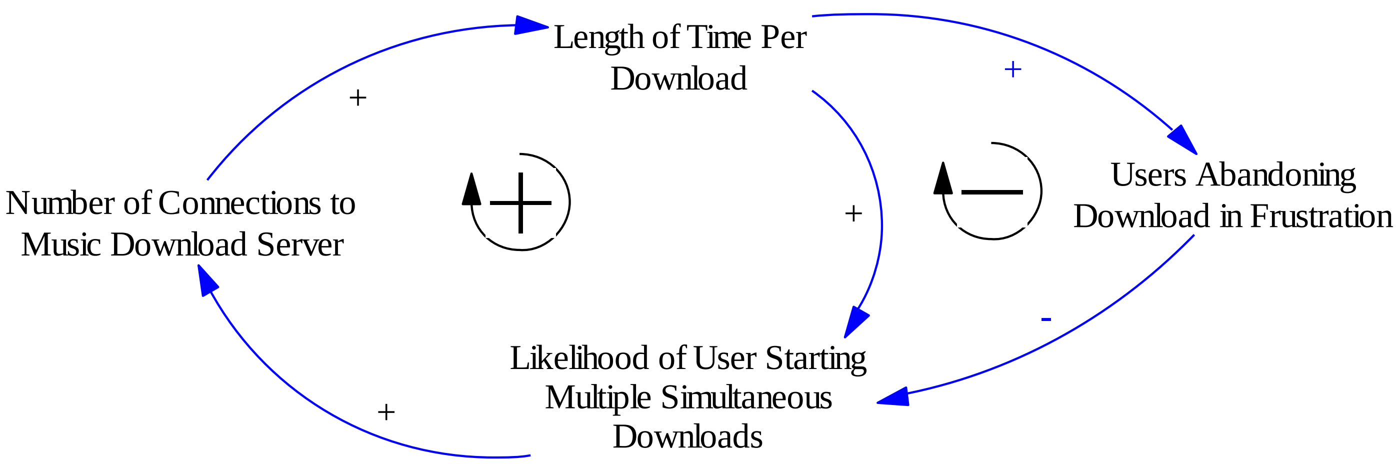
Example Vicious/Virtuous Cycles

- Positive (reinforcing) feedback can lead to extremely rapid changes in situation

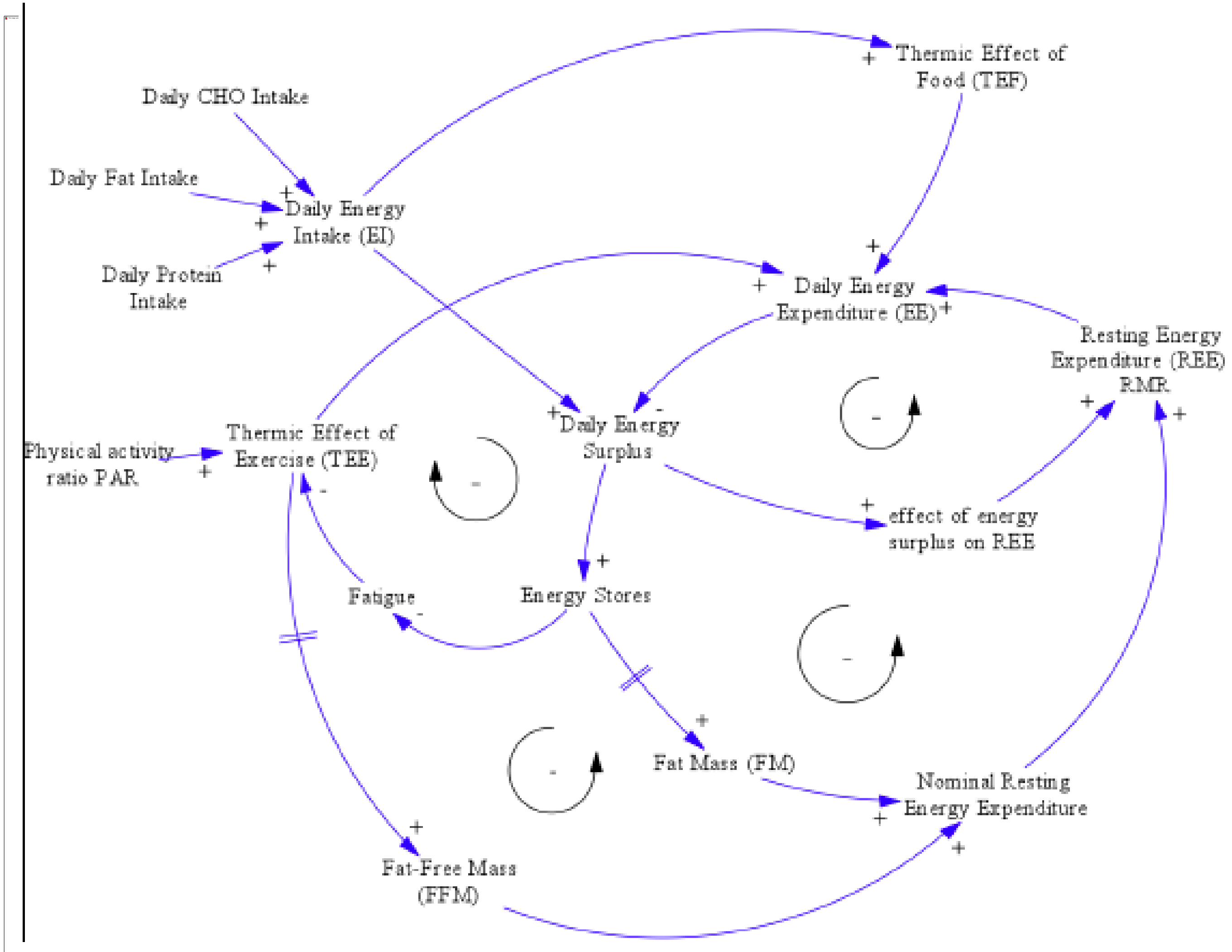


Elaborating Causal Loops



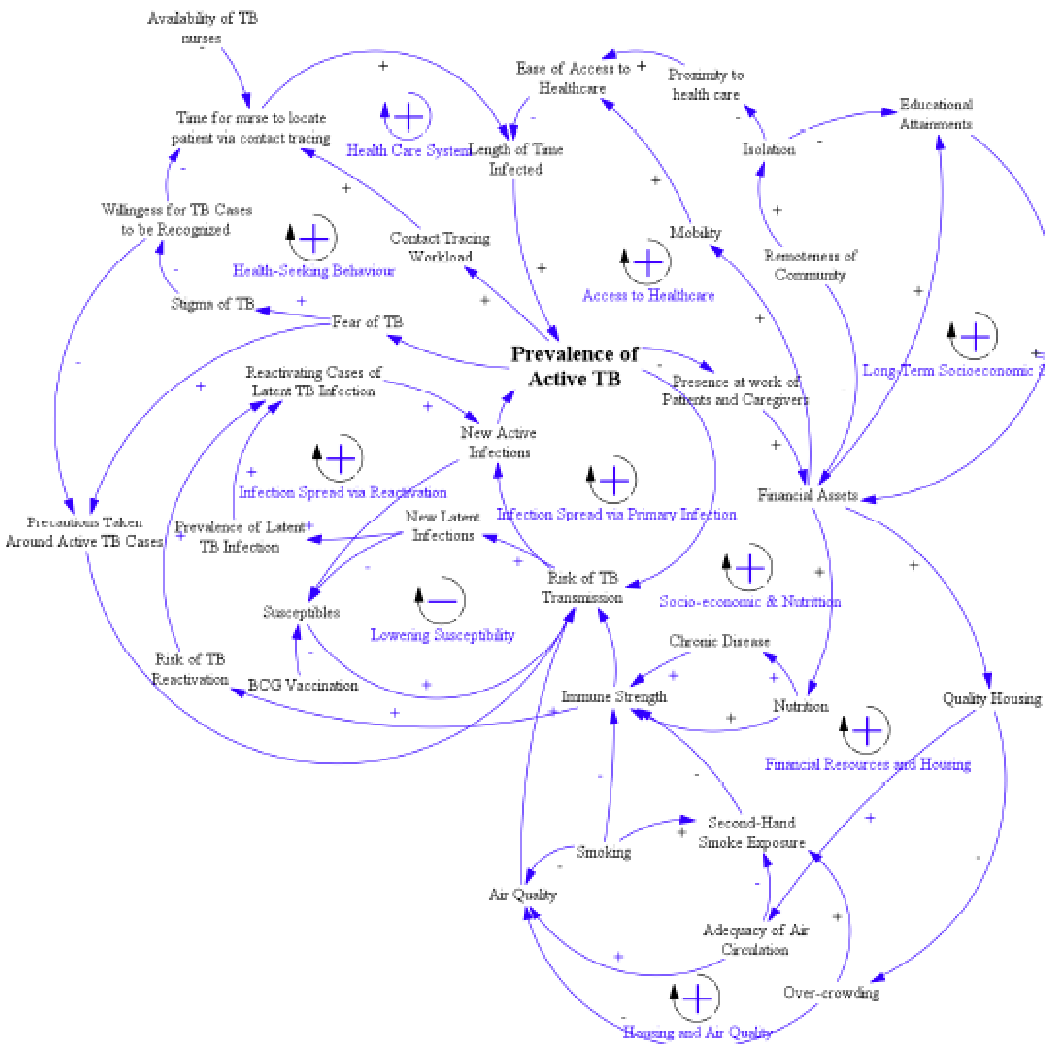


More Elaborate Diagrams



Karanfil, 2008

More Elaborate Diagrams 2



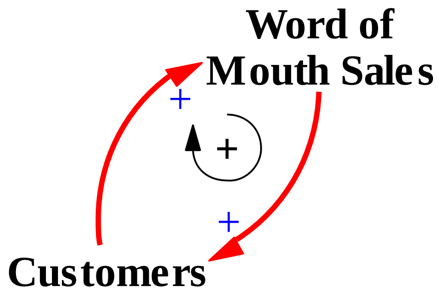
LaVallee& Osgood, 2008

Causal Loop Structure : Dynamic Implications

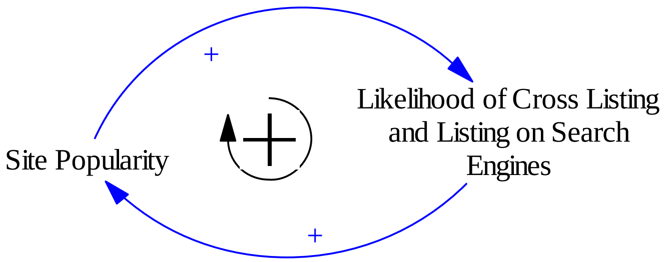
- **Each loop in a causal loop diagram is associated with qualitative dynamic behavior**
- **Most Common Single-Loop Modes of Dynamic Behavior**
  - Exponential growth
  - Goal Seeking Adjustment
  - Oscillation
- **When composed, get novel behaviors due to shifting loop dominance**
  - **Behaviour of system more than sum of parts**

CL Dynamics: Exponential Growth (First Order Reinforcing Loop)

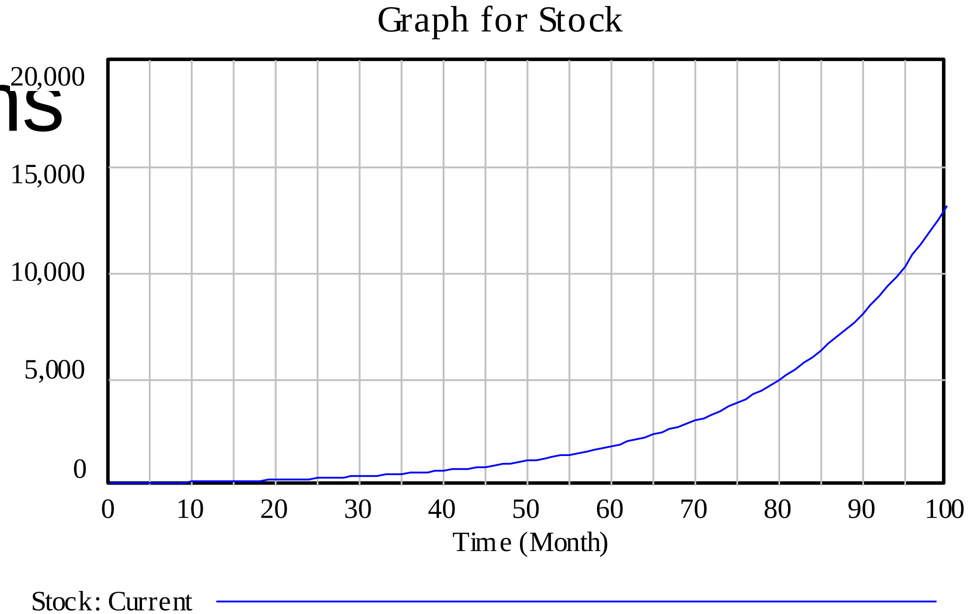
- Example



From Tsai

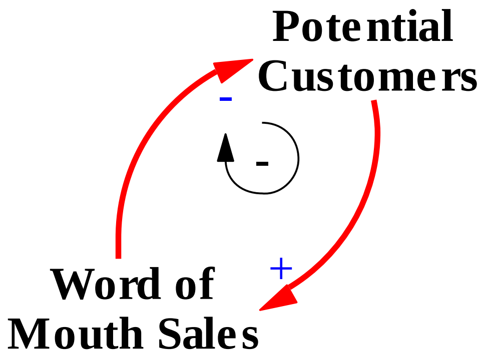


- Dynamic implications



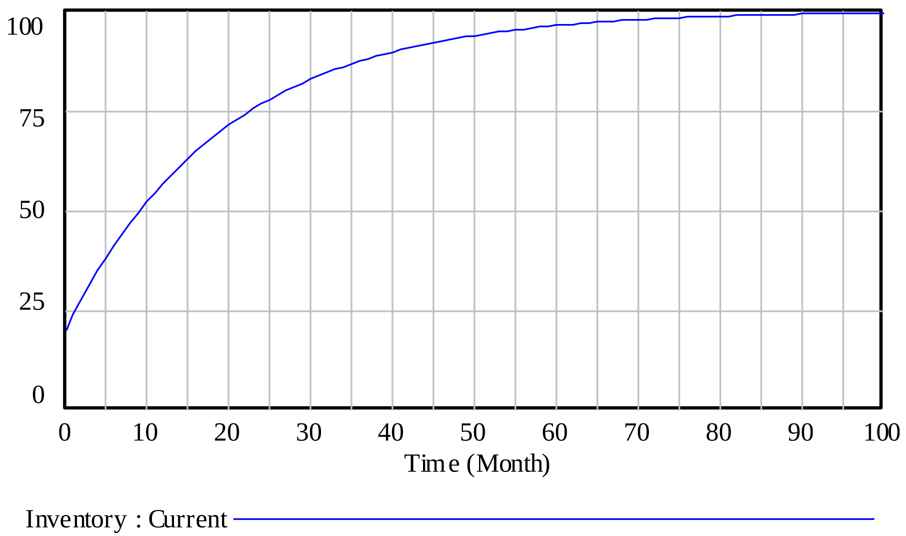
CL Dynamics: Goal Seeking (Balancing Loop)

- Example:



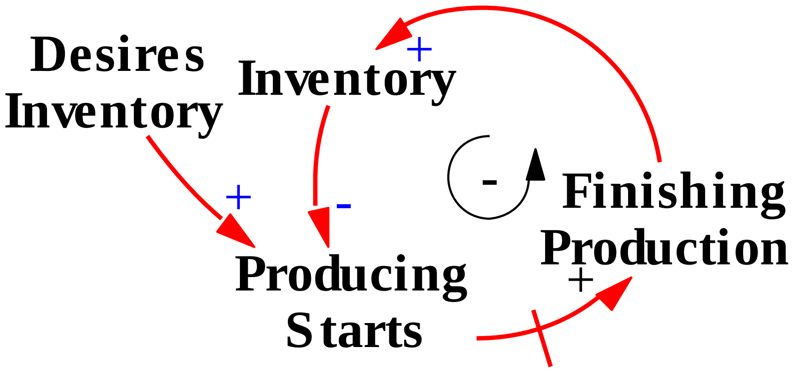
From Tsai

- Dynamic behavior

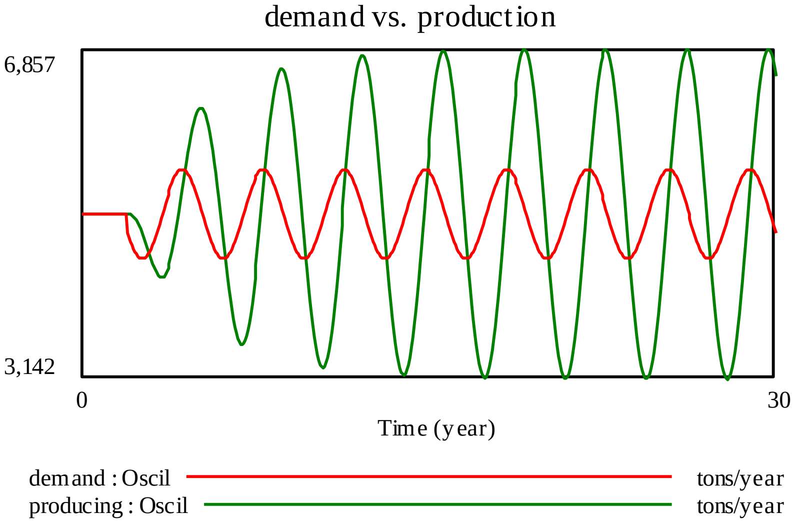


CL Dynamics: Oscillation (Balancing Loop with *Delay*)

- Causal Structure



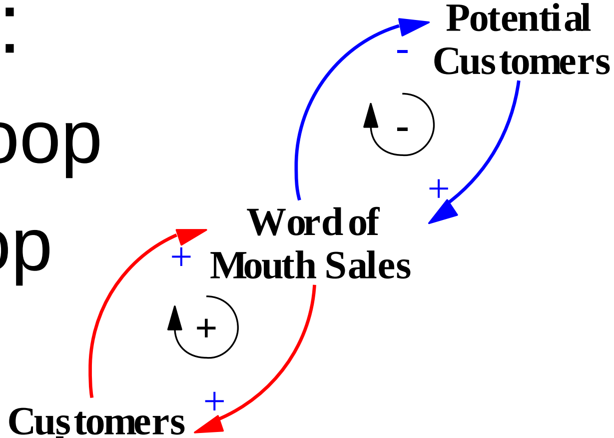
- Dynamic Behavior:

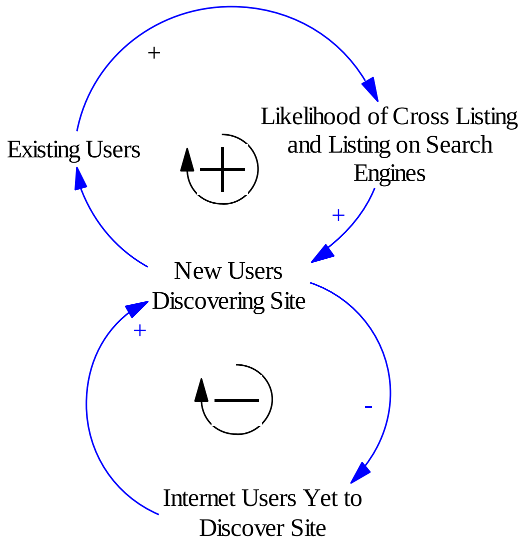


From Tsai

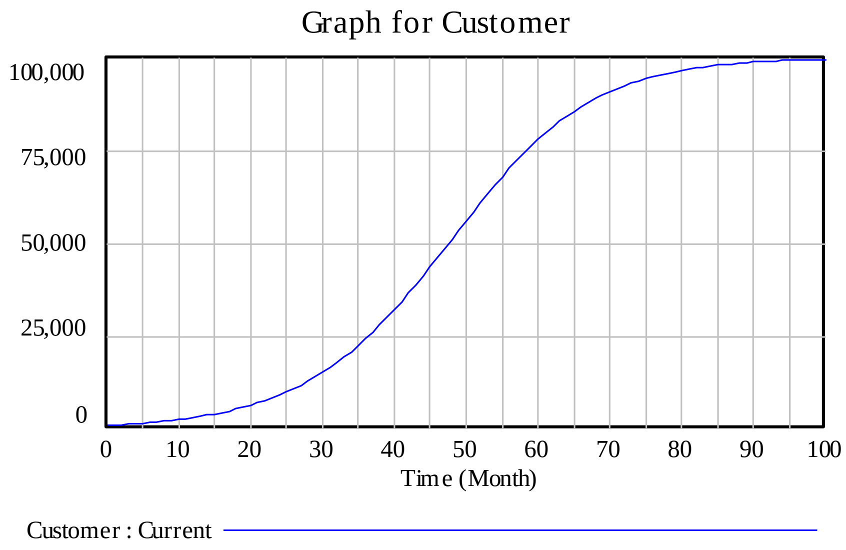
Growth and Plateau

- Loop structure:
  - Reinforcing Loop
  - Balancing Loop



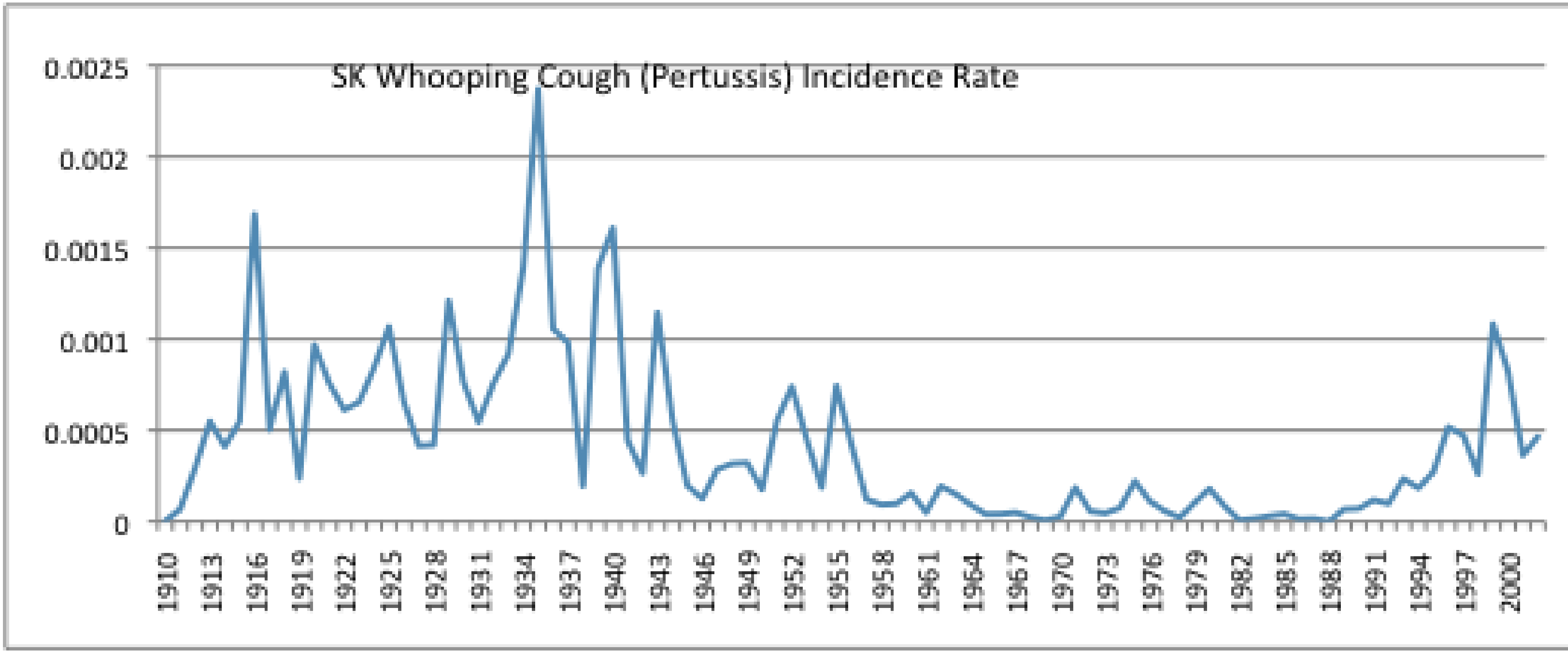


- Dynamic Behavior:

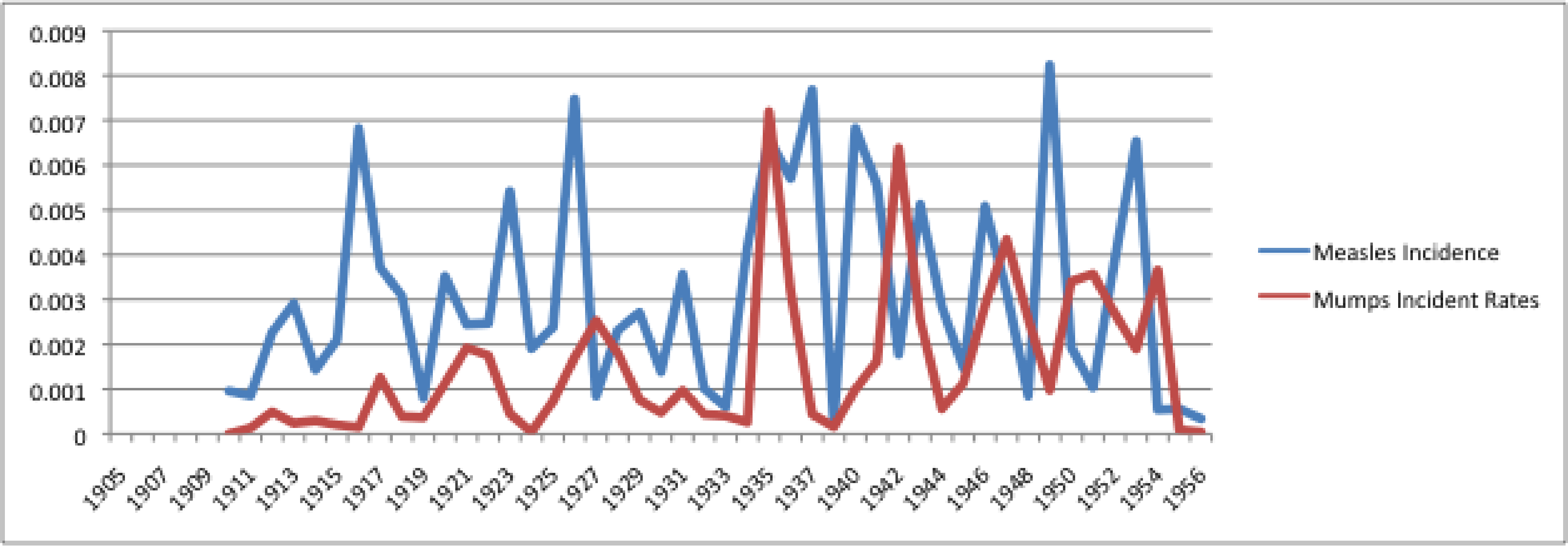


From Tsai

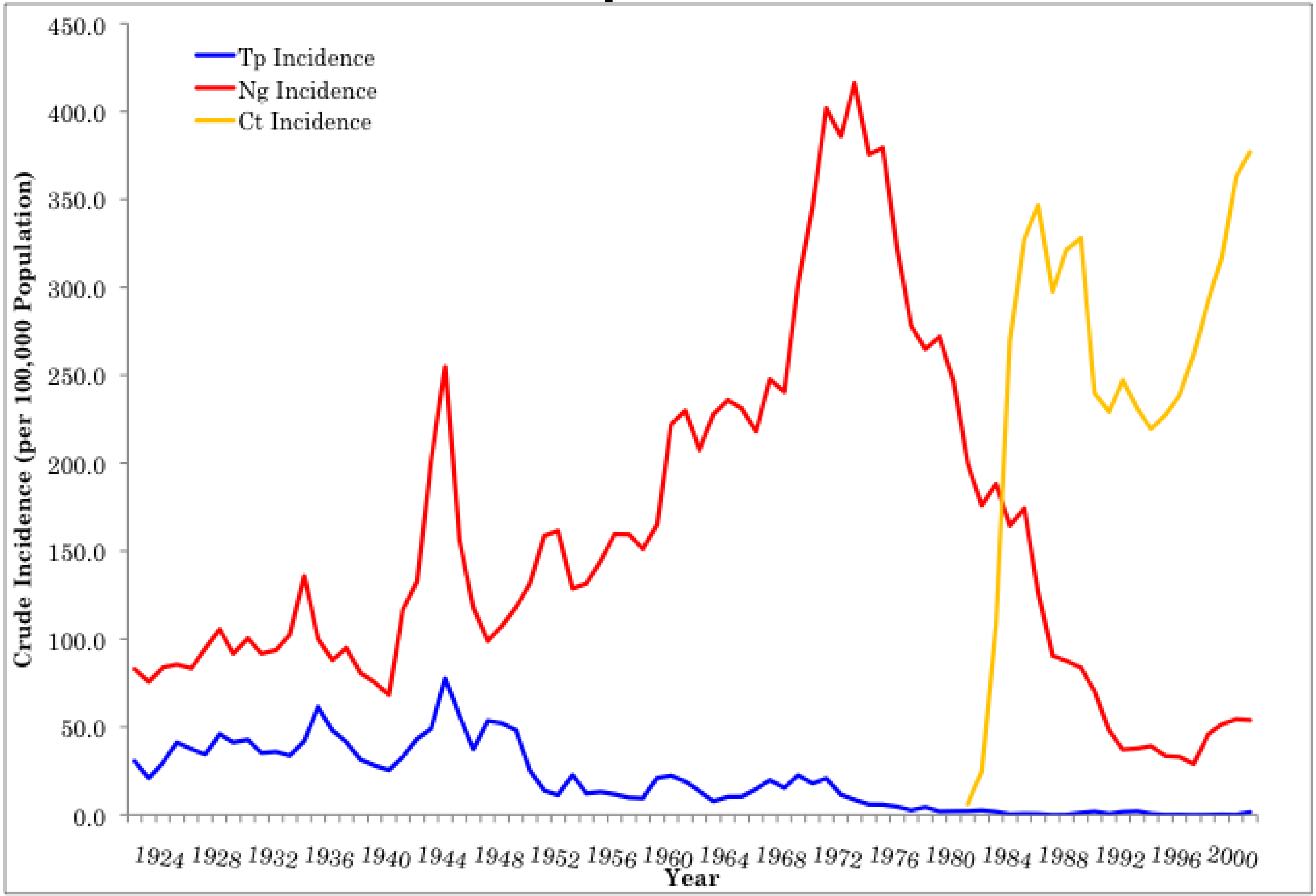
Complexities & Regularities



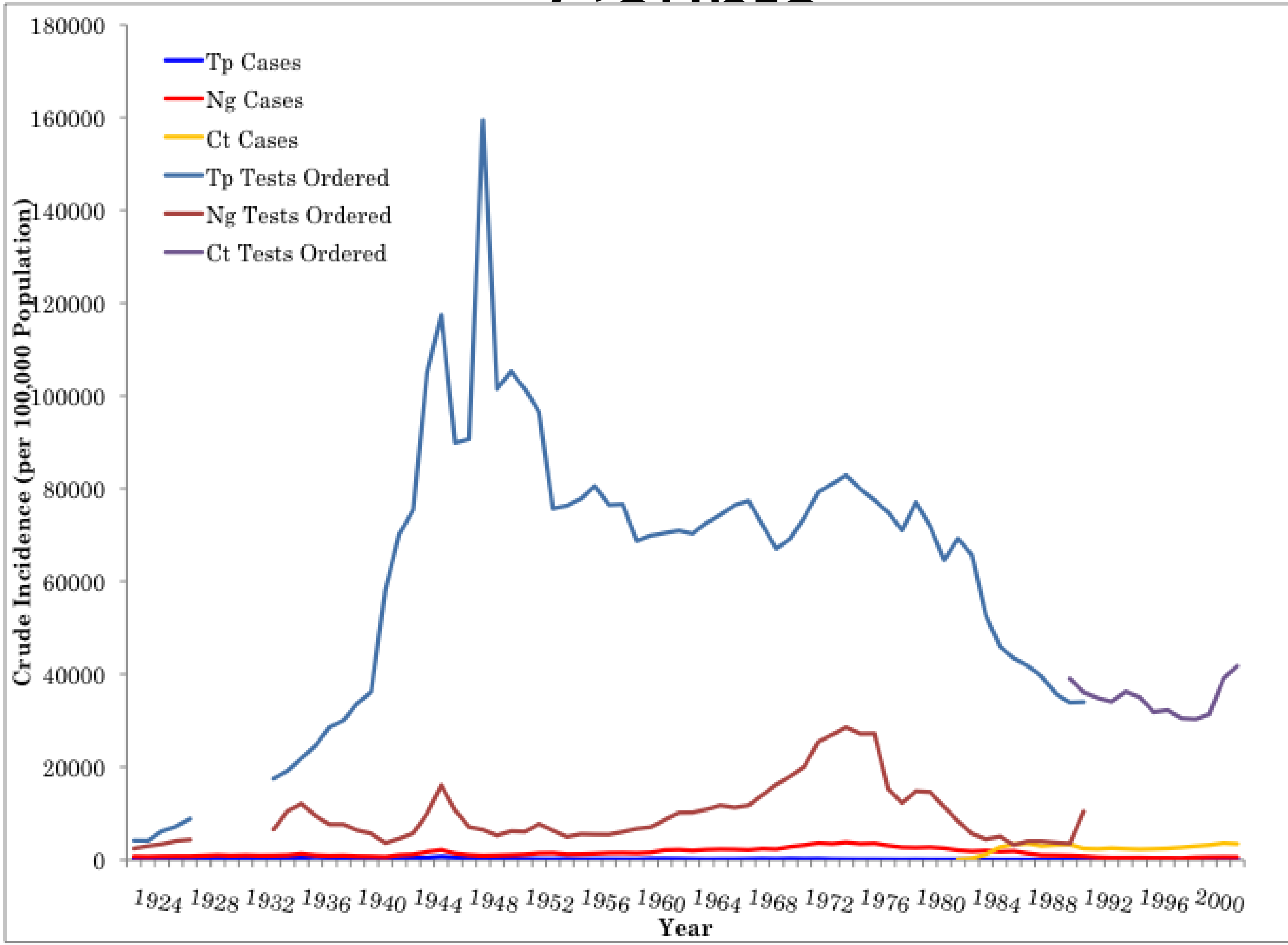
Measles & Mumps in SK



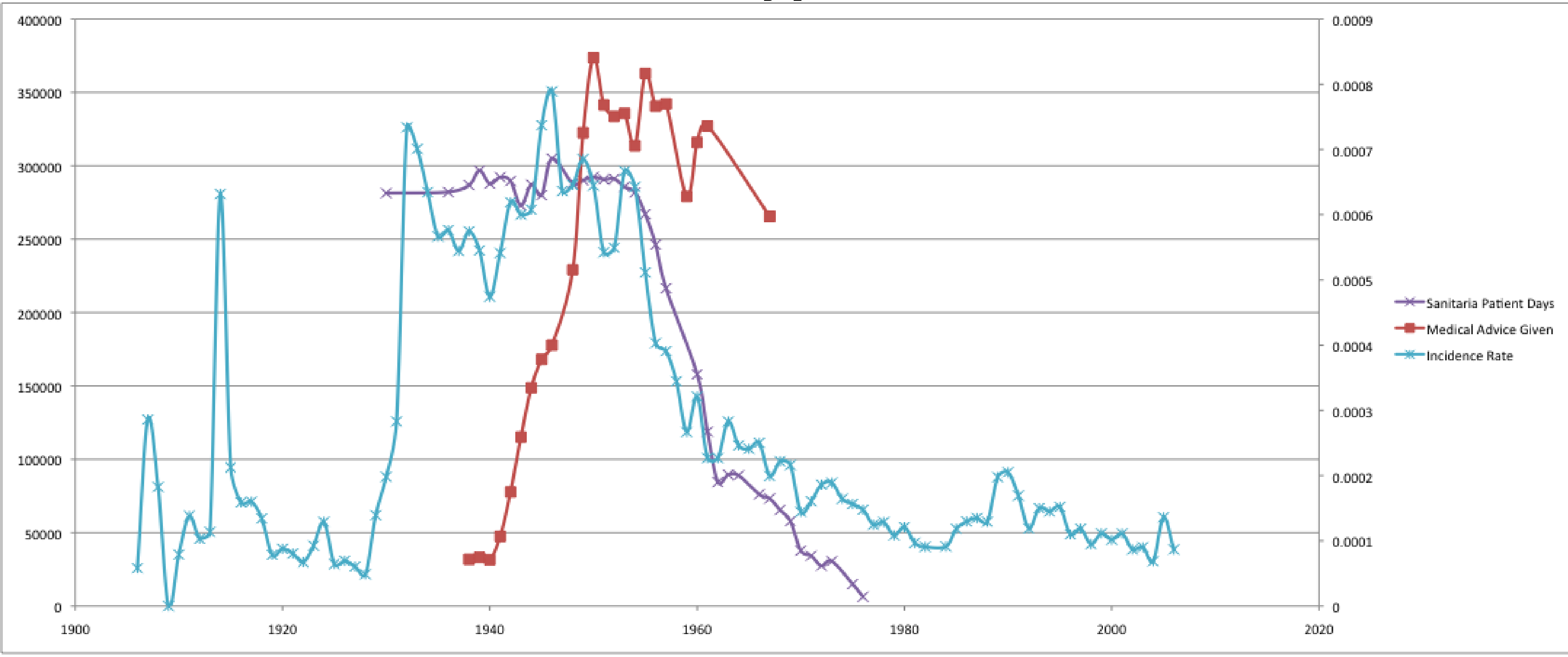
Example: STIs



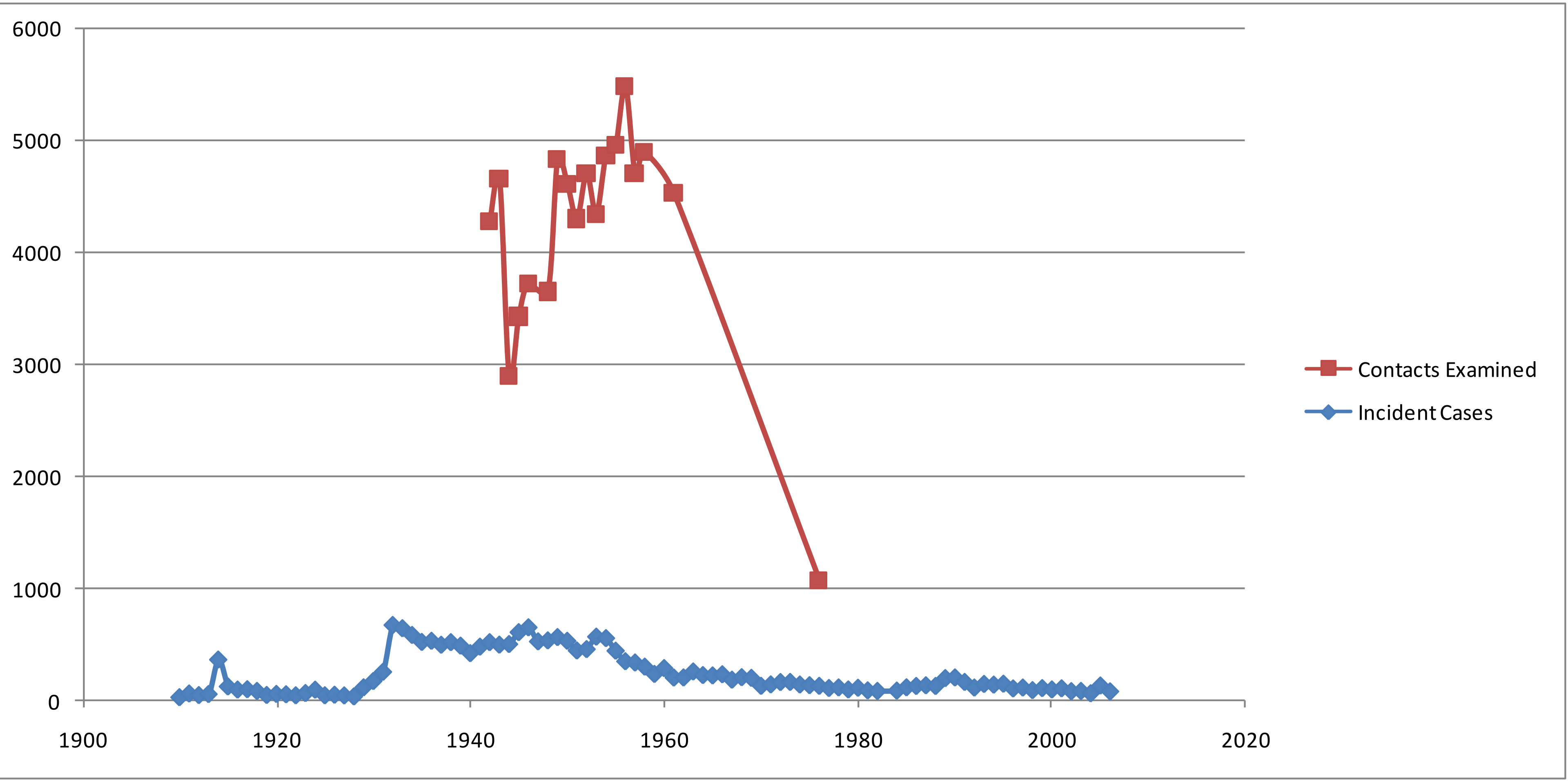
Three STIs: Test Volume vs Case Counts



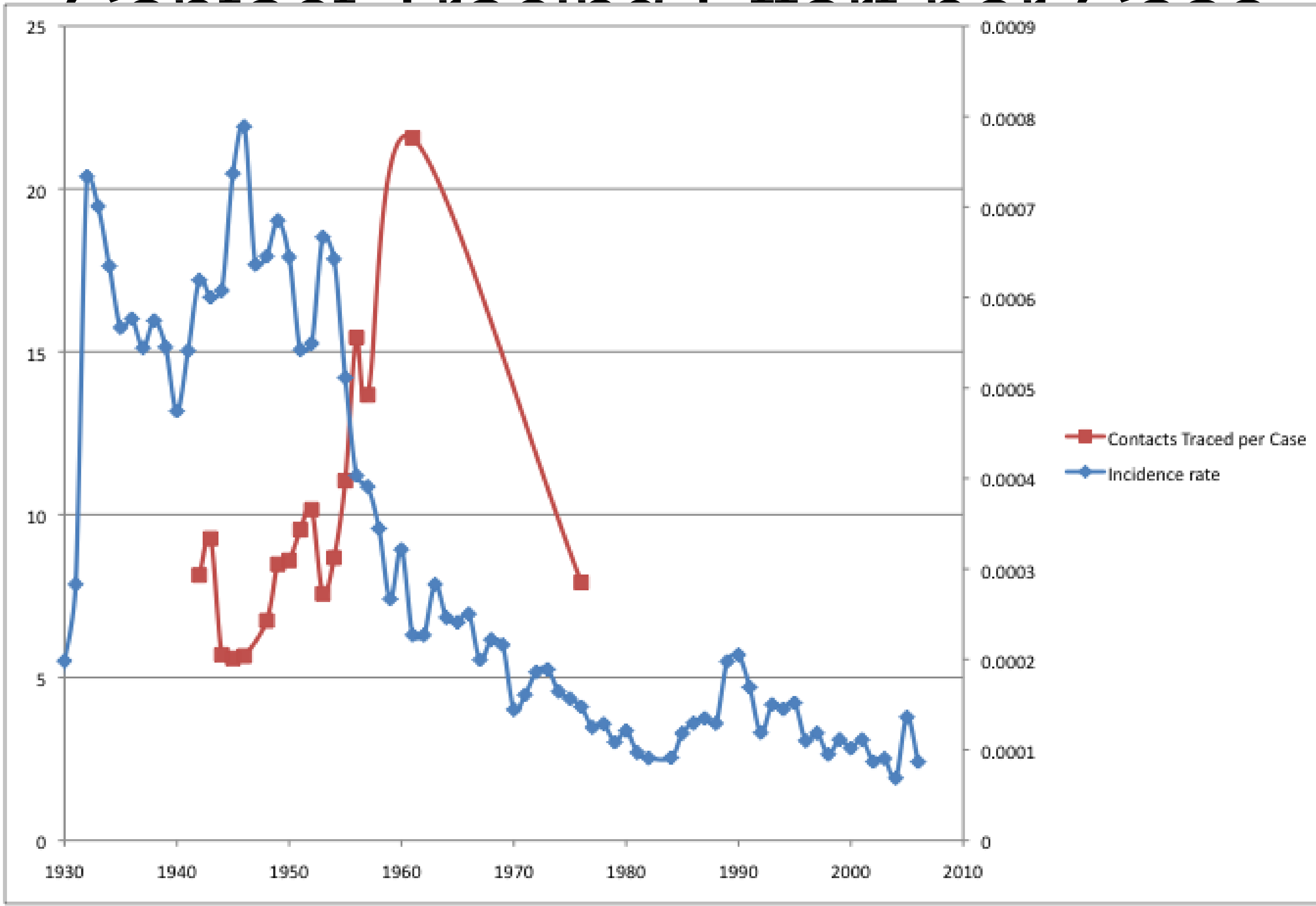
TB Saskatchewan's War on "White Plague"



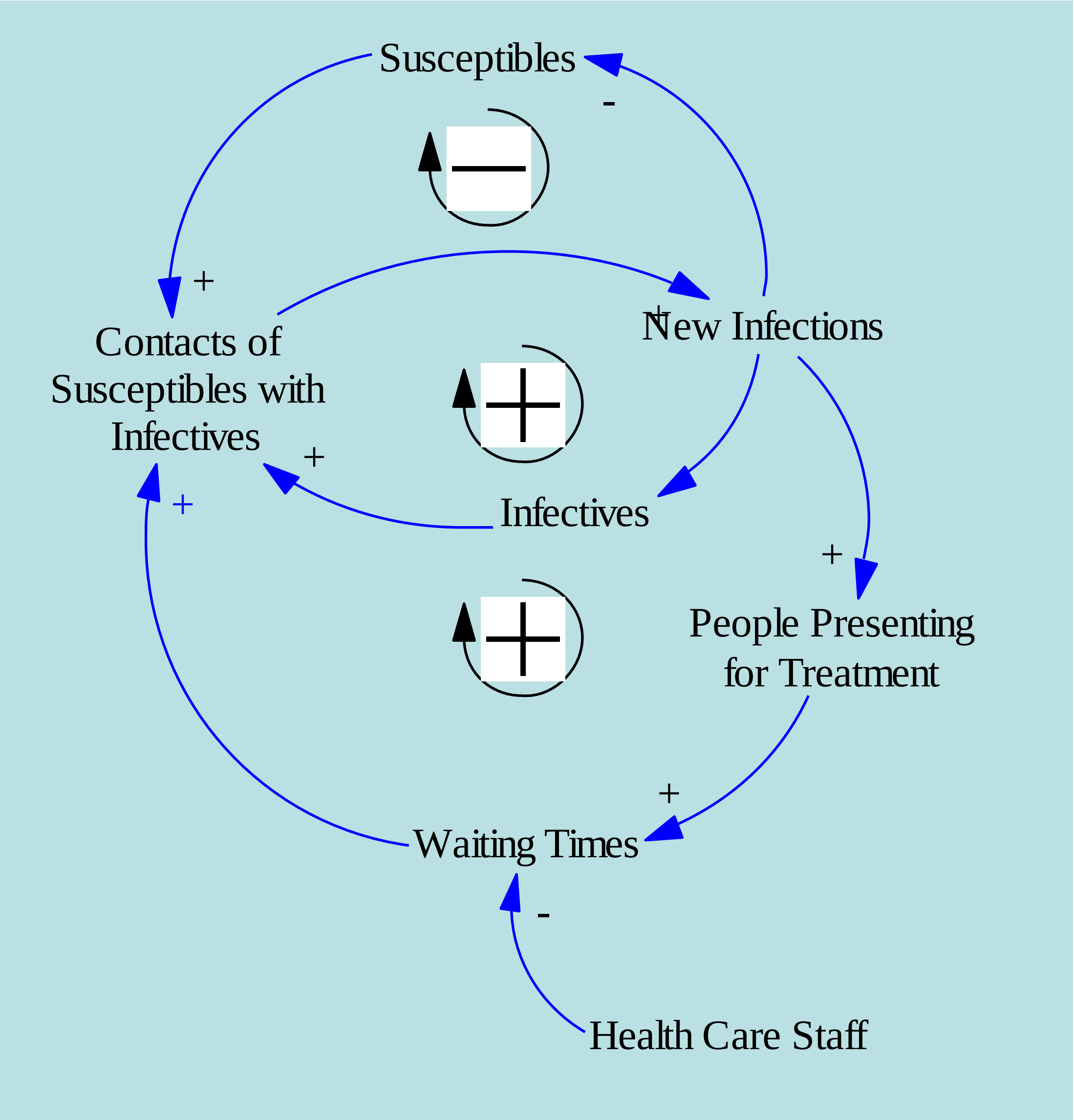
Cases and Contact Tracing



Contact Tracing Effort per Case



Broadening the Model Boundaries: Endogenous Recovery Delay



Common Phenomena In Complex Systems

- Counter-intuitive behaviour*(Often fb interactions)*
- Snowballing: When things go bad, they often go *very* bad very quickly
  - "Vicious cycles" lead to "cascading" of problems

  (Due to positive feedback)
  - "Path dependence": Different starting points can lead to divergence in project progress

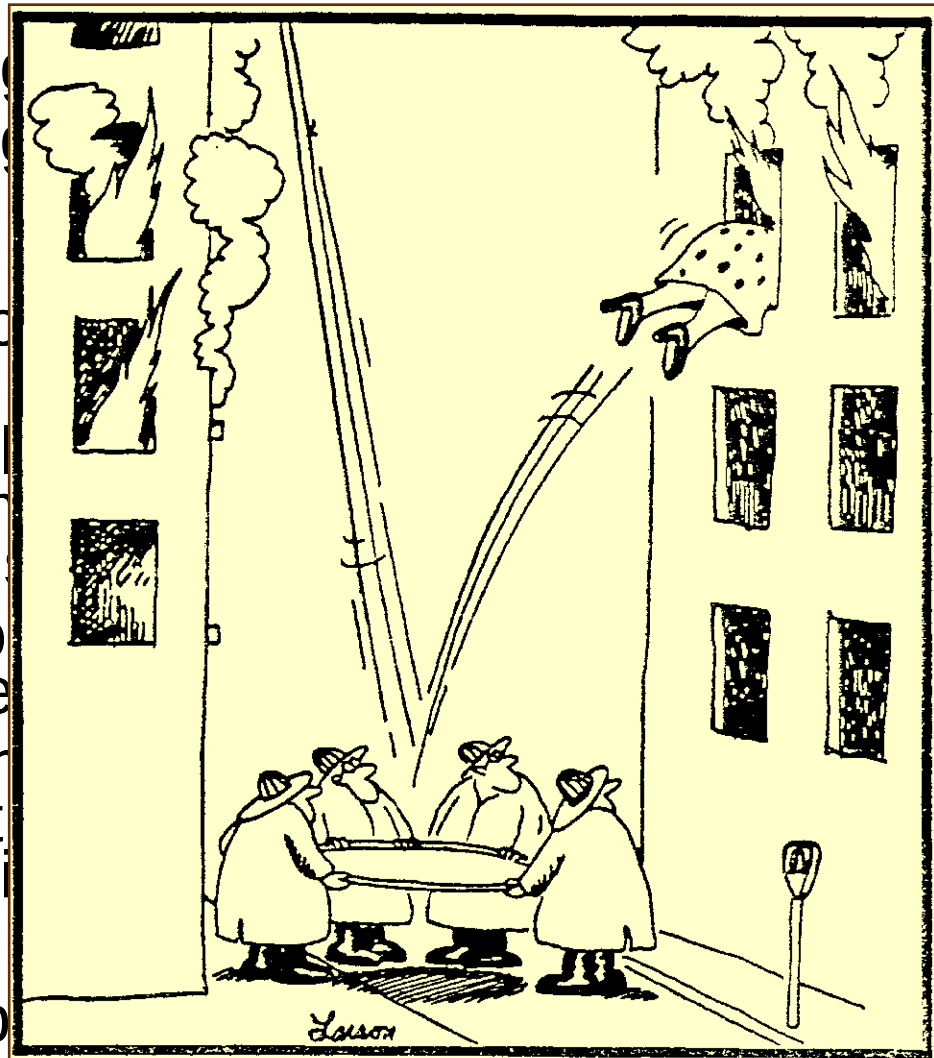
  (Due to positive feedback interacting w/ mult. negative fb)
- Policy resistance: Situation can be unexpectedly difficult to change

  (Typically due to negative feedbacks that resist change)

Examples of Policy Resistance

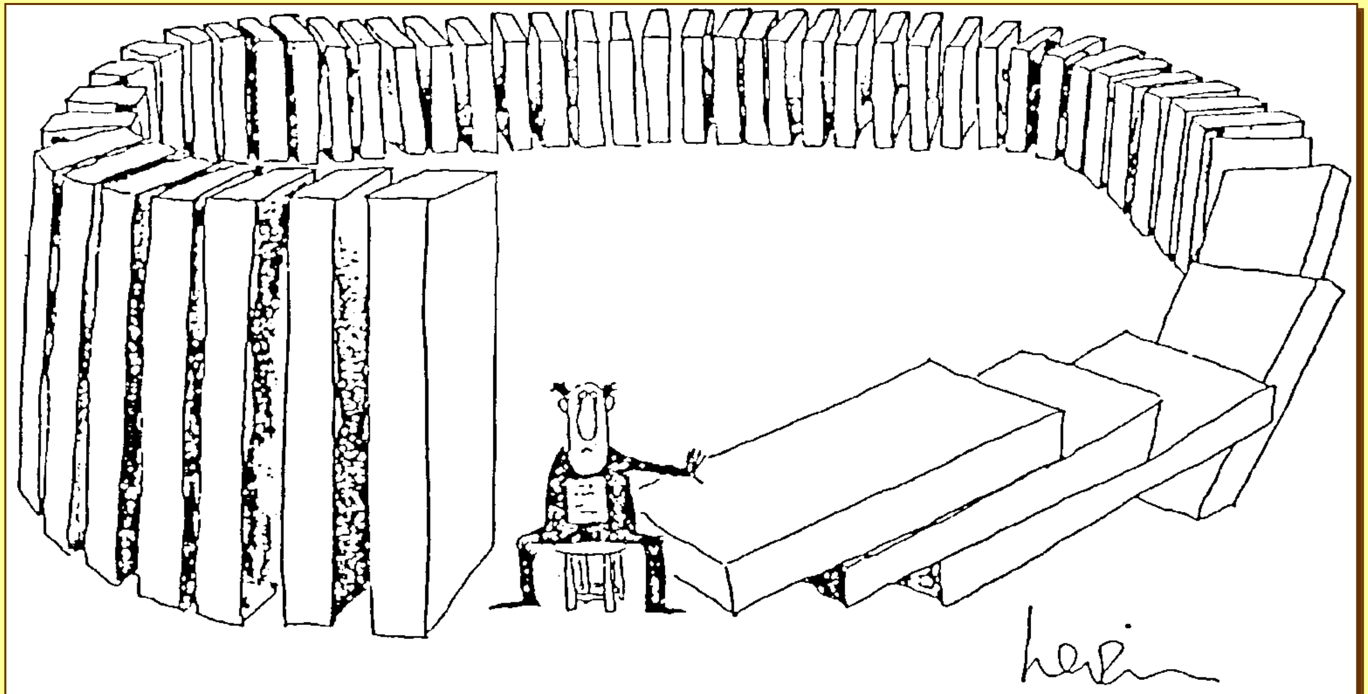
- Cutting cigarette tar levels reduces cessation
- Cutting cigarette nicotine levels leads to compensatory smoking
- Targeted anti-tobacco interventions lead to equally targeted coupon programs by tobacco industry
- Charging for supplies for diabetics as cost-cutting measure leads to higher overall costs due to reduced self-management, faster disease progression, higher demand for dialysis & transplants
- ARVs prolong lives of HIV carriers, but lead to resurgent HIV epidemic due to lower risk perception
- “Saving money” by understaffing STI clinics, leads to long treatment wait, greater risk of transmission by infectives& bigger epidemics
- Antibiotic overuse worsens pathogen resistance
- Antilock breaks lead to more risky driving
- Natural feedback: Intergenerational “Vicious Cycles”

Examples of Policy Resistance



- Cutting cig… …tion
- Cutting cig… …ompensatory smoking
- Targeted … …o equally targeted c… …ustry
- Charging … …t-cutting measure l… …e to reduced self-managem… … higher demand for dialysi…
- ARVs pro… …ad to resurgent HIV epide… …n
- “Saving m… …cs, leads to long treatment… …n by infectives& bigger epi…
- Antibiotic … …stance
- Antilock b…
- Natural feedback: Intergenerational “Vicious Cycles”

“Complexity is All Around Us”



Drawing by Levin; © 1976 The New Yorker Magazine, Inc.

Issues with Causal Loop Diagrams

- Unclear variables
- Diagrams can become very large
- Confusion regarding polarity
- Non-causal relationship
- Conservation not captured
- Behavior not always same as archetype
- Unclear paths/Missing causal factors
- Missing links
- Asymmetry in direction of change

Unclear Variables

Variables Lacking Clear Polarity

- Gender
- Ethnicity
- Shape

Often categorical & non-ordinal

- Ask whether “more X” is
  - Meaningful
  - Unambiguous

Implicit Polarity

- Population (size)
- Revenue (amount of)
- Sound, Color (more of)
- Socioeconomic status (more of)

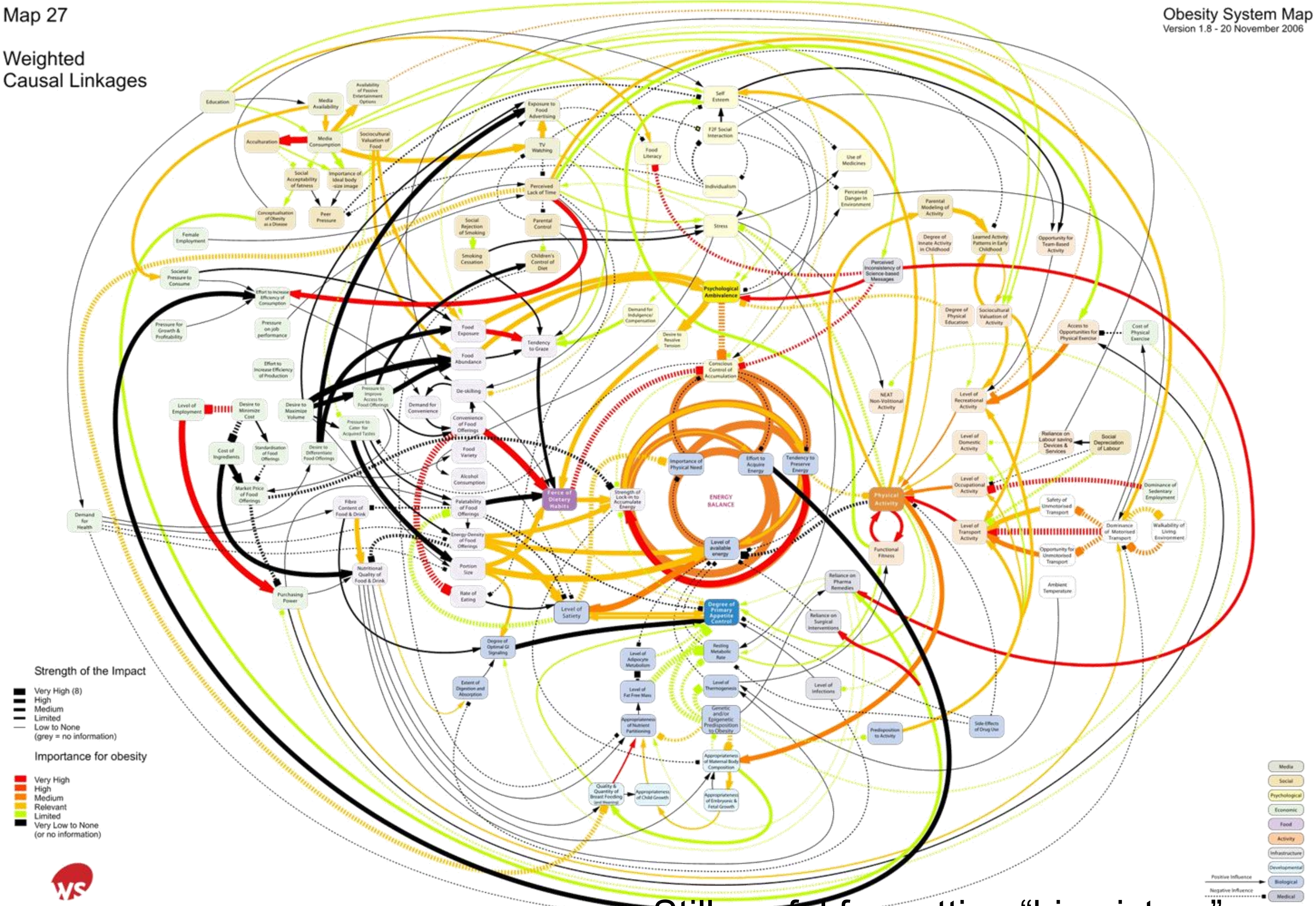
Unclear Links

- Causal loop diagrams should make clear the causal pathway one has in mind
- One of the most common problems in causal loop diagrams is showing a link without the meaning being clear
  - Often there are many possible pathways, and distinguishing them can help make the diagram much clearer

Refining a Diagram

- It takes time to arrive at an acceptable diagram
- Some of the biggest investments lie in
  - Figuring out the appropriate variables to use
  - Illustrating the different pathways
  - Refining the names of the variables

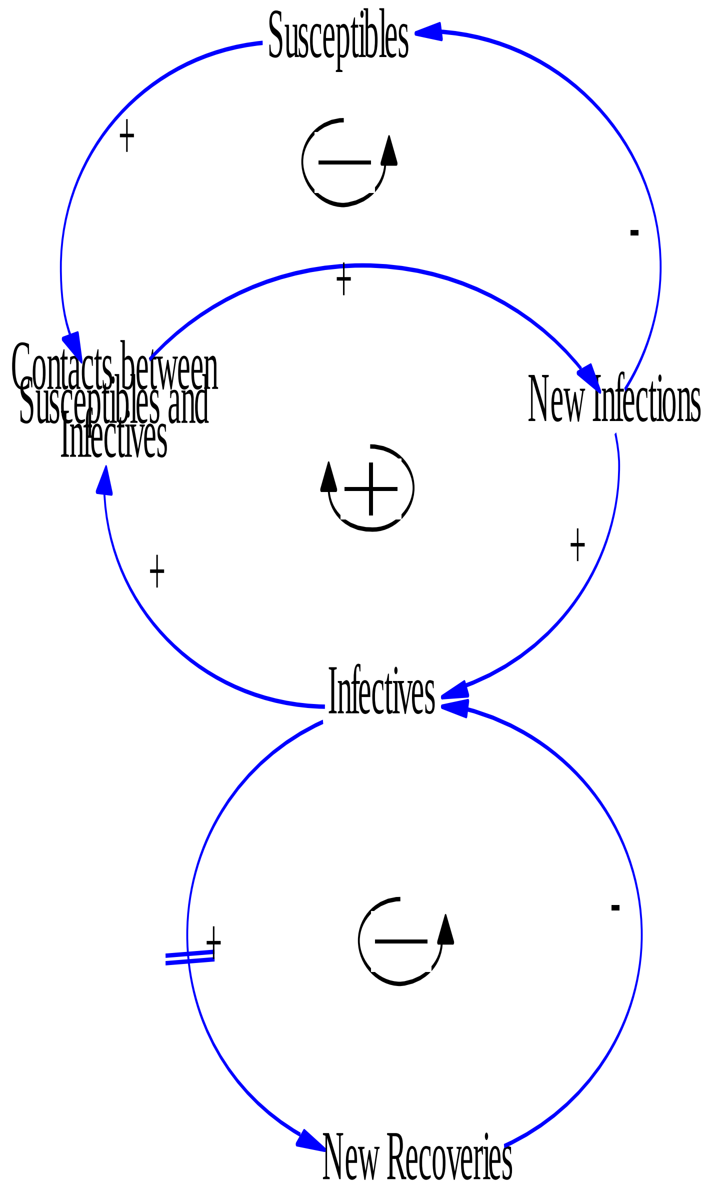
Very Large Diagrams



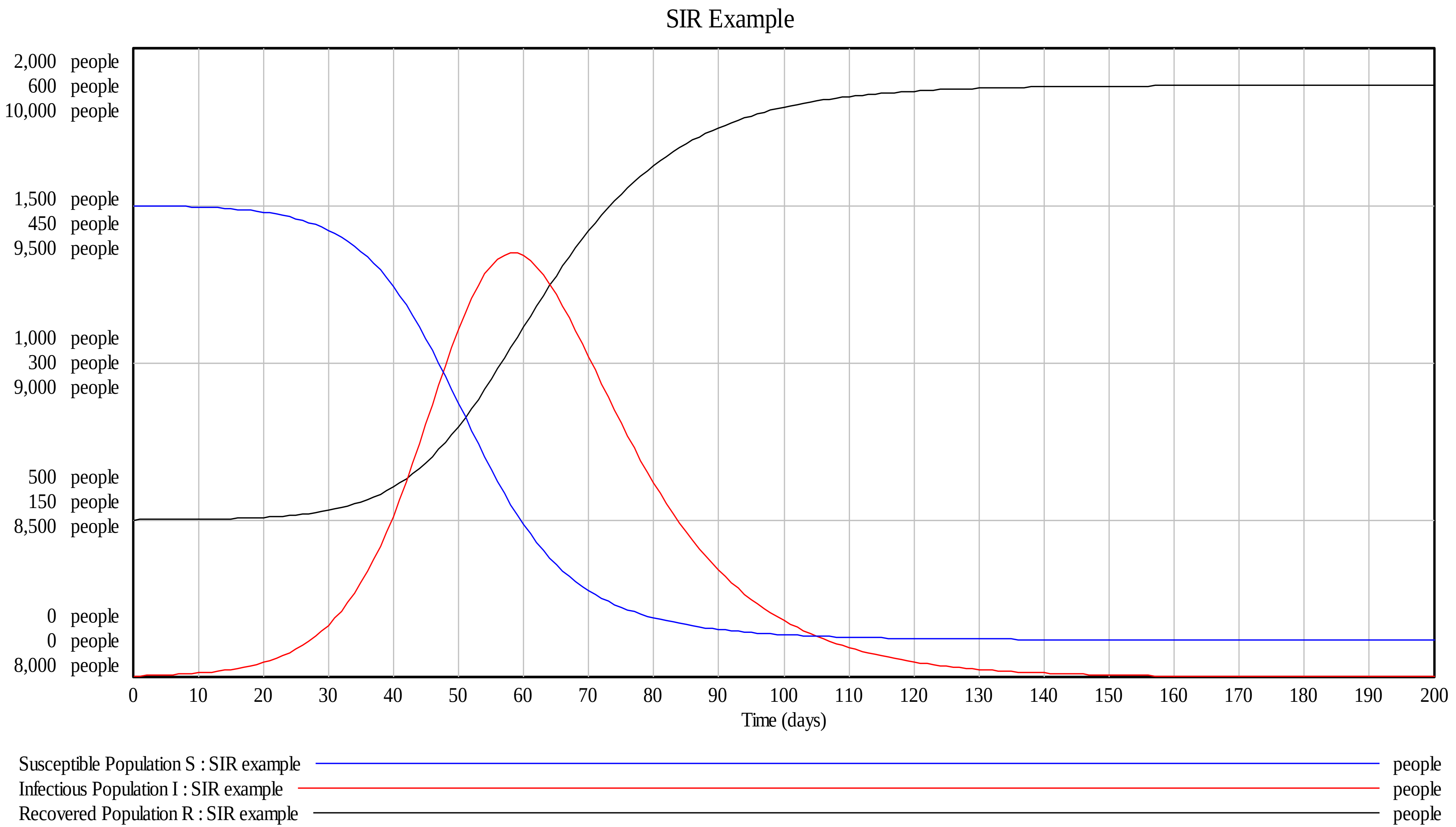
Still useful for getting “big picture”

http://kim.foresight.gov.uk/Obesity/Obesity.html identifying where research “fits in”, research gaps

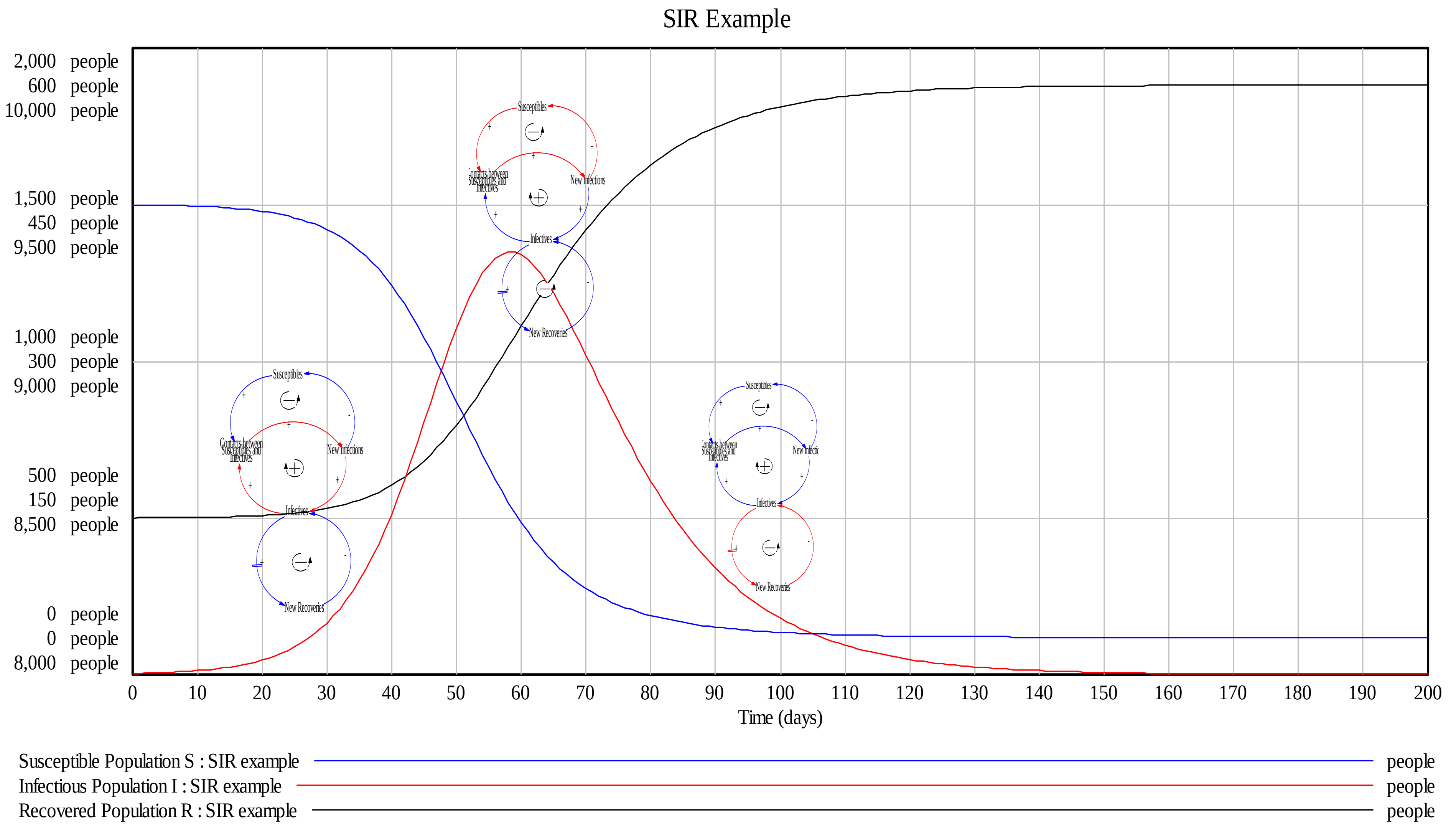
Feedbacks Driving Infectious Disease Dynamics



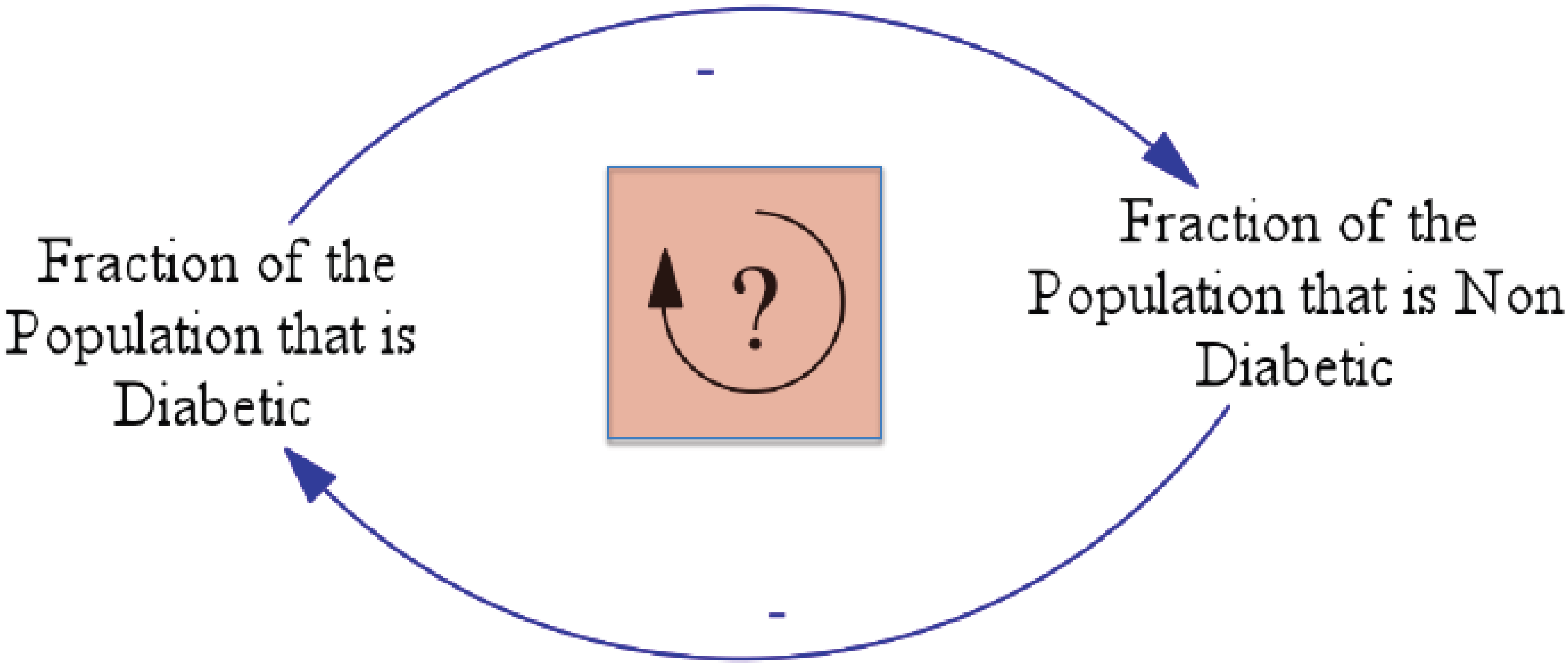
Example Dynamics of SIR Model (No Births or Deaths)



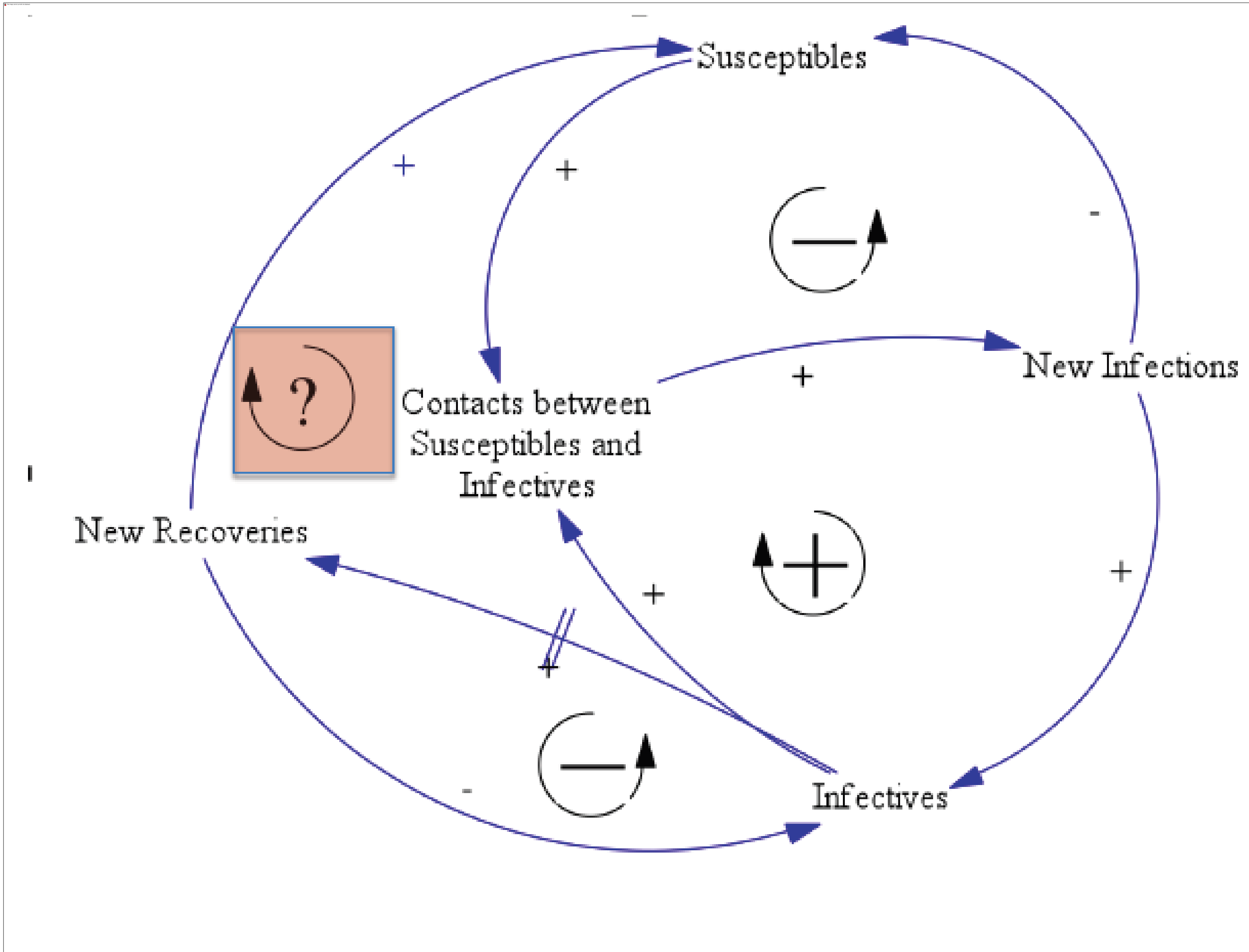
Shifting Feedback Dominance



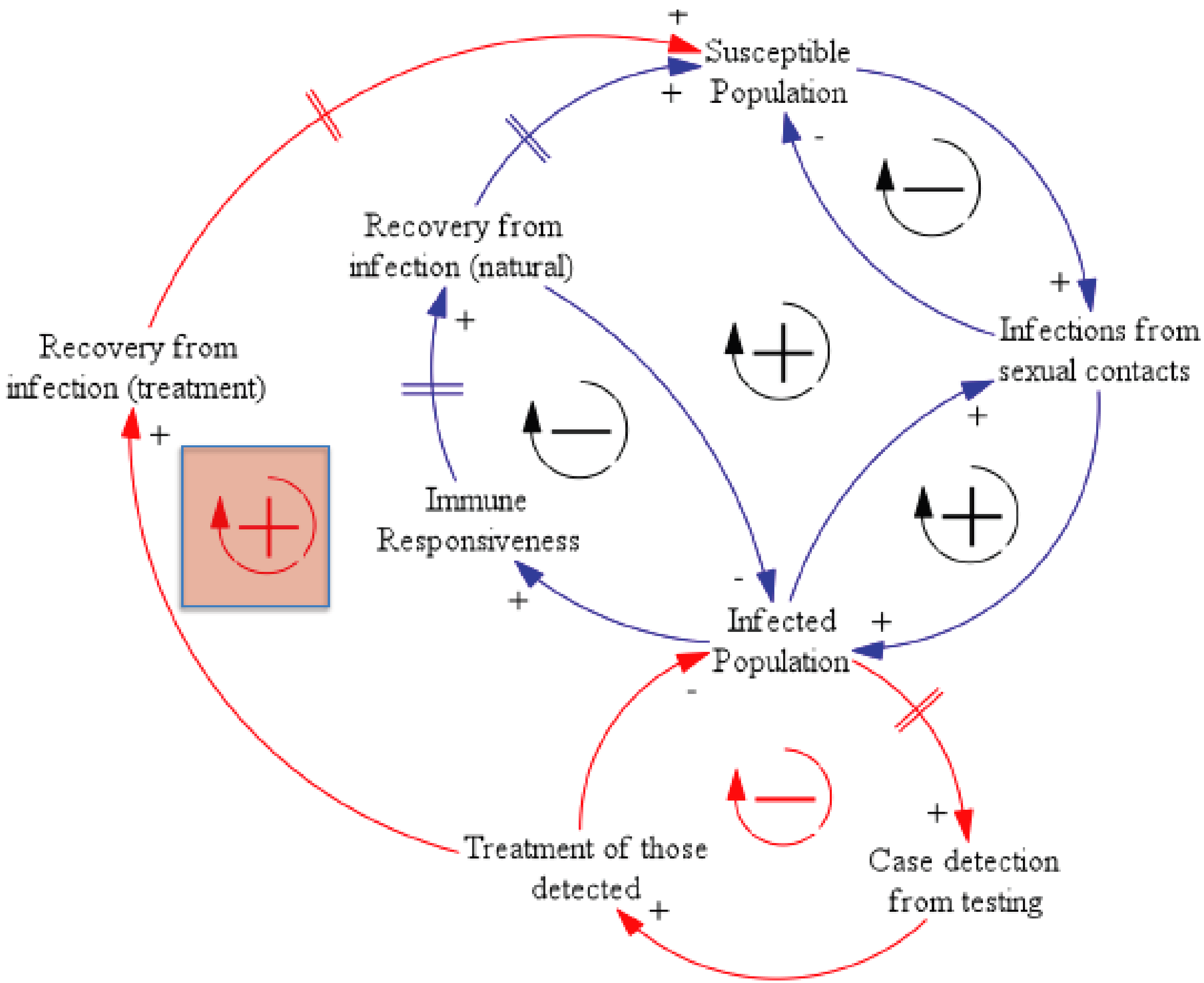
Artifactual Loop



Artifactual Loop 2



Artifactual Loop 3



State of the System: Stocks (Levels, State Variables)

- Stocks (Levels) represent accumulations
  - These capture the "state of the system"
  - Mathematically, we will call these "state variables"
- These can be measured at *one instant in time*
- Stocks are only changed by changes to the flows into & out of them
  - There are no inputs that immediately change stocks

Examples of Stocks

- Water in a tub or reservoir
- People of different types
  - { Susceptible, infective, immune} people
  - Pregnant women
  - Women between the age of x and *y*
  - High-risk individuals
- Healthcare workers
- Medicine in stocks
- Money in bank account
- CO_2 in atmosphere
- Blood sugar
- Stored Energy
- Degree of belief in X
- Stockpiled vaccines
- Goods in a warehouse
- Beds in an emergency room
- Owned vehicles

Changes to State: Flows ("Fluxes")

- These are always associated with rates
- If these flow out of or into a stock that keeps track of things of type X, the rates are measured in X/Unit Time (e.g. person/year)
- Typically measure by accumulating people over a period of time
  - E.g. Incidence Rates is calculated by accumulating people over a year

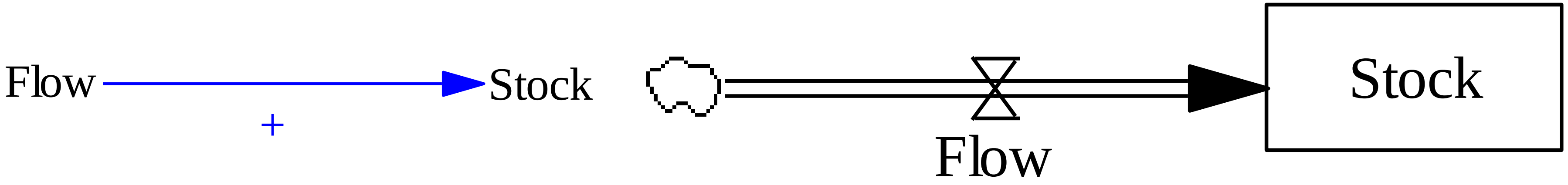
Examples of Flows

- Inflow or outflow of a bathtub (litres/minute)
- Rate of infection (e.g. people/month)
- Rate of recovery
- Rate of Mortality (e.g. people/year)
- Rate of Births (e.g. babies/year)
- Rate of treatment (people/day)
- Rate of caloric consumption
- Rate of pregnancies (pregnancies/month)
- Reactivation Rate (# of TB casess reactivating per unit time)
- Revenue ($/month)
- Spending rate ($/month)
- Power (Watts)
- Rate of energy expenditure
- Vehicle sales

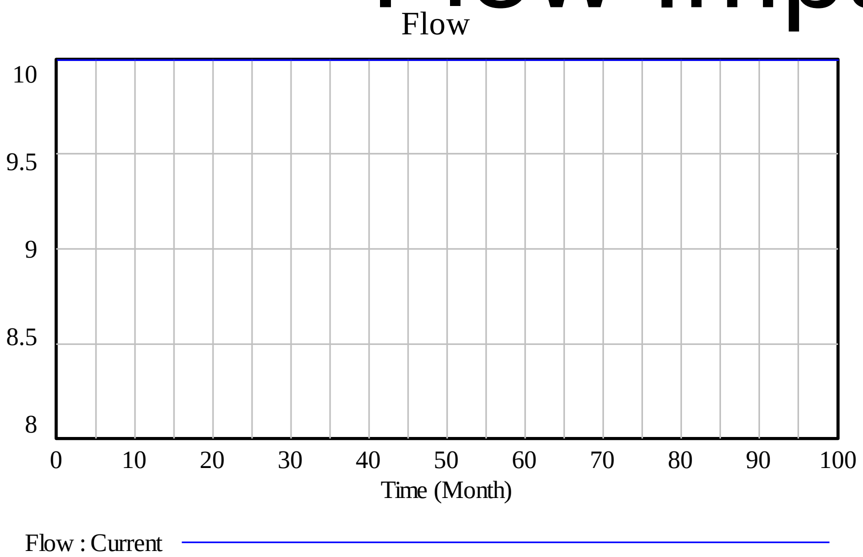
Flows 2

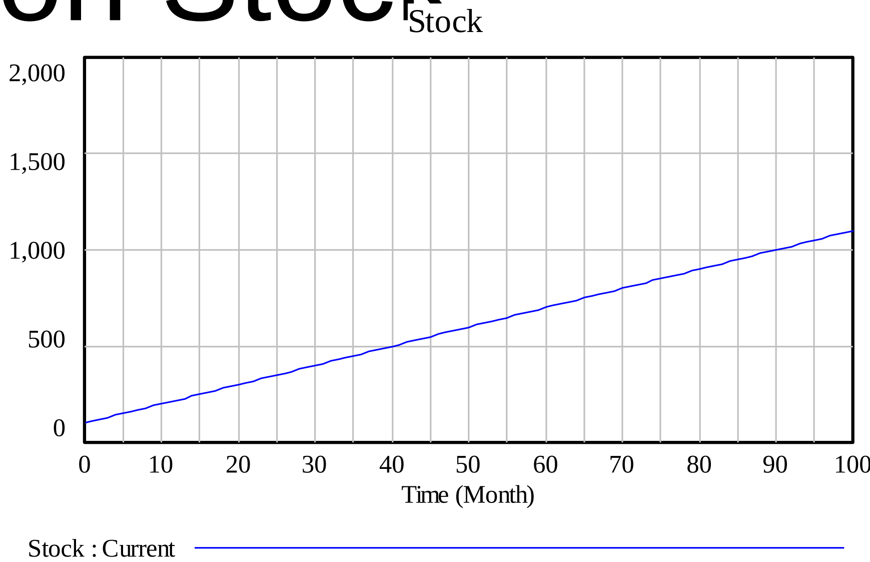
- May be *measured* by totalling up over a period of time and dividing by the time
- We can ask conceptually about the rate at any given point – and may change over time
- When speaking about “Rates” for flows, we always mean something measured as X/*Unit Time* (also called a *rate of change per time)*
  - Not all things called “rates” are flows
    - Exchange rate
    - Rate of return

Key Component: Stock & Flow

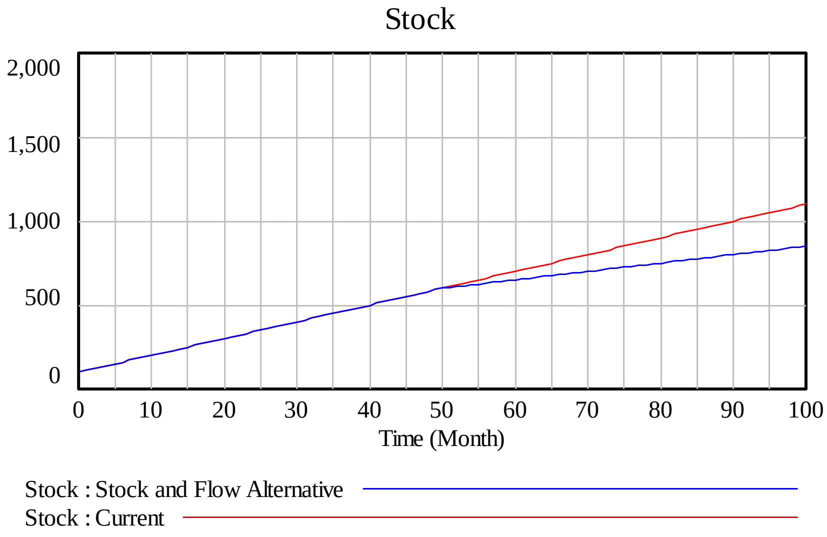


Flow Impact on Stock





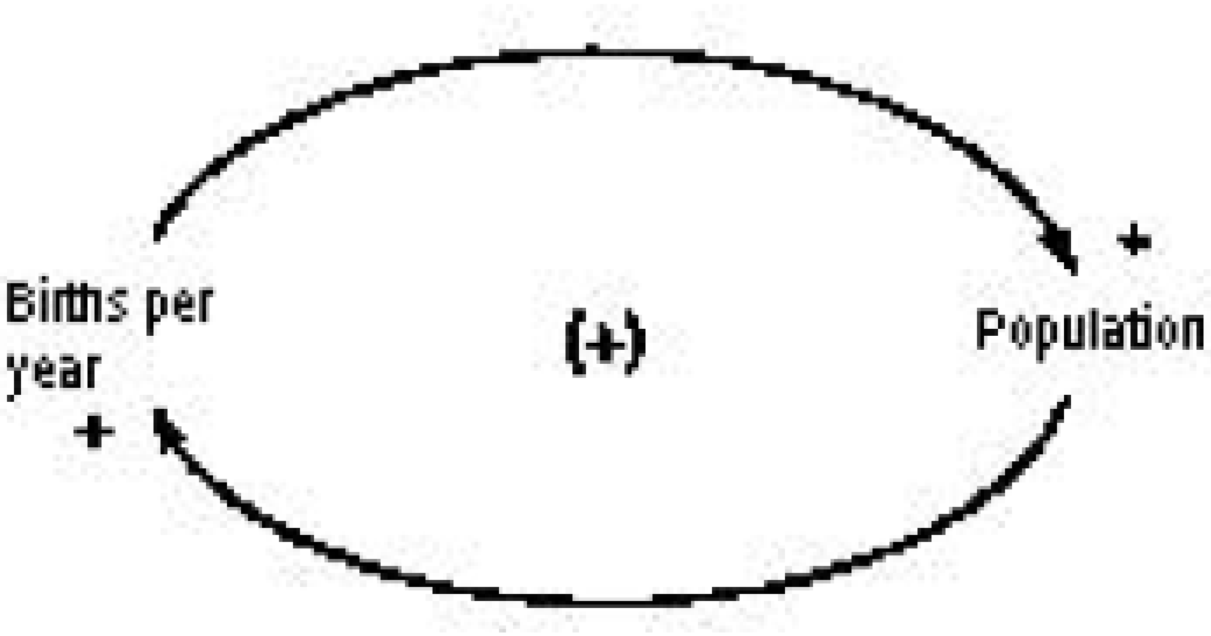
Impact of Lowering Flow (Rate) to 5/Month?



Loops & Stocks

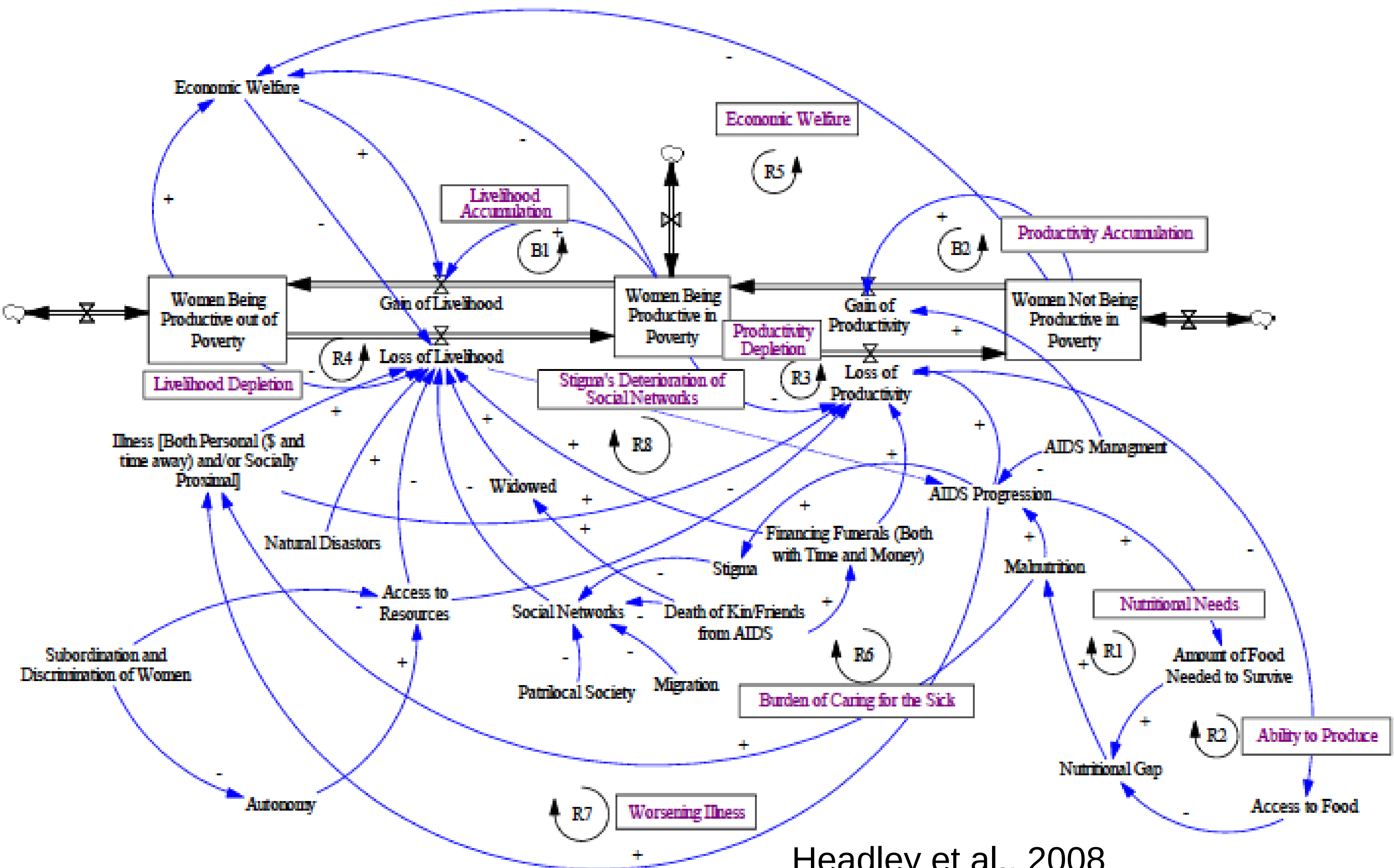
- Causation does not effect big change instantaneously
  - Loops are not instantaneous
- Stocks only change by changes to the flows into & out of them
  - There are no inputs that immediately change stocks
- All causal loops must involve at least one stock!

Delayed Impact

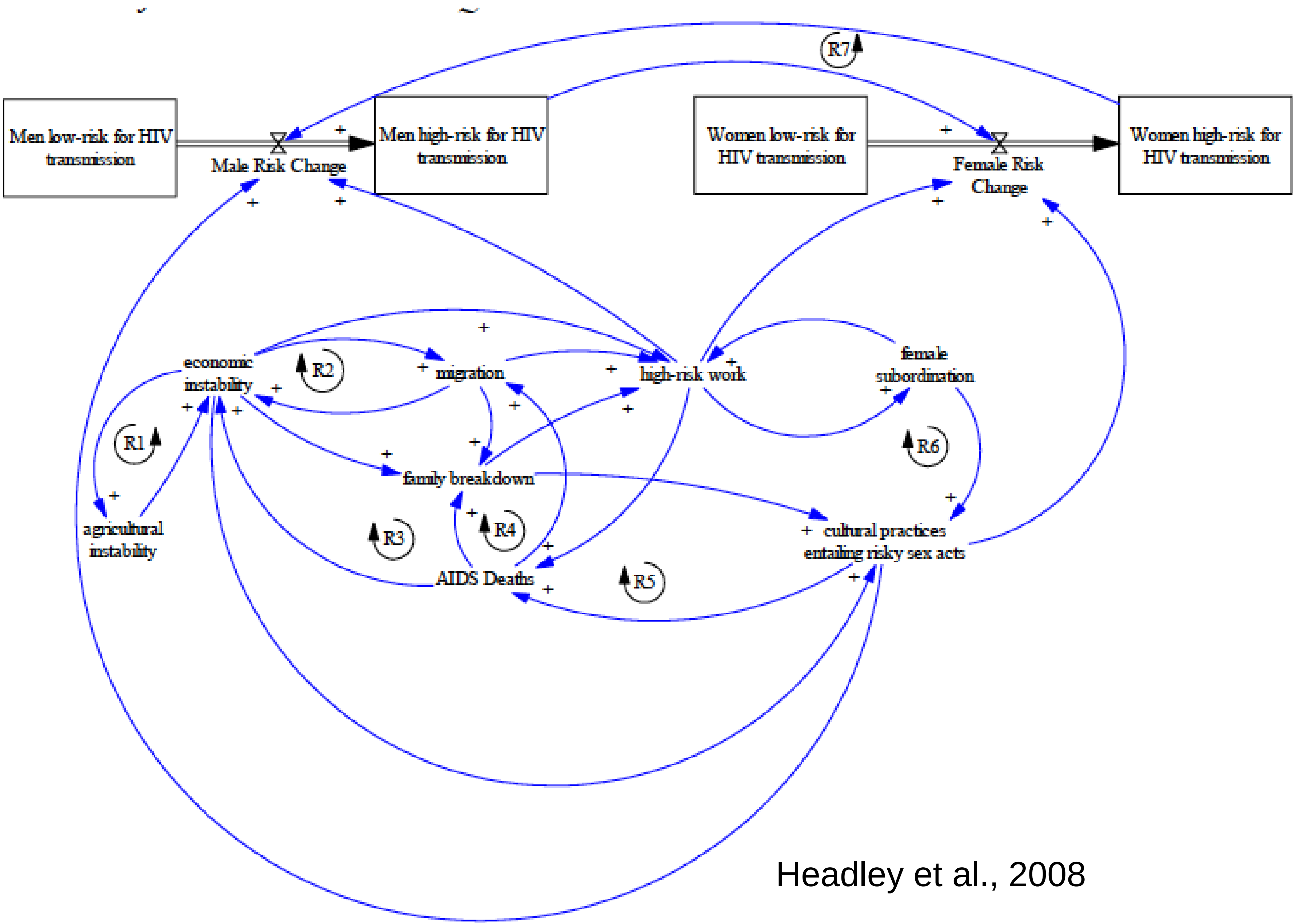


System Structure Diagrams

- Semi-quantitative models
- Combine causal loops diagram elements with stock & flow structure
- Clearly distinguish stocks & flows
- If complete, all loops will go “through a stock”
  - Loop goes into the flow of a stock (as one variable in the diagram)
  - Loop comes comes out of stock (as next variable in diagram)

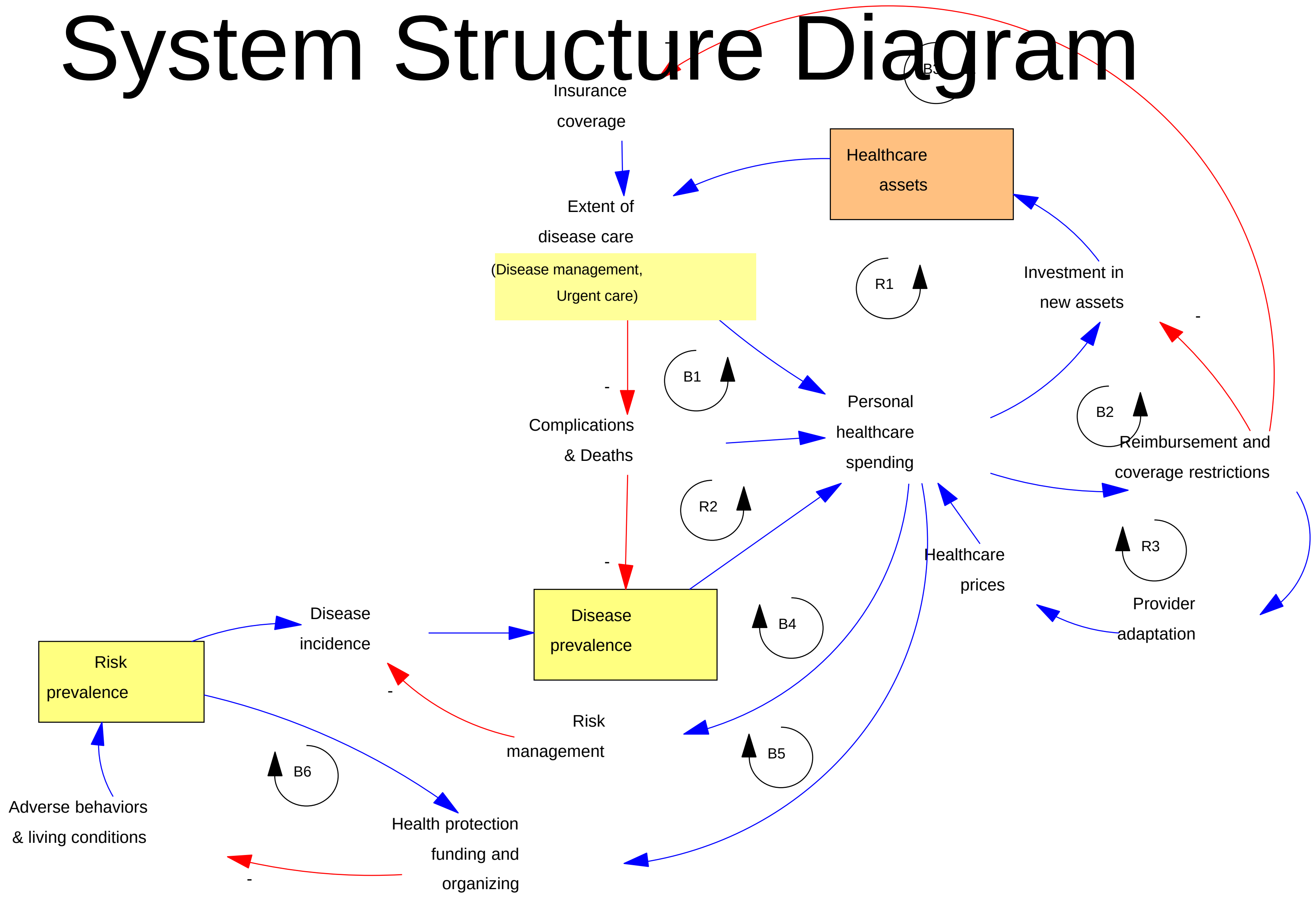


Headley et al., 2008



Headley et al., 2008

System Structure Diagram



Homer, 2007