Keep it simple: Dominance assessment of short feedback loops

Rogelio Oliva

Mays Business School

roliva@tamu.edu

Mohammad Mojtahedzadeh

Attune Group, Inc.

mohammad@attunegroup.com

International System Dynamics Conference

Oxford, UK

July 25-29, 2004

Abstract

Two approaches have been developed to establish a formal link between system structure and behavior. Eigenvalue elasticity approaches take a system-wide perspective and have been based either on ad-hoc selection of loops (Forrester 1982; Kampmann 1996)—resulting in non-generalizable explanations—or on loops formed by the aggregate paths between state variables (Gonçalves et al 2000)—resulting in low-resolution explanations. The second approach, Pathway Participation Method (PPM) (Mojtahedzadeh et al 2004), considers pathways as the building blocks of influential structure, but frequently identifies loops as the structure most responsible for an observed behavior. In this study we show, for various models, that the Shortest Independent Loop Set (Oliva 2003) contains the loops identified as most influential by PPM. Since the SILS is structurally derived, and under most circumstances unique, we propose it as a starting point for Kampmann method to derive complete, granular, and generalizable structure-behavior explanations.

Eigenvalue elasticity

- Forrester (1982)
  - –Initial work linking loops gains to system eigenvalues
  - –Loop (or link) importance determined by eigenvalue elasticity

- Kampmann (1996)
  - –Decompose characteristic polynomial based on a cycle decomposition
  - –Simultaneous evaluation of different loops and their interactions
  - –Proposed the Independent Loop Set (ILS)
    - Maximal set of loops whose incidence vectors are linearly independent
  - –But
    - Not unique
    - Results contingent on loop selection

Eigenvalue elasticity (cont.)

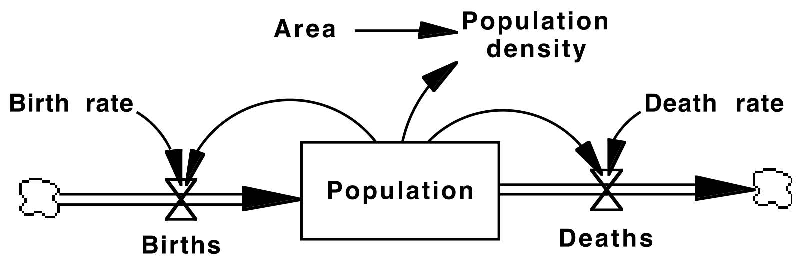
- Gonçalves, Lertpattarapong and Hines (2000)
  - Compress the model to aggregated paths between stock variables
  - Cycle decomposition is unique
  - But
    - Difficult to interpret if multiple paths between stock variables (very common on SD models)
    - Lacks granularity to explain the effect of individual variables/parameters on dynamics
    - Lacks granularity to drive policy analysis

Model Structural Analysis

- Oliva (2003)
  - Based on model structural complexity, developed a model partition strategy and calibration sequence that permits incremental development of model confidence
    - Graph theory can be used to analyze structural complexity
    - Posits that structural decompositions could be the basis for more formal analysis of dynamic complexity
  - Shortest Independent Loop Set (SILS)
    - ILS formed by the shortest possible loops
    - Simplest and most granular representation of the structure in a cycle set
    - Parsimonious description of the feedback complexity of a graph
    - Unique under certain conditions

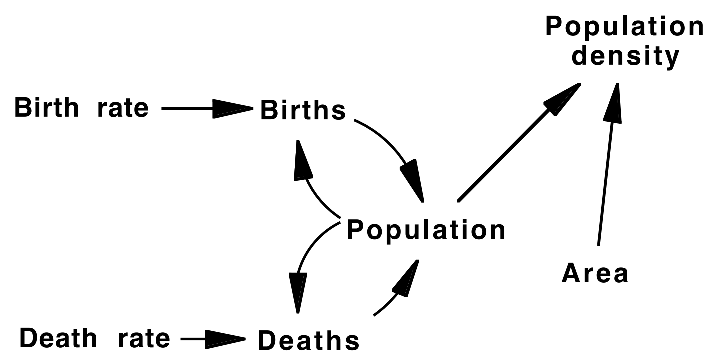
Graph representation of system structure

SD Model



(d/dt)P=B-D
*B=Br*P*
*D=Dr*P*
Pd=P/A

Digraph



Adjacency Matrix

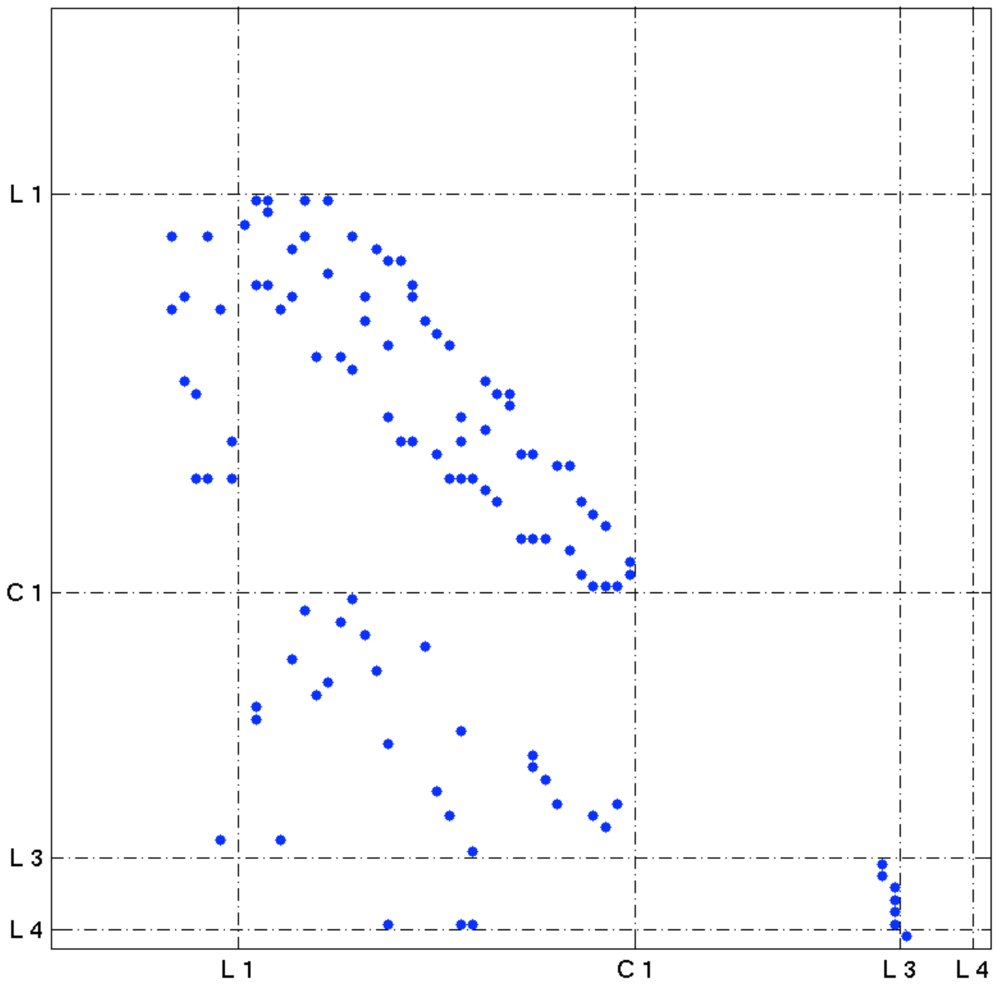
	Br	*B*	*P*	*Dr*	*D*	*Pd*	*A*
Br	0	1	0	0	0	0	0
B	0	0	1	0	0	0	0
P	0	1	0	0	1	1	0
Dr	0	0	0	0	1	0	0
D	0	0	1	0	0	0	0
Pd	0	0	0	0	0	0	0
A	0	0	0	0	0	1	0

Adjacency matrix block-ordered by levels

		Pd	*A*	*P*	*B*	*D*	*Br*	*Dr*
*L*1	*Pd*	0	0	0	0	0	0	0
	A	1	0	0	0	0	0	0
*L*2	*P*	1	0	0	1	1	0	0
	B	0	0	1	0	0	0	0
	D	0	0	1	0	0	0	0
*L*3	*Br*	0	0	0	1	0	0	0
	Dr	0	0	0	0	1	0	0

Adjacency matrix block ordered by level

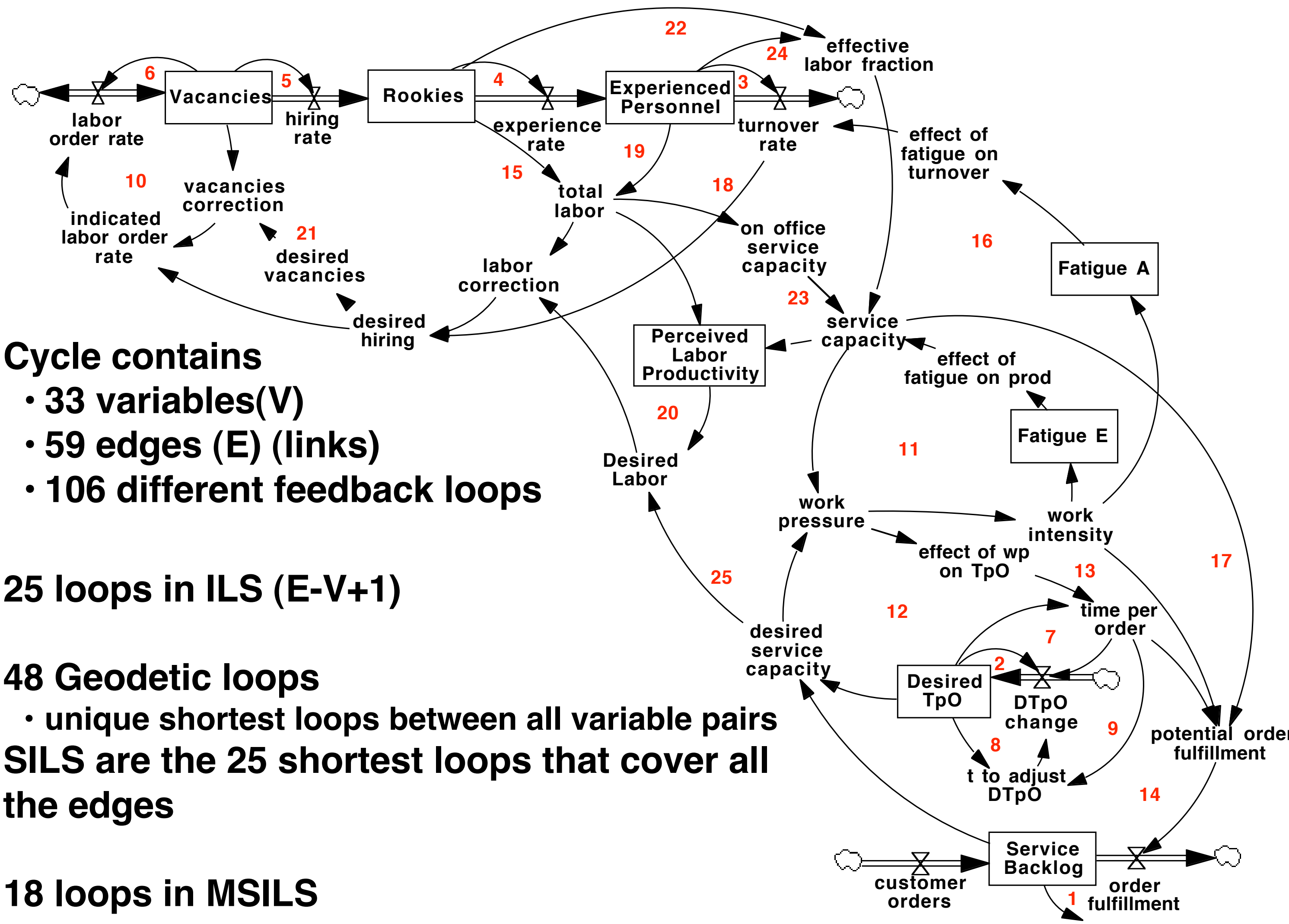
Oliva & Sterman (2001)



- 77 Equation model
  - 5 structural levels
  - 1 cycle (2nd level)
    - 33 variables in cycle
    - (43% of total)

Stock & flow diagram of cycle partition

Oliva & Sterman (2001)



- Cycle contains
  - 33 variables(V)
  - 59 edges (E) (links)
  - 106 different feedback loops
- 25 loops in ILS (E-V+1)
- 48 Geodetic loops
  - unique shortest loops between all variable pairs
- SILS are the 25 shortest loops that cover all the edges
- 18 loops in MSILS

Research question

- SILS is a parsimonious and intuitive description of feedback complexity
- Is unique under most circumstances
- Oliva (2003) posits that it would be a good framework to explain system behavior

- But
  - How relevant is SILS to explain behavior?
  - Is the SILS a significant (useful) cycle decomposition?
  - Are "structurally" short loops capable of explaining system behavior?

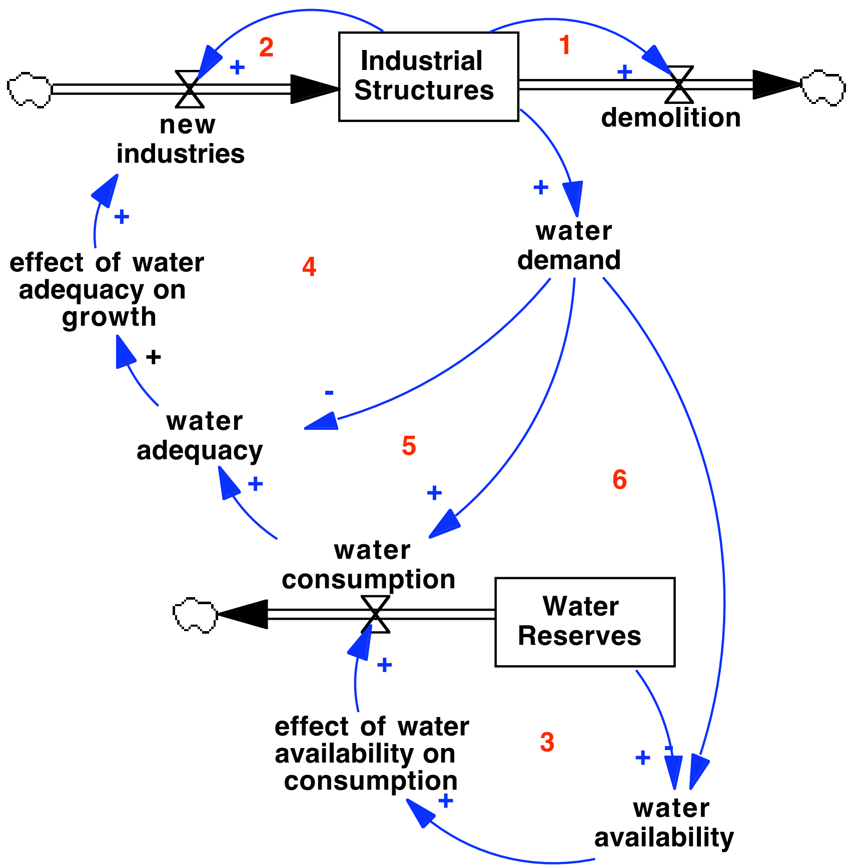
Pathway Participation Method (PPM)

- Mojtahedzadeh, Anderson & Richardson (2004)
  - Pathways (sequence of links) are the building blocks of influential structure
  - The most influential path is is defined as the path whose participation is the largest in magnitude and has the same sign as the total change in the variable under consideration
  - Frequently identifies loops as the structure most responsible for an observed behavior
  - Huge contribution to the structure-behavior problem
  - But
    - Just the most influential path is detected
    - It does not provide a comparative analysis of loops

- Use PPM test the significance of the SILS
  - Run PPM and see how the influential explanations compare to the loops in the SILS

Stock & flow diagram of cycle partition

Mojtahedzadeh, Anderson & Richardson (2004)



SILS=MSILS

1 Structure Demolition (B)
demolition
Industrial Structures

2 Structure Growth (R)
Industrial Structures
new industries

3 Water Consumption Limit (B)
effect of water availability on consumption
water consumption
Water Reserves
water availability

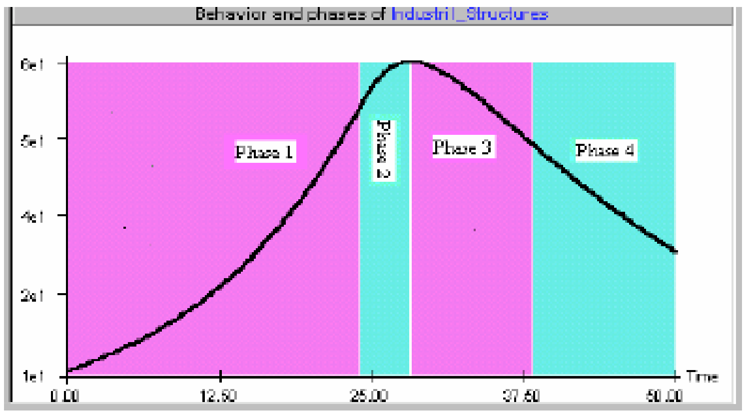
4 Industry Growth Limit (B)
effect of water adequacy on growth
new industries
Industrial Structures
water demand
water adequacy

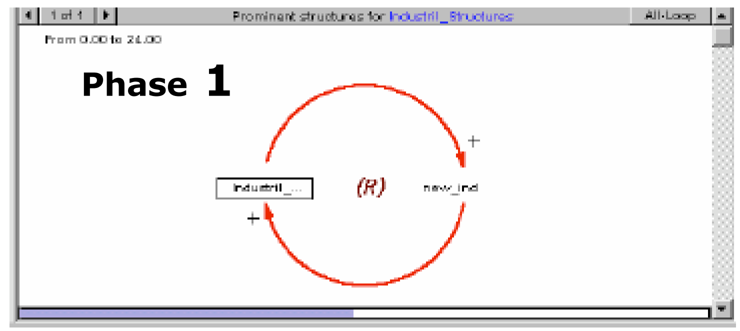
5 Water Consumption Growth (R)
effect of water adequacy on growth
new industries
Industrial Structures
water demand
water consumption
water adequacy

6 Industry Growth and Consumption Limit (B)
effect of water adequacy on growth
new industries
Industrial Structures
water demand
water availability
effect of water availability on consumption
water consumption
water adequacy

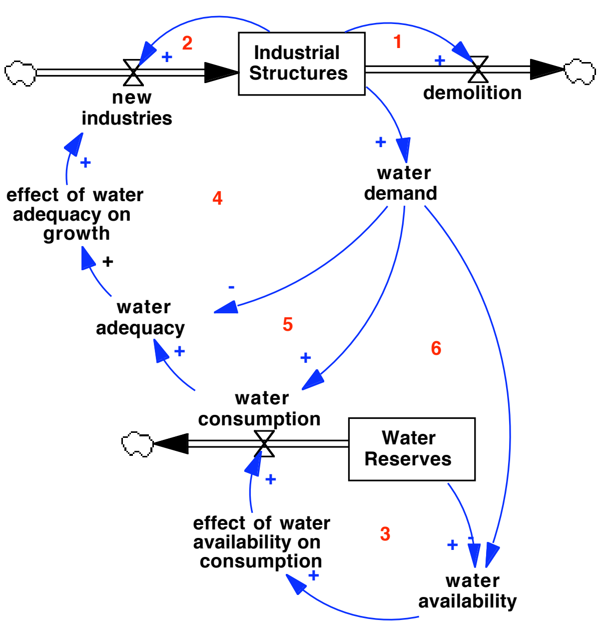
Pathway Participation Analysis
Industry Structures

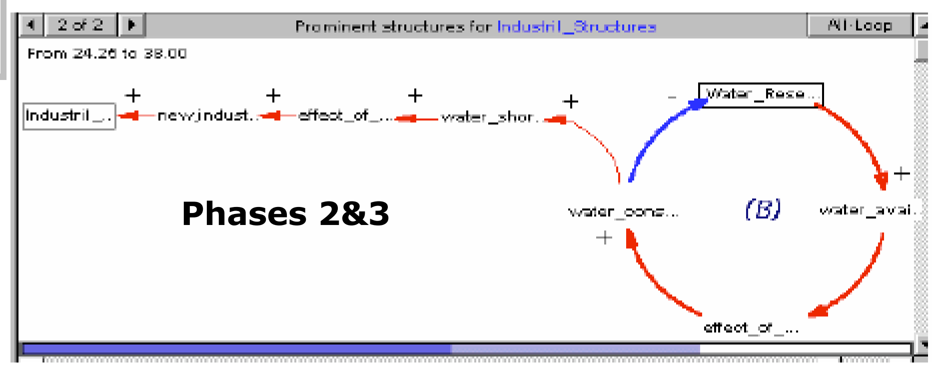
SILS Loop #



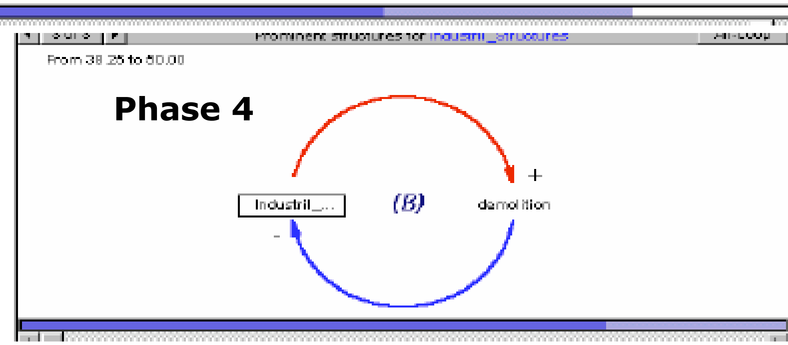


2





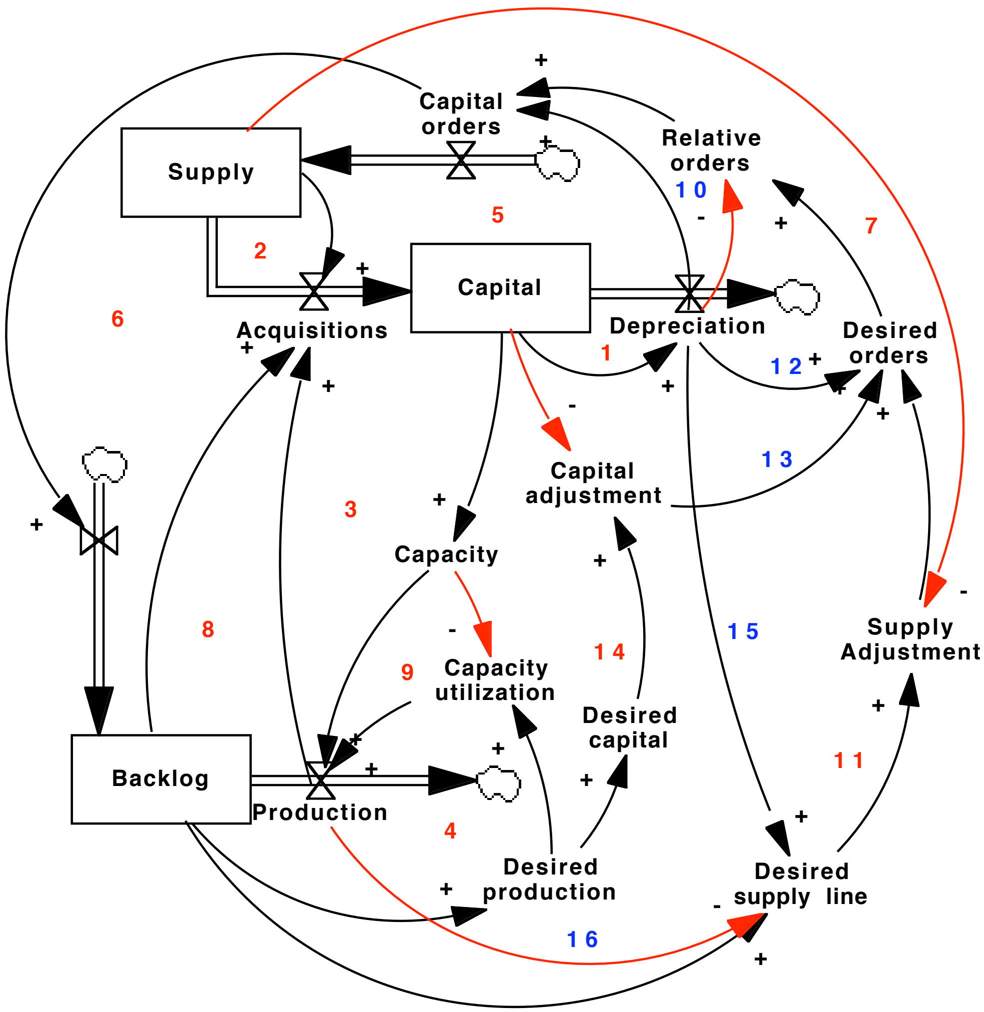
3



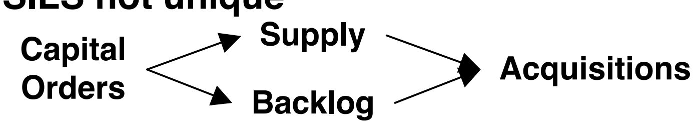
1

Stock & flow diagram of cycle partition

(Kampmann 1996; Ford 1999)



- SILS -- Intuitive loops
  1. Capital decay (B)
  2. Supply 1st order control (B)
  3. Economic growth (R)
  4. Overtime (goal) (B)
  5. Capital steady-state (R)
  6. Capital steady-state (orders) (R)
  7. Supply line adjustment (cc) (B)
  8. Order fulfillment (B)
  9. Overtime (cc) (B)
  10. Capacity steady-state (baseline) (B)
  11. Supply line adj. (goal orders) (R)
  12. Capital replenishment (R)
  13. Capital adjustment (cc) (B)
  14. Capital self-ordering (goal) (R)
  15. Supply line adj. (goal depreciation) (R)
  16. Supply line adj. (cc production) (B)
- SILS not unique

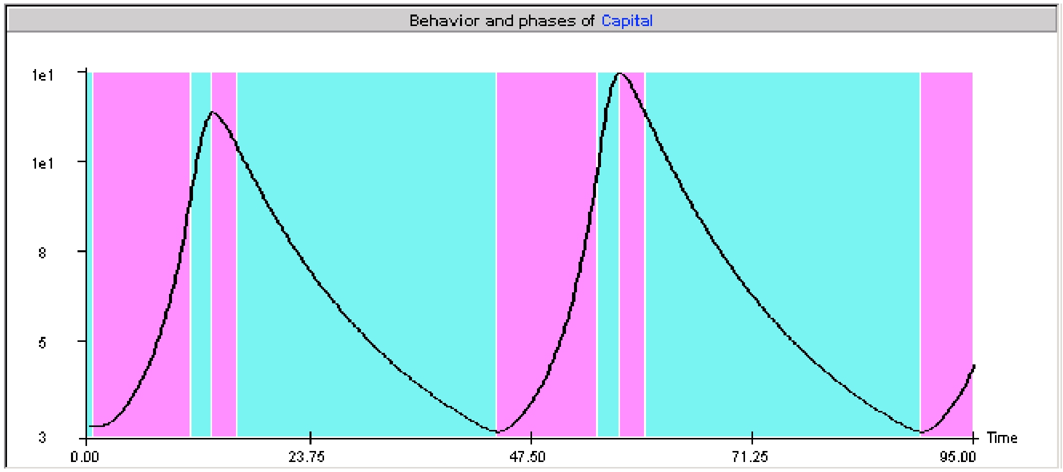


  - Loops 10, 12, 13, 15, and 16
- MSILS≠SILS
  - Loops 3, 6 and 8 could be eliminated

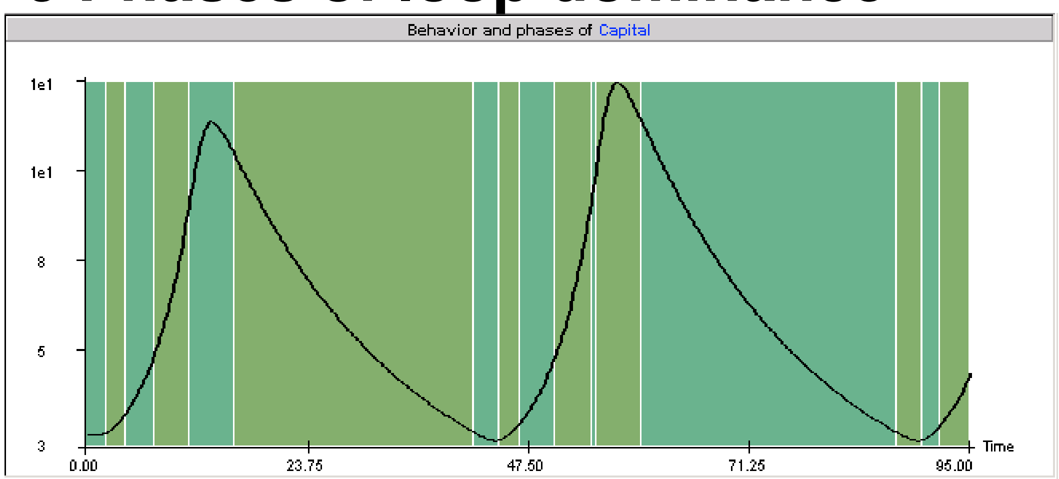
Pathway Participation Analysis

Long wave model

4 Reference modes



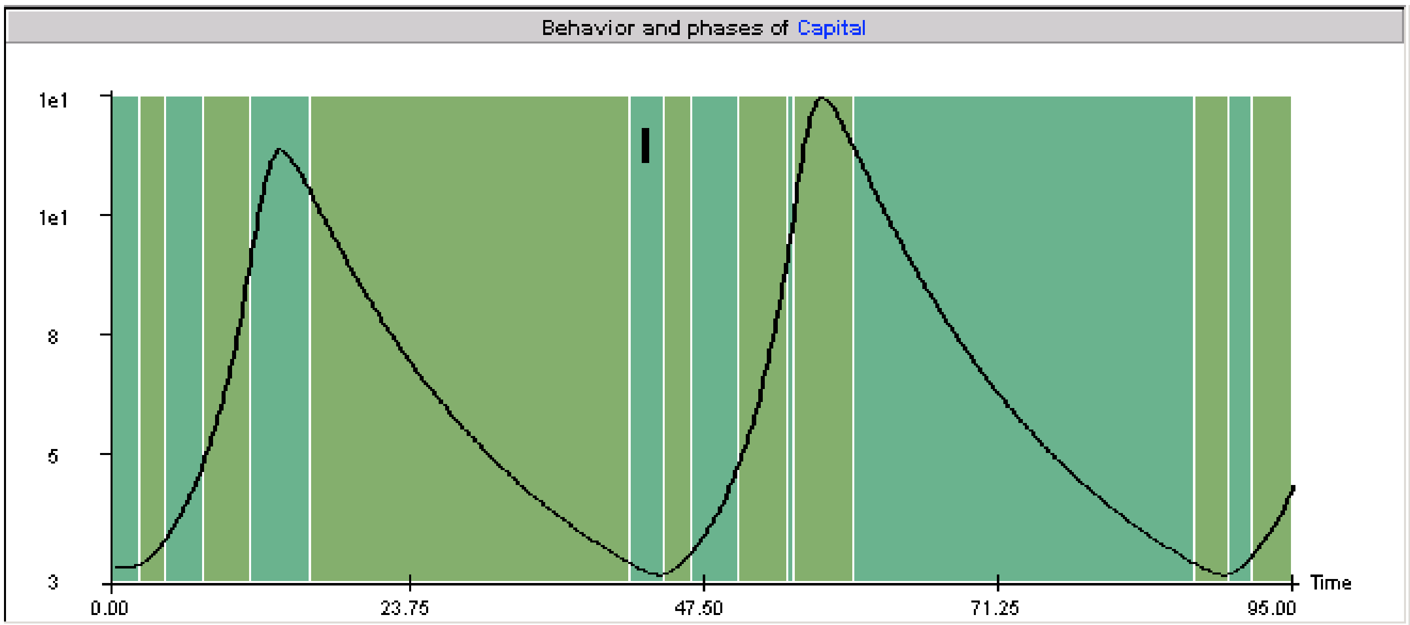
6 Phases of loop dominance

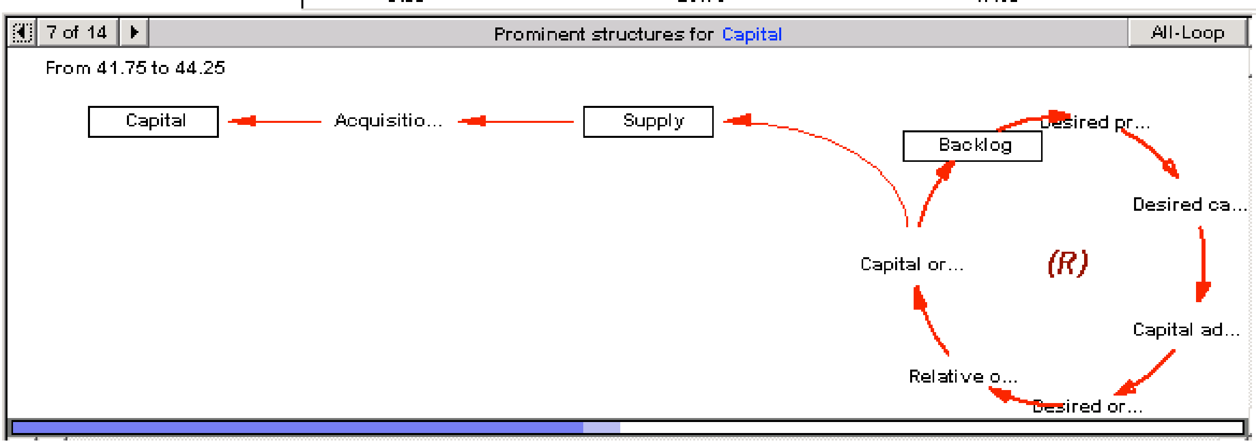


Lag of impact of shift in loop dominance on Capital

Pathway Participation Analysis

Long wave model



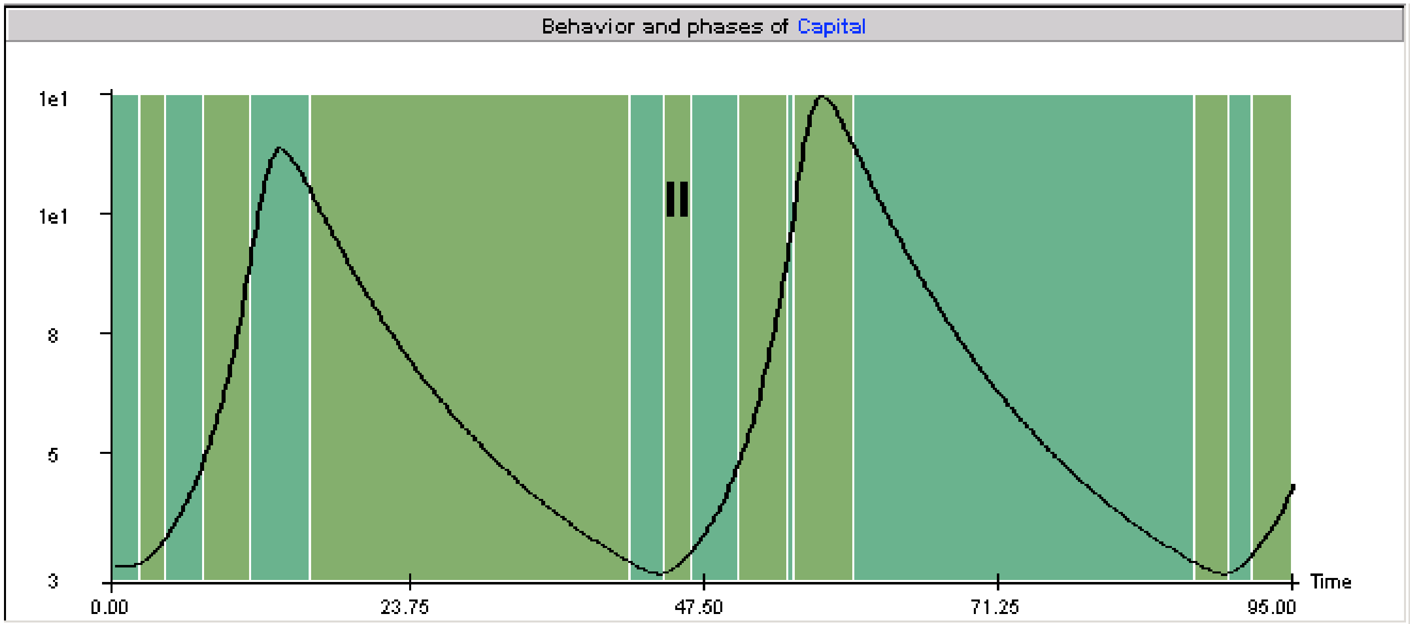


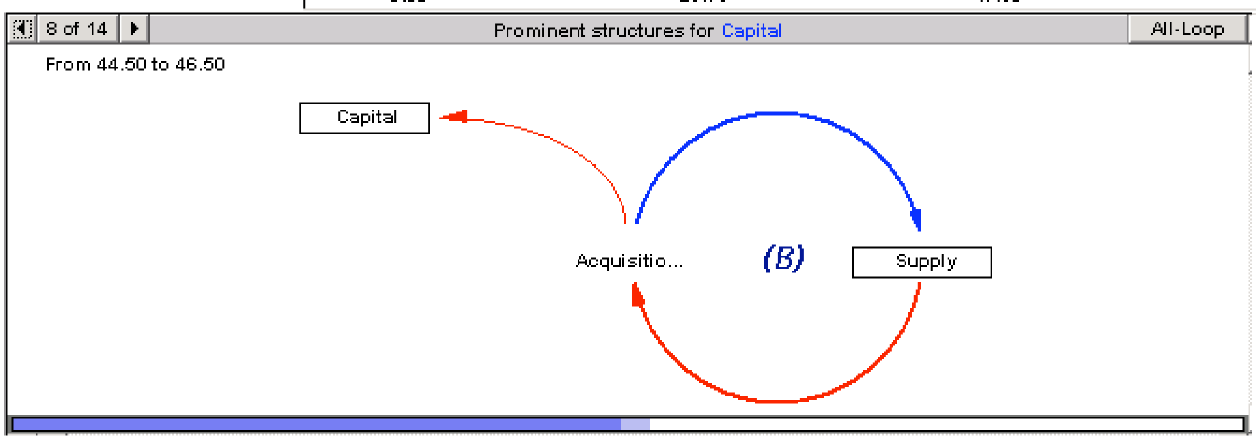
I-14. Capital Self-ordering

As capital drops below desired capital, orders for the capital sector are placed, reducing the net depletion rate

Pathway Participation Analysis

Long wave model



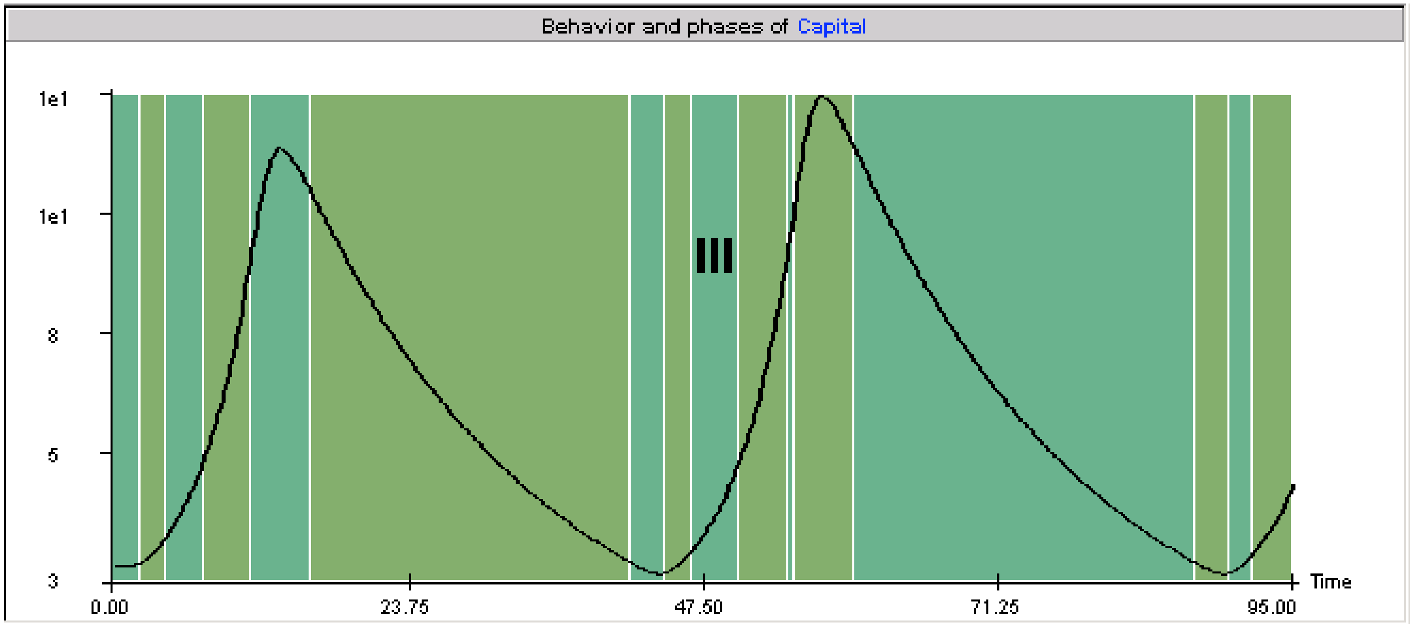


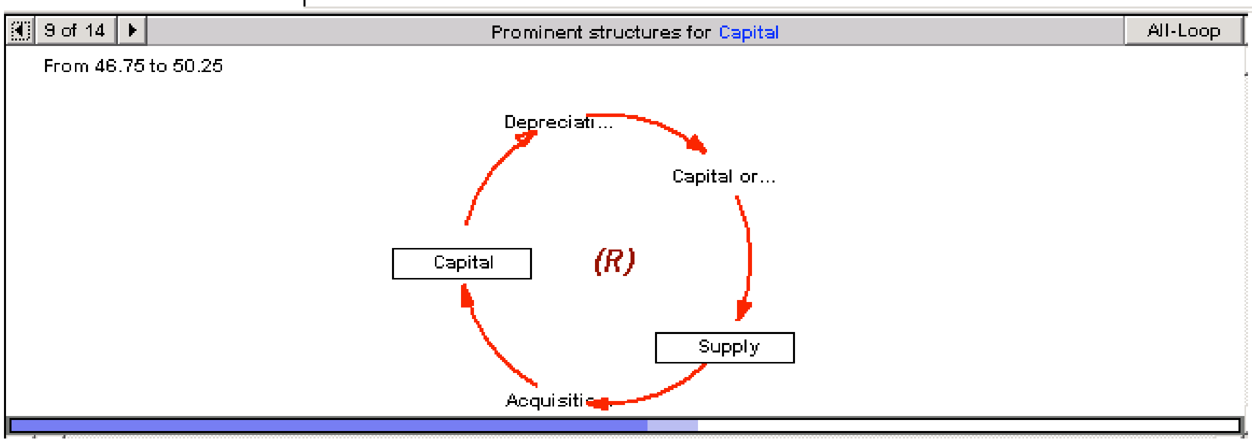
II-2. Supply 1st ordr control

Acquisitions>Depreciation, but growth is limited by orders in the supply line

Pathway Participation Analysis

Long wave model



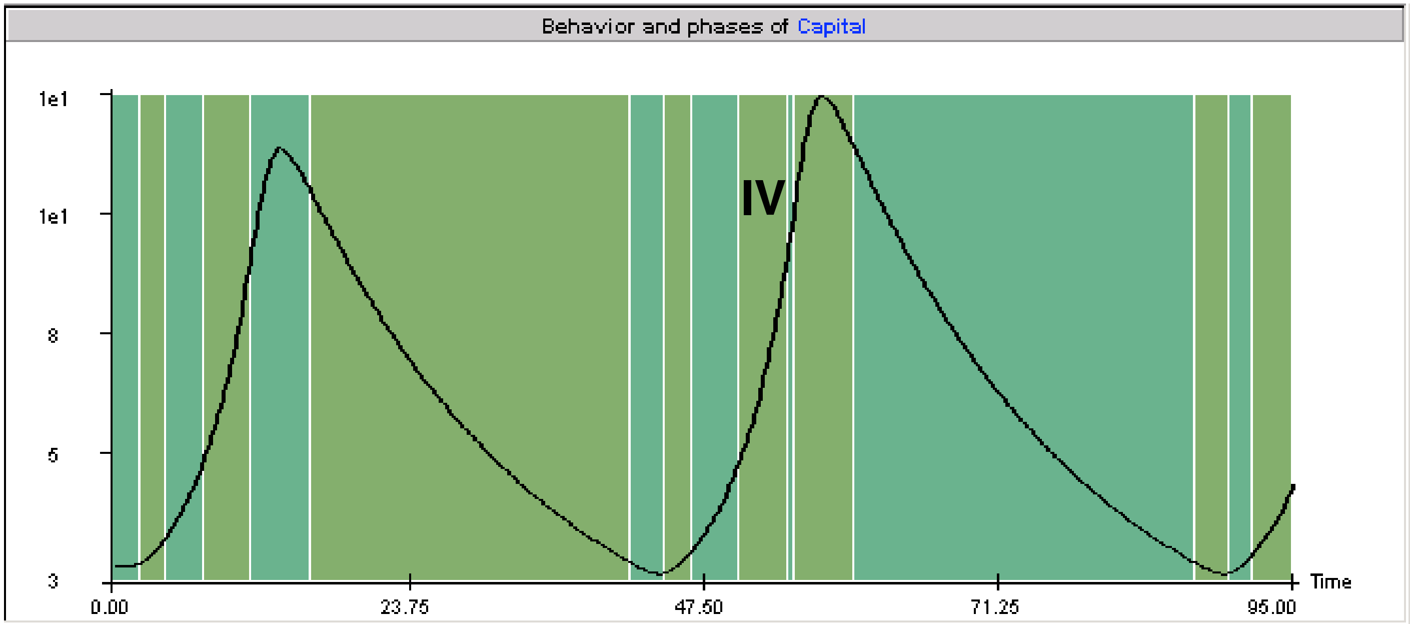


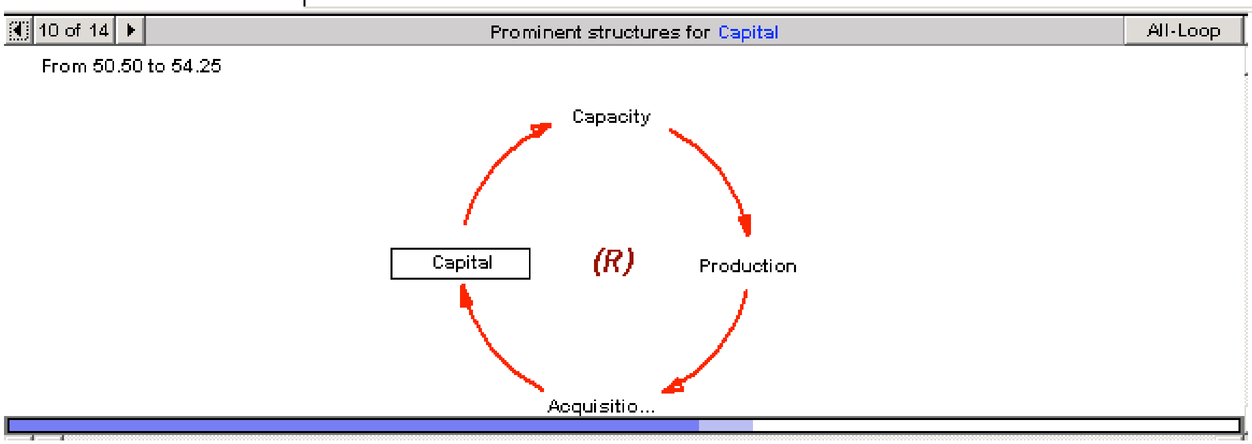
III-5. Capital Steady State

Replacement of capital depreciation drives growth for a while

Pathway Participation Analysis

Long wave model



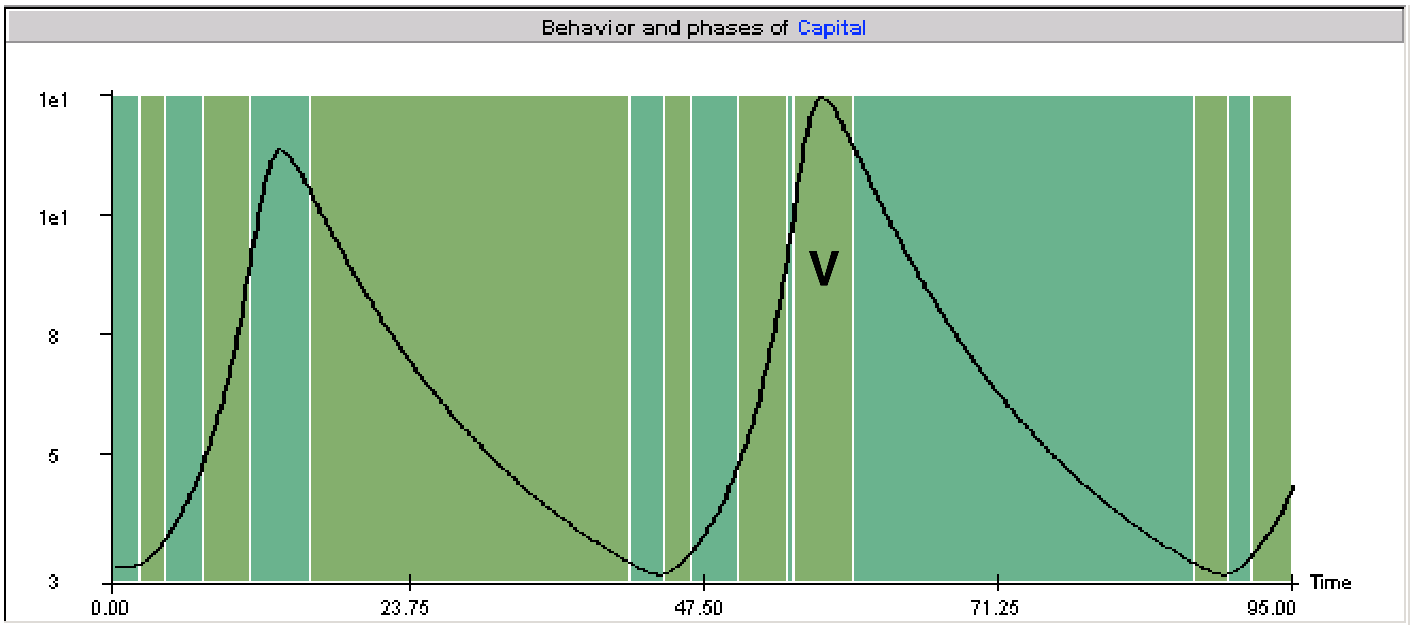


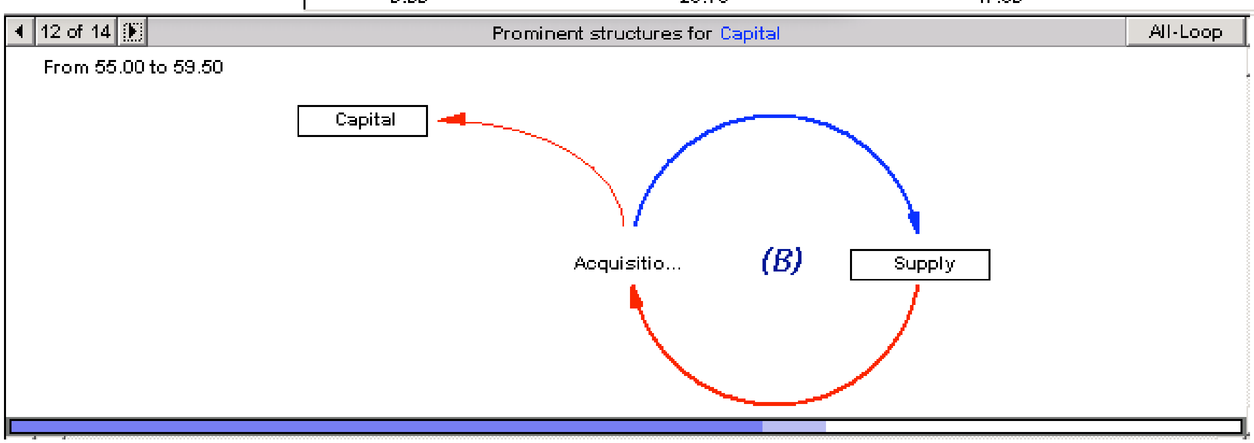
IV-3. Economic growth

Capital infrastructure has grown enough to drive the production of additional of capital infrastructure production > orders placed

Pathway Participation Analysis

Long wave model



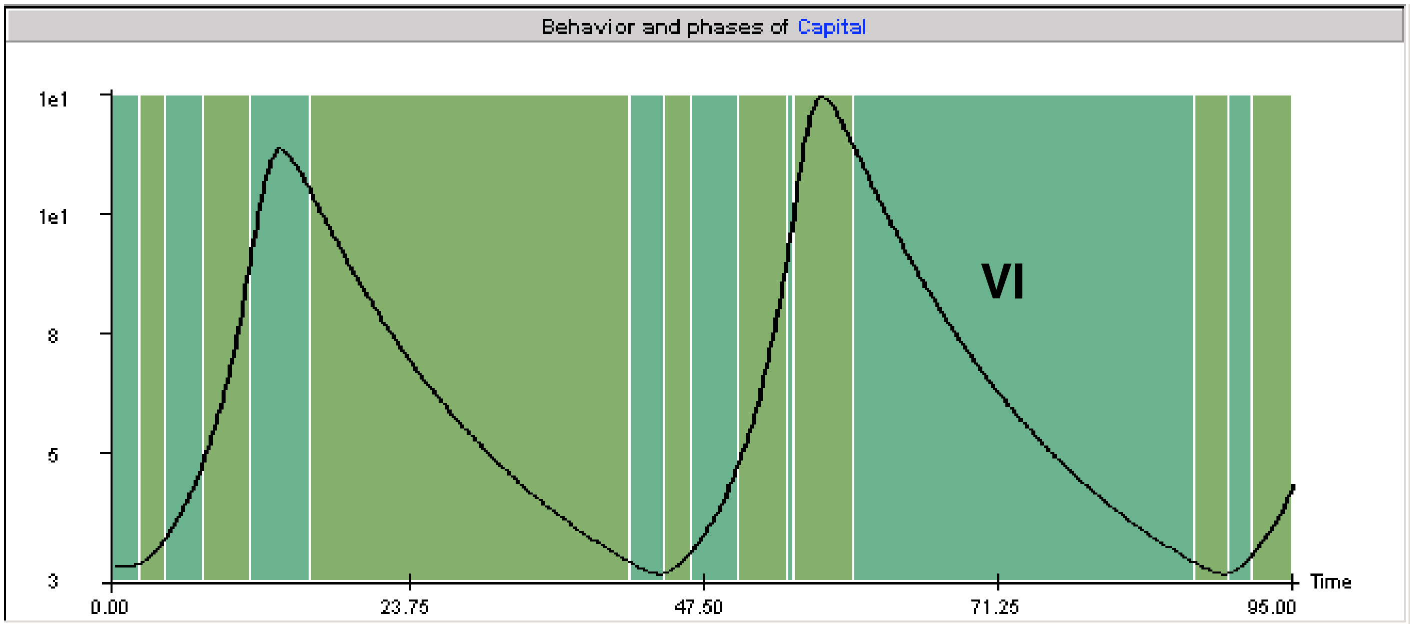


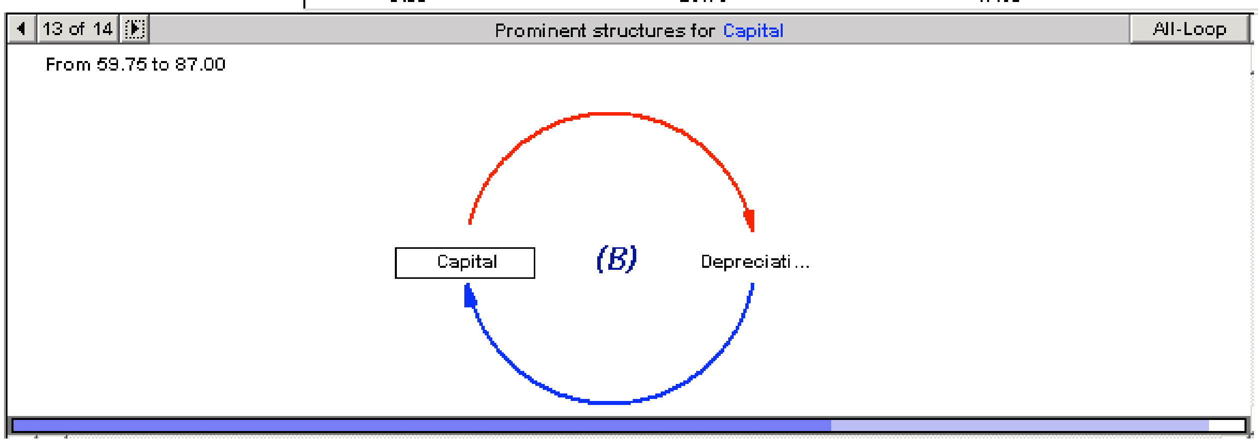
V-2. Supply 1st ordr control

Since the Supply stock has been depleted, it limits the Capital growth rate

Pathway Participation Analysis

Long wave model



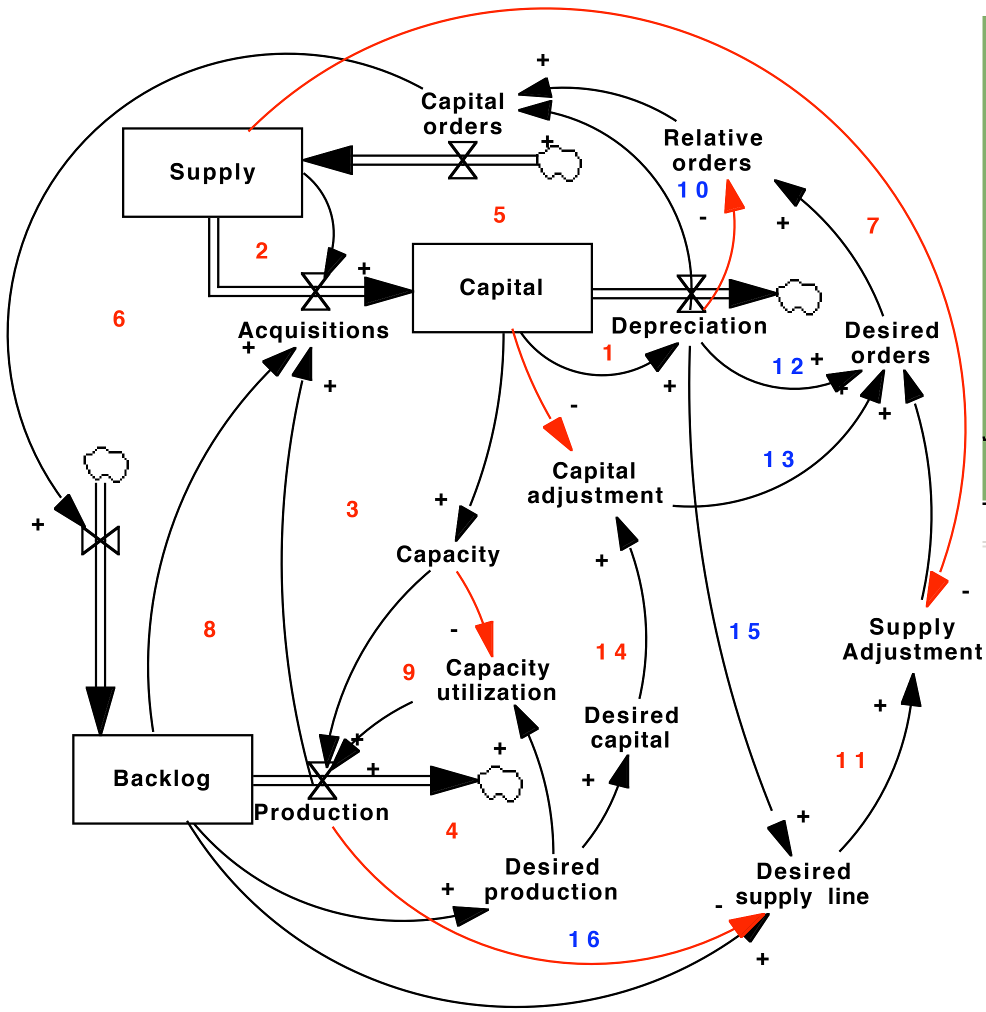


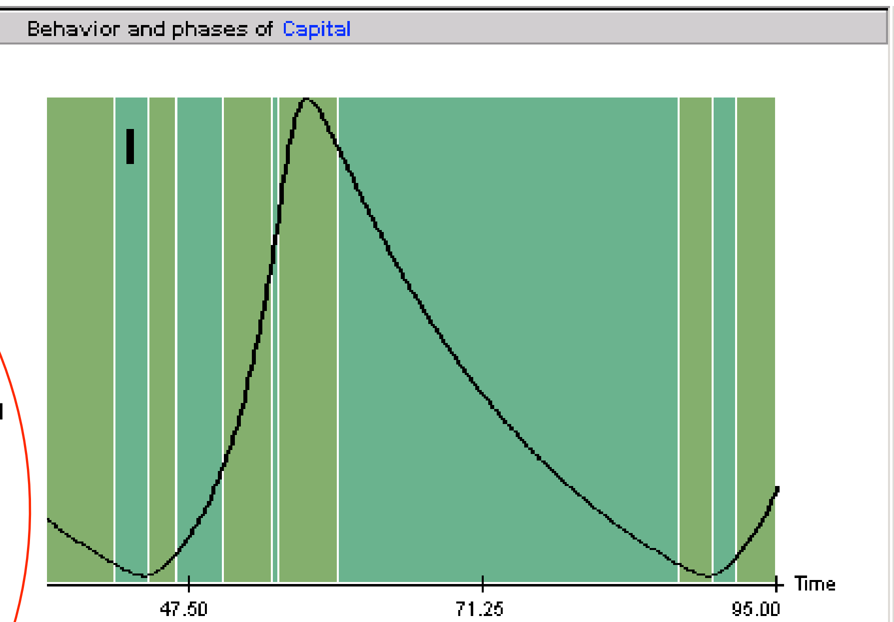
VI-1. Capital decay

Slow depletion of the Capital stock

Pathway Participation Analysis

Long wave model



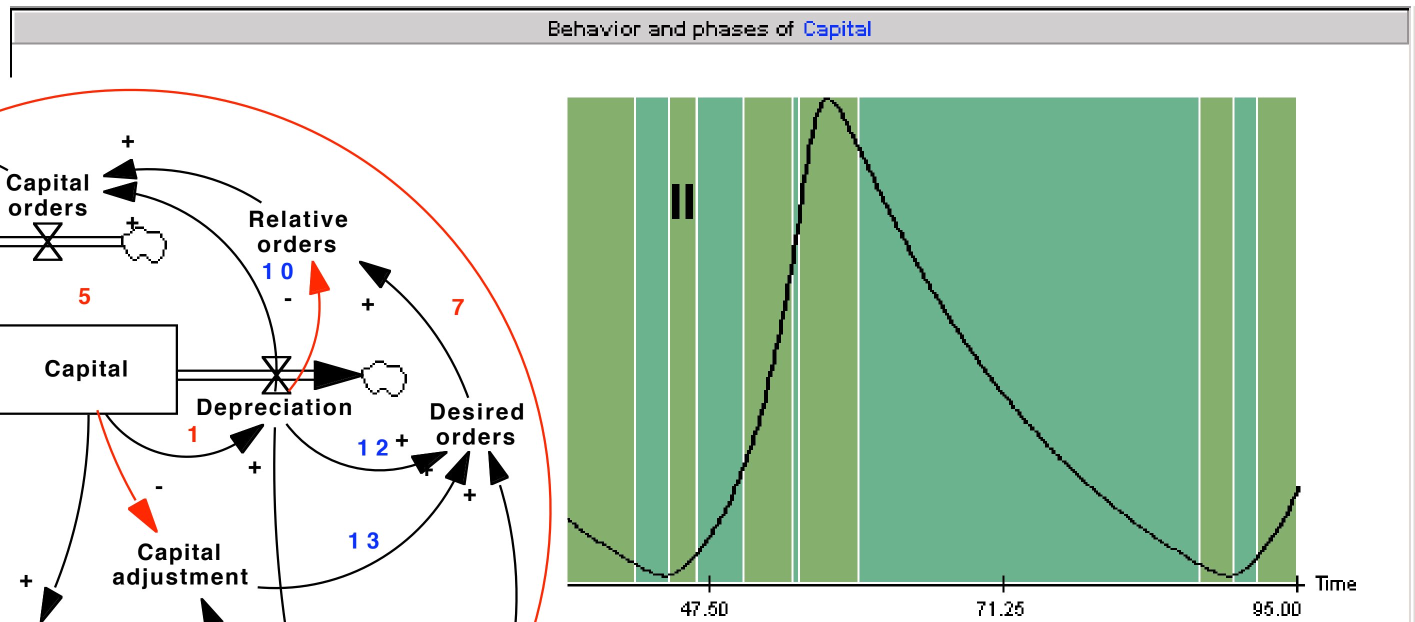


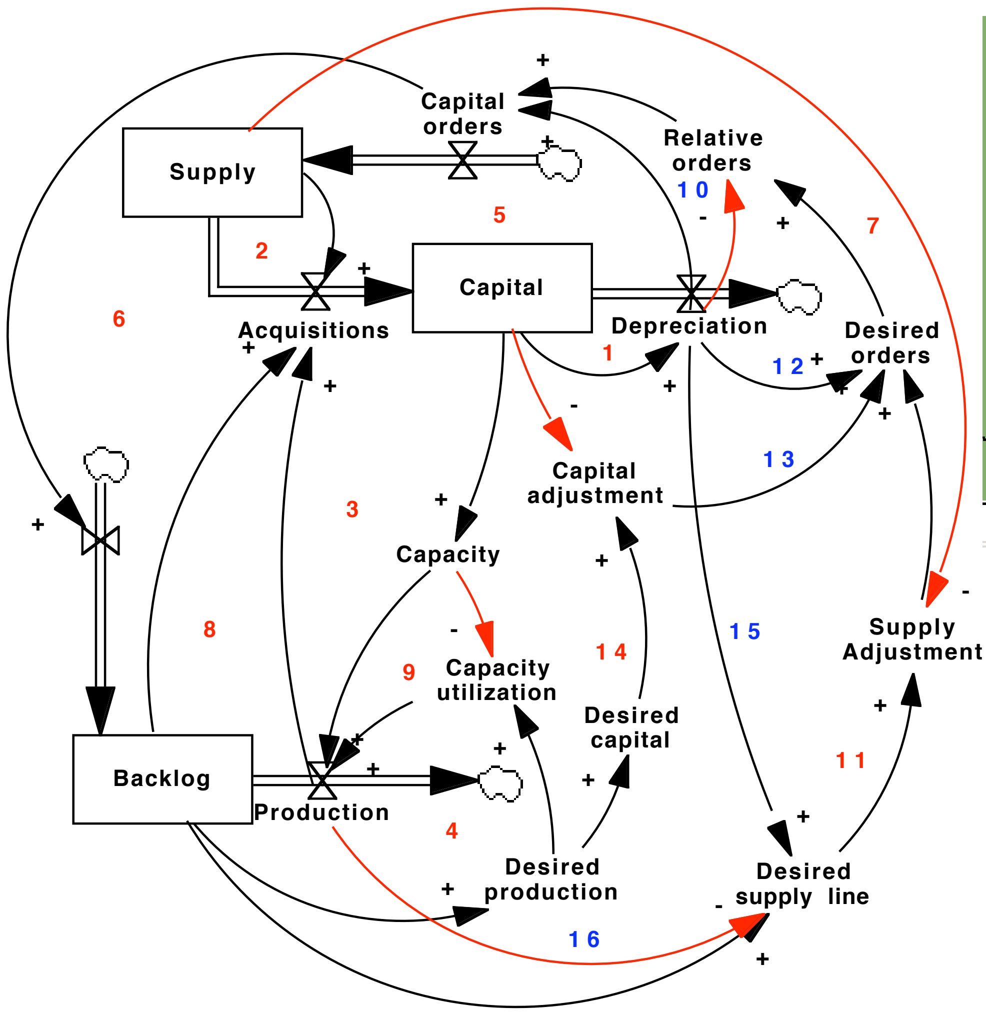
I-14. Capital Self-ordering

As capital drops below desired capital, orders for the capital sector are placed, reducing the net depletion rate

Pathway Participation Analysis

Long wave model



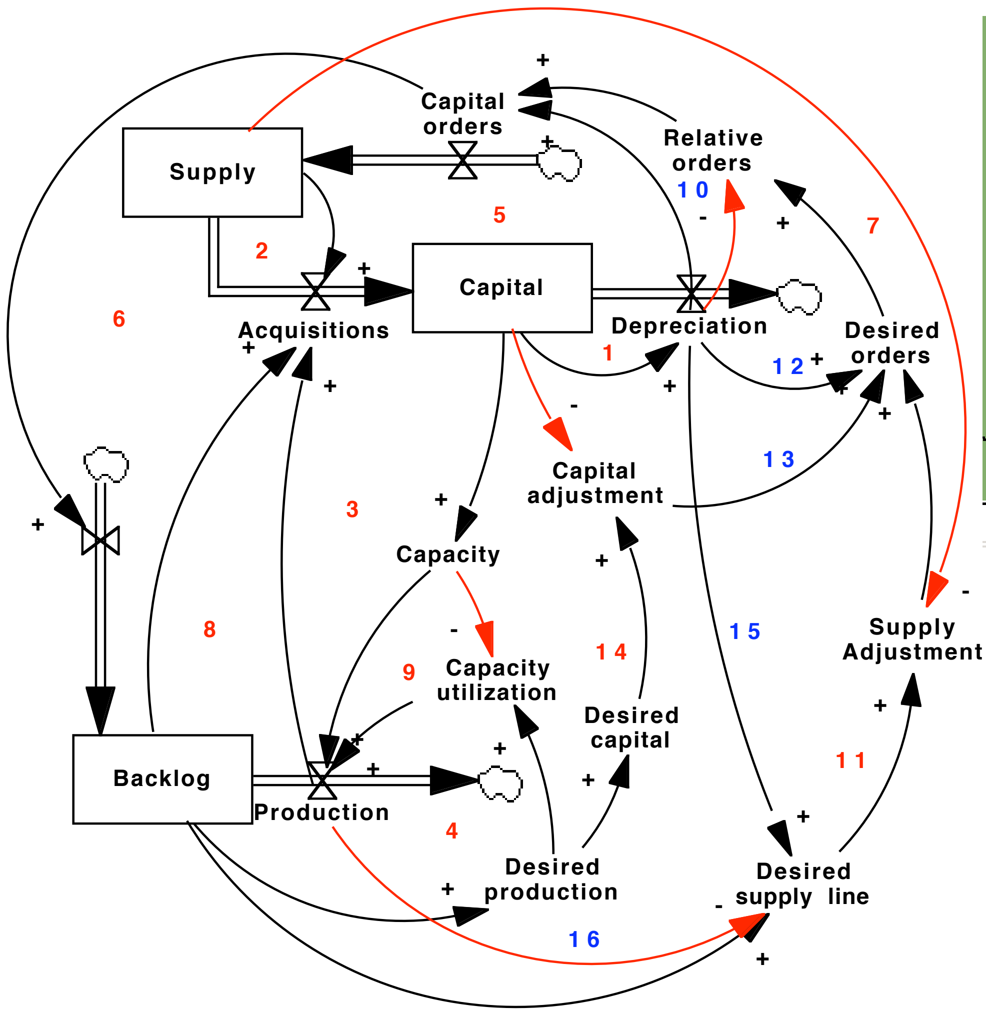


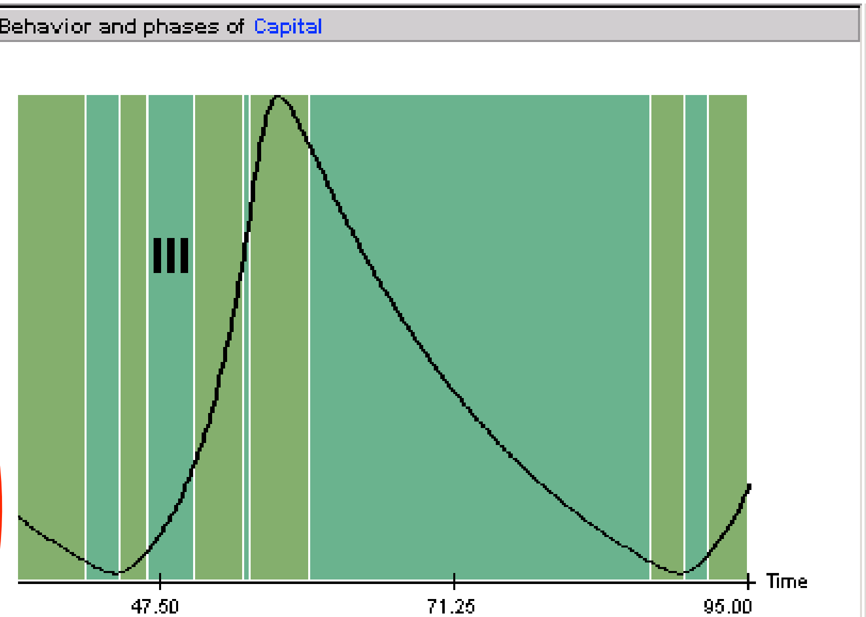
II-2. Supply 1st ordr control

Acquisitions>Depreciation, but growth is limited by orders in the supply line

Pathway Participation Analysis

Long wave model



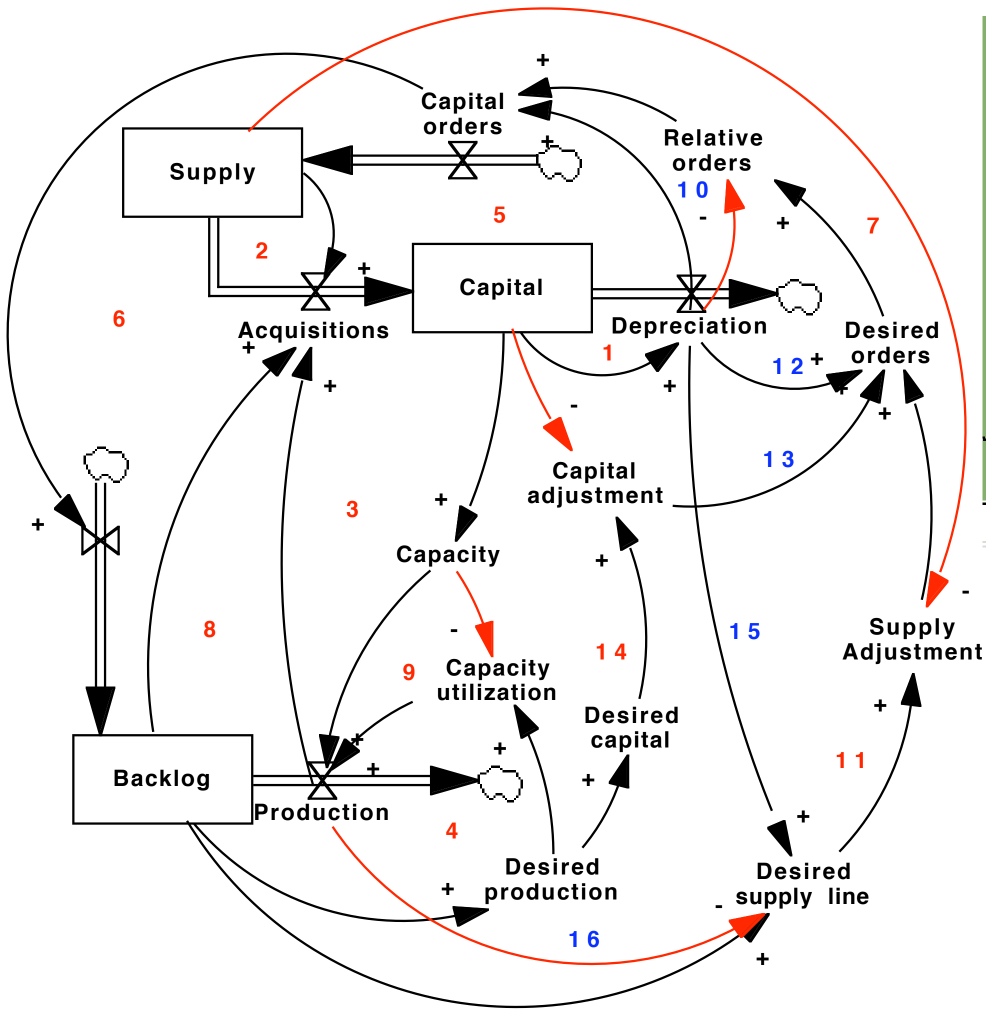


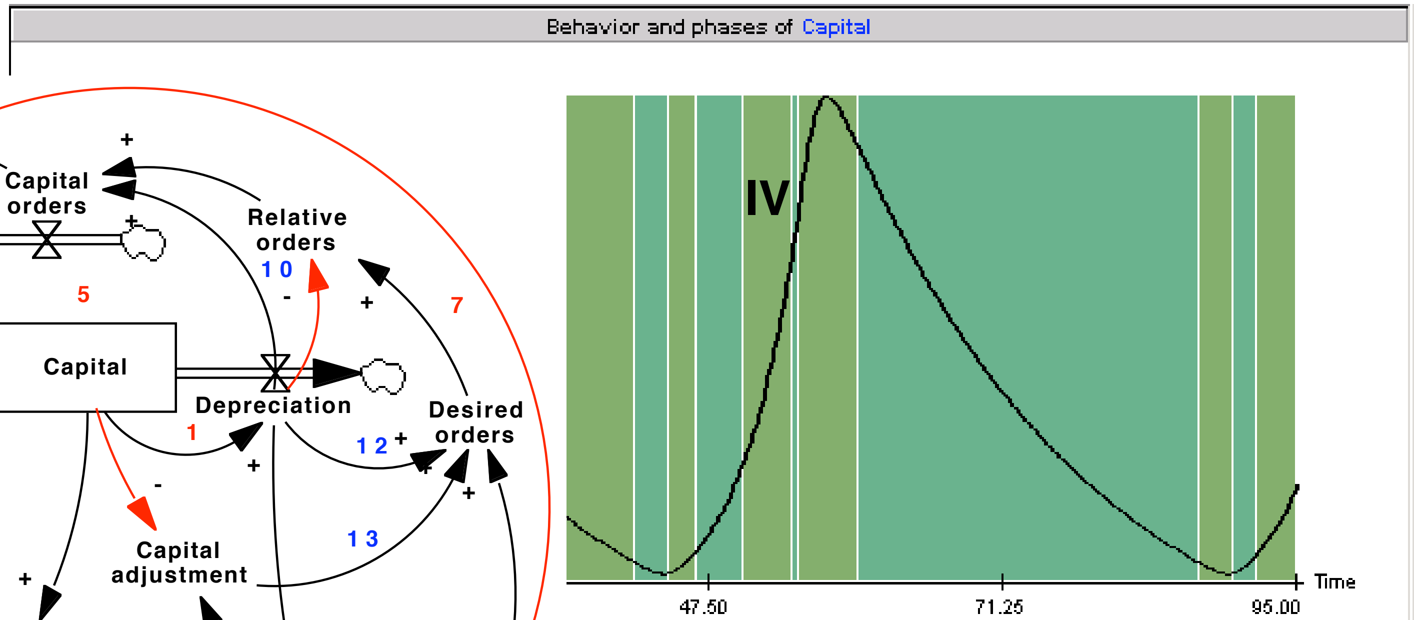
III-5. Capital Steady State

Replacement of capital depreciation drives growth for a while

Pathway Participation Analysis

Long wave model



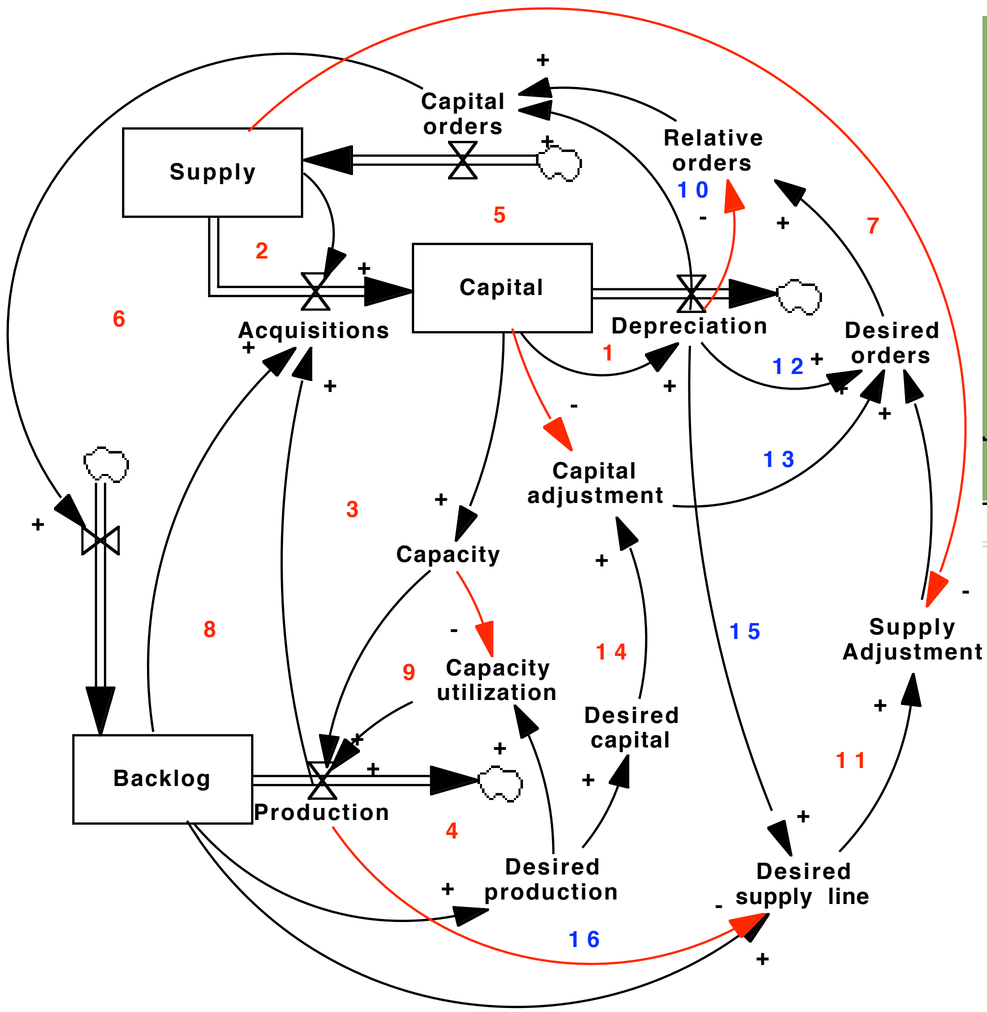


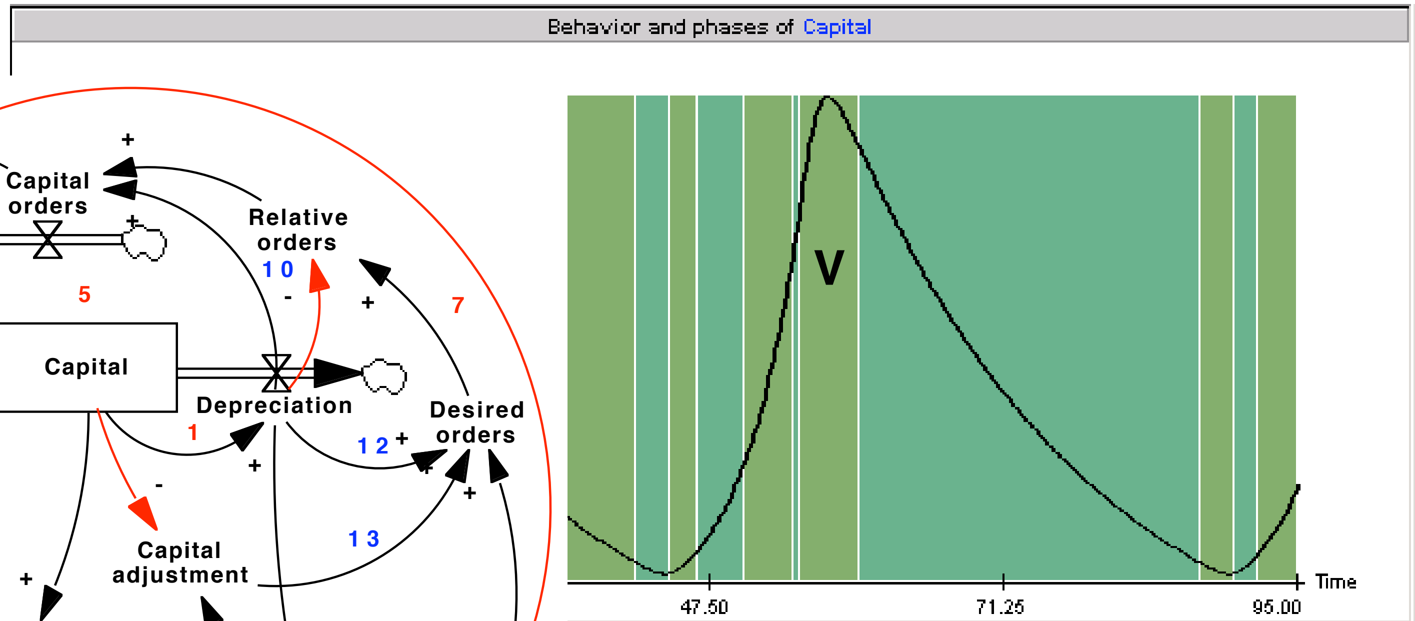
IV-3. Economic growth

Capital infrastructure has grown enough to drive the production of additional of capital infrastructure production > orders placed

Pathway Participation Analysis

Long wave model



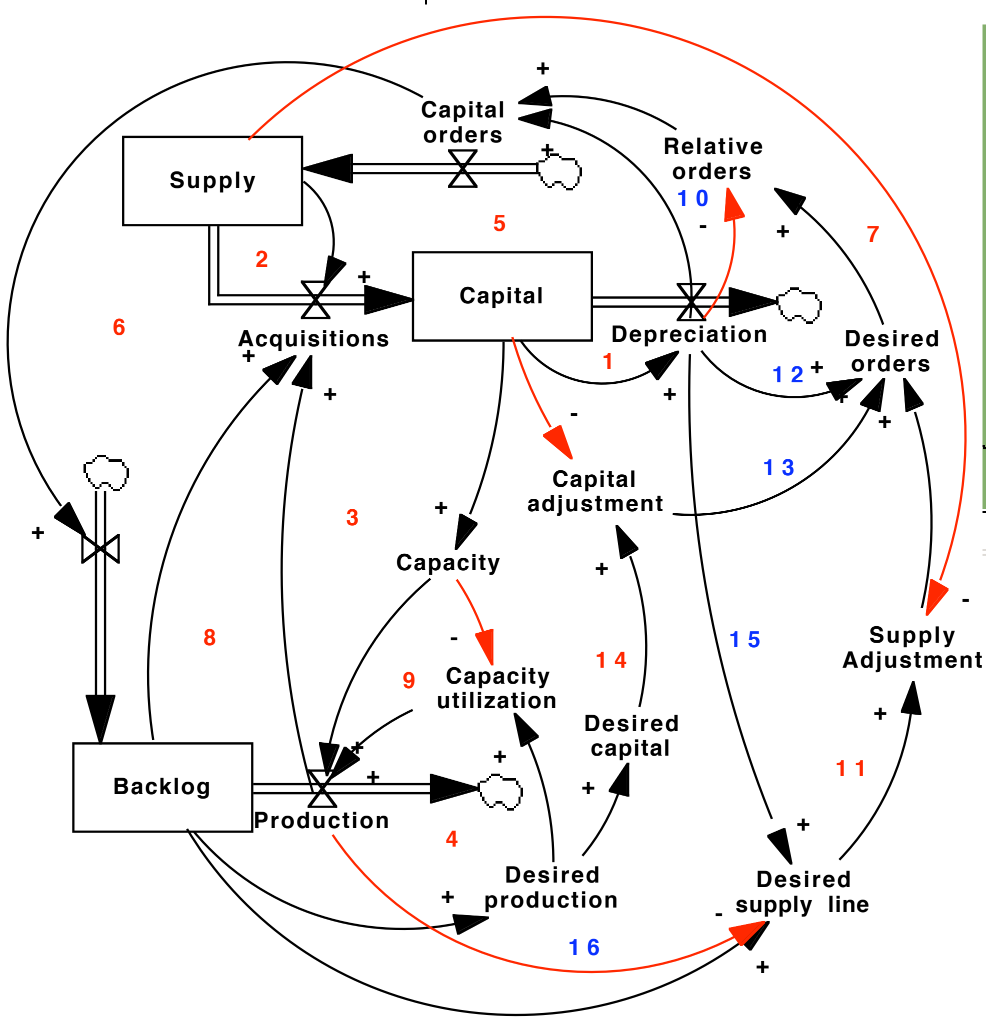


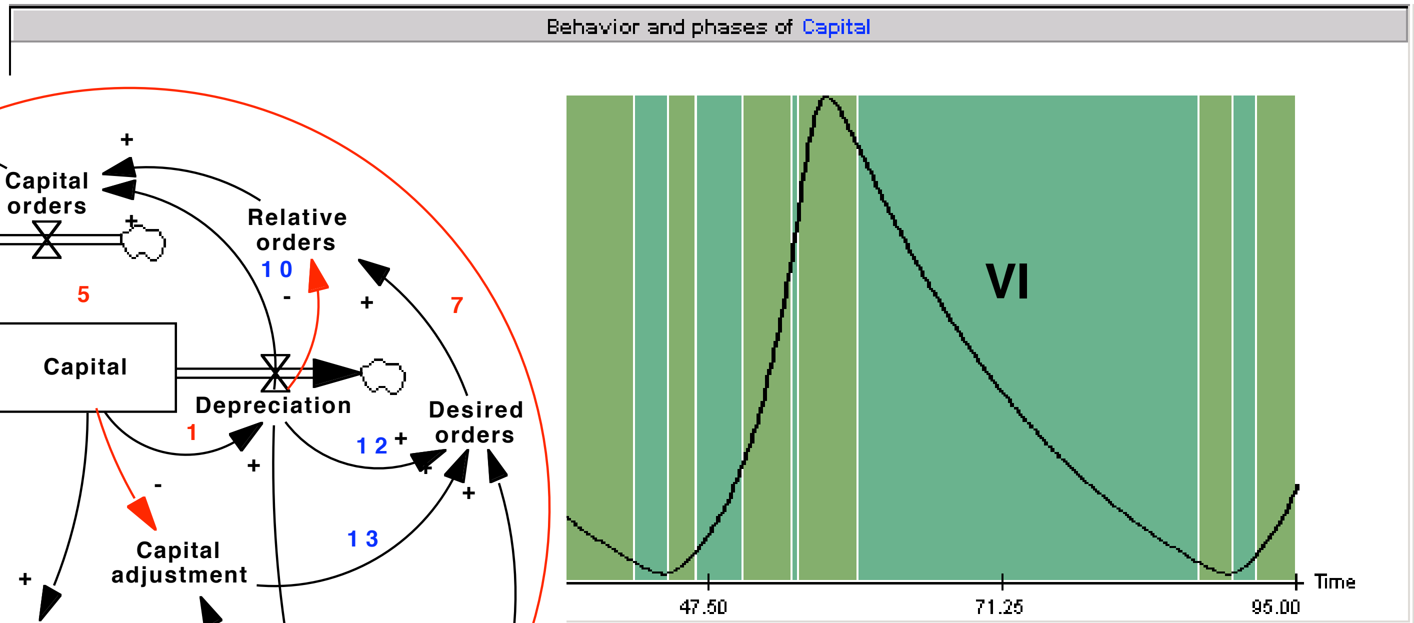
V-2. Supply 1st ordr control

Since the Supply stock has been depleted, it limits the Capital growth rate

Pathway Participation Analysis

Long wave model





VI-1. Capital decay

Slow depletion of the Capital stock

Results

- **For all tested models**
  - Loops in SILS proved more intuitive
  - Loops in SILS captured the core dynamics
    - All of Digest analyses found a loop in the SILS as the most significant (all phases)
  - "System stories" based on sorter loops were move intuitive

- **Additional Insight**
  - Not a good idea to reduce the SILS into a MSILS … it is in these core loops that some of the key dynamics are taking place

Implications

- **Using a cycle decomposition based on the SILS to perform Kampmann's proposed analysis will**
  - **Allow for an exploration of *interacting* feedback loops based on the simplest, most granular and intuitive loops**
    - **The analysis will be system-wide (overall interaction of different loops) AND based on an intuitive set of loops**
  - **Proposed process seems promising since SILS is unique under most conditions**

Resources

- http://www.people.hbs.edu/roliva/research/sd/
- Oliva, R., 2003. Model Structure Analysis through Graph Theory: Partition Heuristics and Feedback Structure Decomposition. Harvard Business School Working Paper Series, No. 04-016.
  - Translator from model equations (Vensim) to adjacency binary matrix
  - Model Structure Analysis (MSA) functions for MATLAB (D-4864)

References

- Forrester N. 1982. A dynamic synthesis of basic macroeconomic policy: Implications for stabilization policy analysis. PhD Thesis, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA.
- Gonçalves P, Lerpattarapong C, Hines JH. 2000. Implementing formal model analysis. *Proceedings of the 2000 Int. System Dynamics Conference*. Bergen, Norway.
- Kampmann CE. 1996. Feedback loop gains and system behavior (unpublished manuscript). Summarized in Proceedings of 1996 Int. System Dynamics Conference (p. 260-263). Cambridge MA.
- Mojtahedzadeh MT, Andersen D, Richardson GP. 2004. Using *Digest* to implement the pathway participation method for detecting influential system structure. *System Dynamics Review* (forthcoming).
- Mojtahedzadeh MT. 1996. A path taken: Computer assisted heuristics for understanding dynamic systems. PhD. Dissertation, University at Albany, SUNY, NY.
- Oliva R. 2003. Model structure analysis through graph theory: Partition heuristics and feedback structure decomposition. Harvard Business School, Working Paper Series, 04-016. Boston, MA.