

# **Interdependency and Infrastructure**

## **Lecture 3 –Applications Modeling of Interdependency I**

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# Overview

- **Modeling**
- **Simulation**
- **Simulation Methods**
- **Modeling and Simulation**
- **Application**

# Modeling

- **An abstraction or representation of an object, system, etc.**
- **We model**
  - **what we cannot observe, but need to understand**
    - **Exists beyond current time**
    - **Spans beyond observational time**
  - **what we can observe, but cannot tinker with**





# Simulation

- **Imitating**
  - a real thing
  - a process
  - characteristics or behaviors of a physical or abstract systemso as to better understand that which is imitated
- **Simulation <> Modeling**
  - Model is presence
  - Simulation is realization

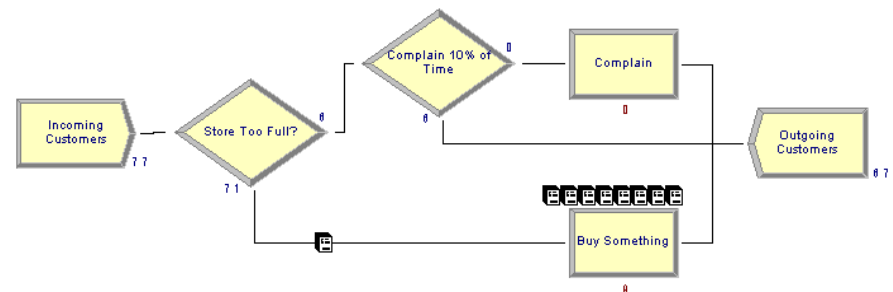


# Simulation Methods

- **Discrete Event Simulation**
- **Agent-Based Simulation**
- **System Dynamics**
- **Economic Modeling**

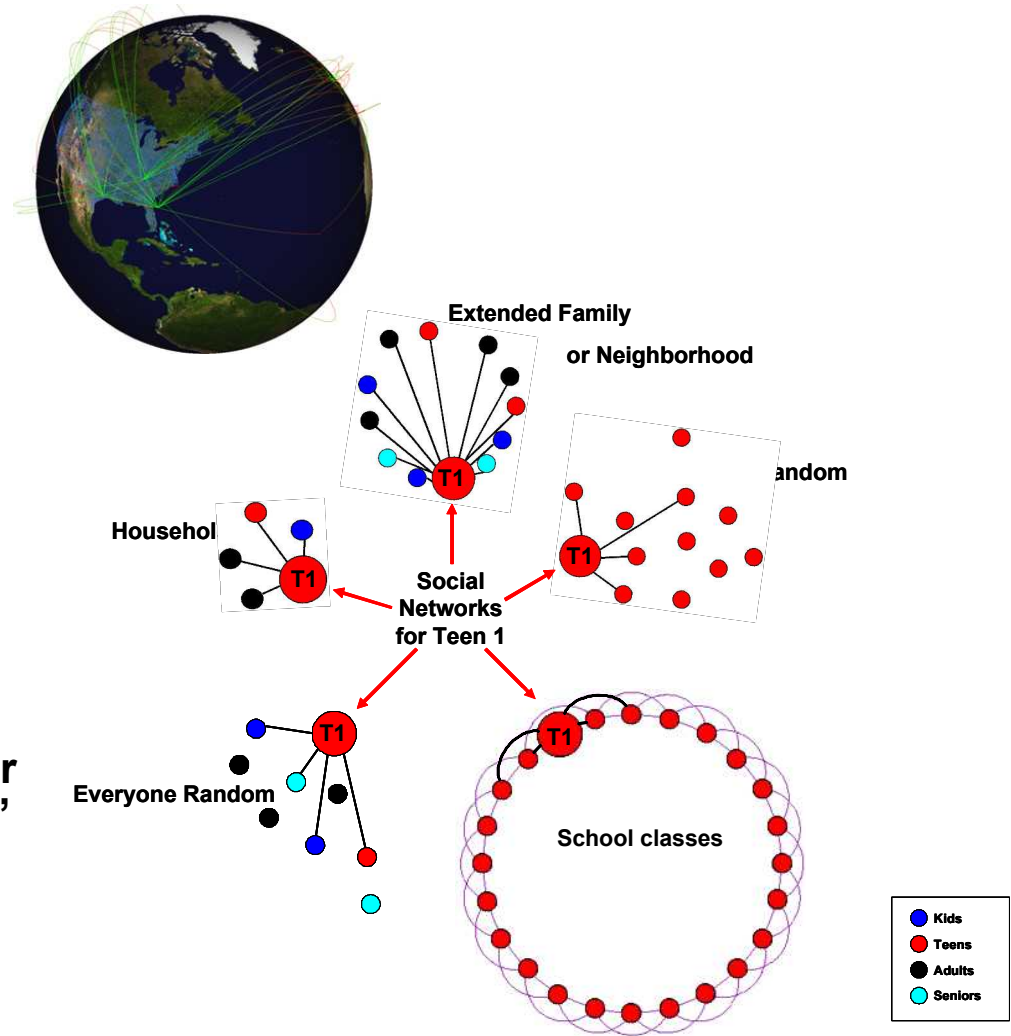
# Simulation Methods

- **Discrete Event Simulation (DES)**
  - aka Monte Carlo Simulation
  - Discrete event based
  - Stochastic processes
  - Events are random or structured variables
  - Queue – Seize – Delay – Release
  - Used in simulating
    - Banks (tellers, customers)
    - Factories (processing of raw materials into parts)
  - Definitive read
    - Law & Kelton, *Simulation Modeling and Analysis*



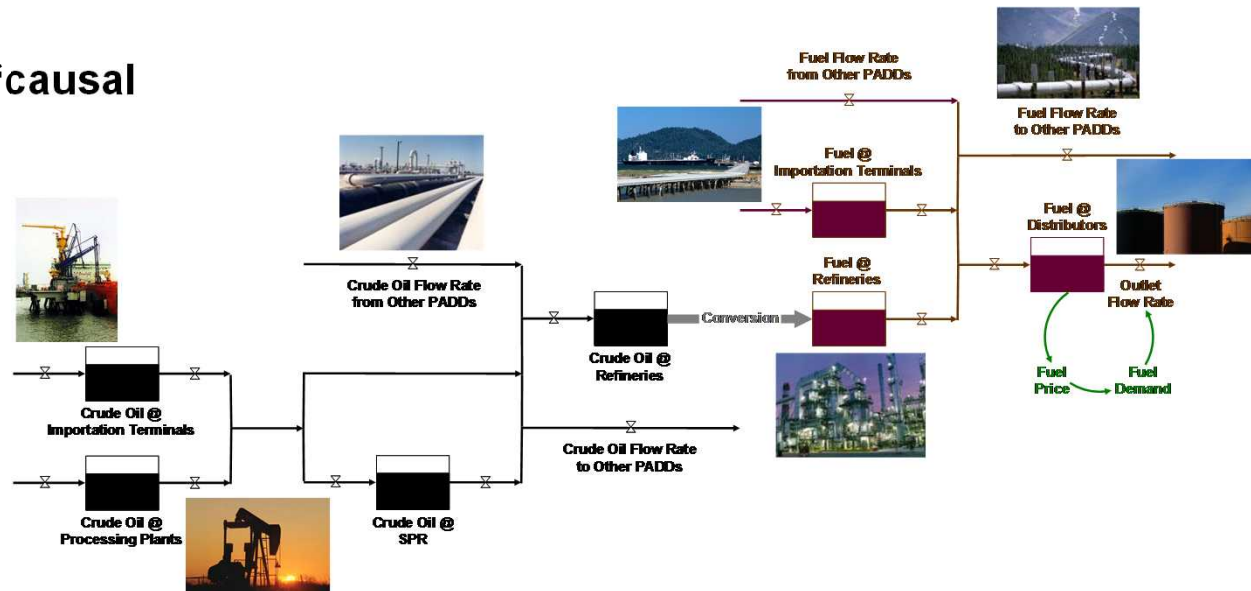
# Simulation Methods

- **Agent-Based Simulation**
  - Has elements of DES (randomness)
  - Communal in nature (social networking)
  - **Agents**
    - are intelligent
    - have purpose/goal
    - are spatially and temporally situated
    - interact with each other and their 'environment'
  - **Definitive read**
    - Buchanan, *Ubiquity*



# Simulation Methods

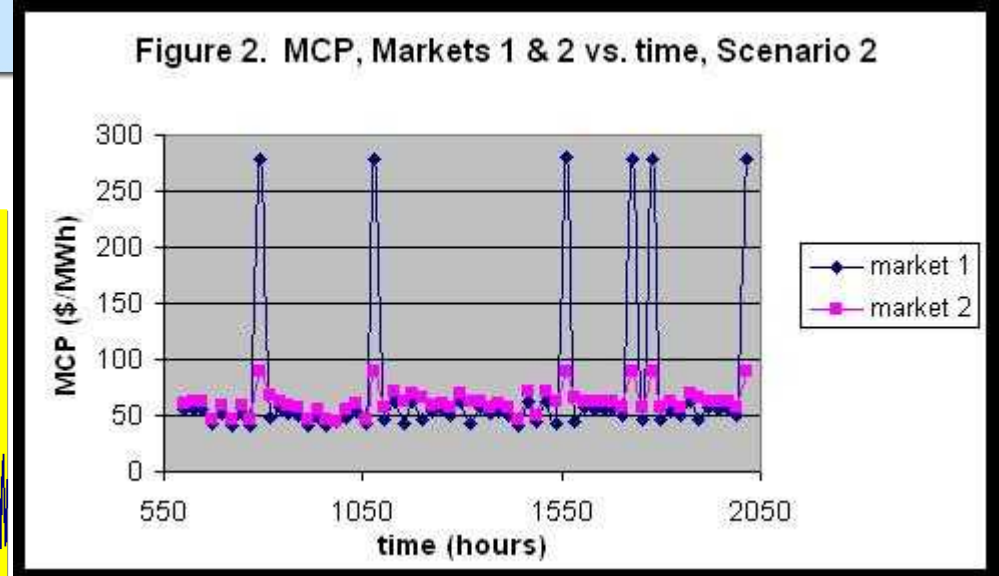
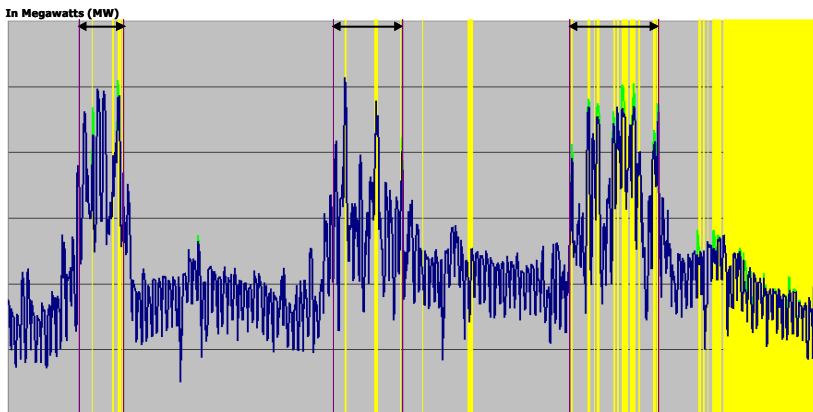
- System Dynamics
  - aka ‘Stock and Flow’, ‘causal loops’
  - Deterministic
  - Continuous
    - Differential equations rather than random variates
  - Definitive reads
    - Forrester, *Industrial Dynamics*
    - Sterman, *Business Dynamics*
    - Radzicki & Taylor, *Introduction to System Dynamics*





# Simulation Methods

- **Economic Modeling**
  - Many ‘flavors’
    - Macroeconomic
    - Microeconomic
    - I/O
    - Agent



# Modeling and Simulation

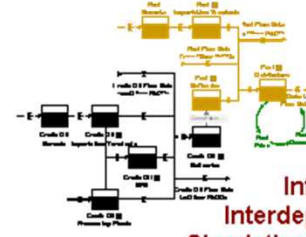


## The Urban Infrastructure Suite

- Urban Population Mobility Simulation Technologies
- Epidemiological Simulation Systems
- Telecommunications Sector
- Transportation Analysis Simulation System

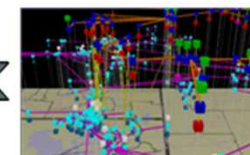


## NISAC Agent-Based Laboratory for Economics



## Dynamic Infrastructure Interdependencies Simulation & Analysis

## Water Infrastructure Simulation Environment



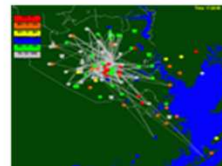
## Interdependent Energy Infrastructure Simulation System



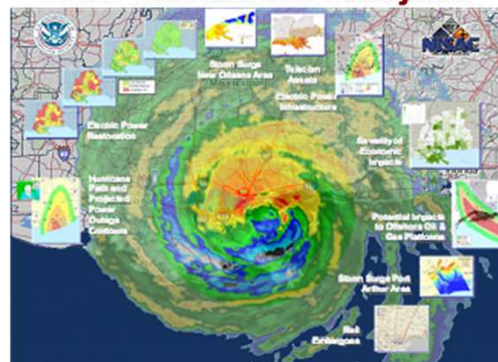
## Transportation Network Optimization Models



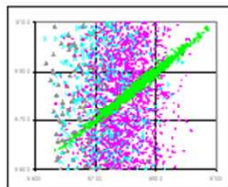
## Telecommunication Network Simulation Modeling and Analysis Tools



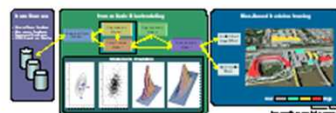
## FAST Turnaround Analyses



## Advanced Modeling & Techniques Investigation



## Methodologies for Asset Prioritization





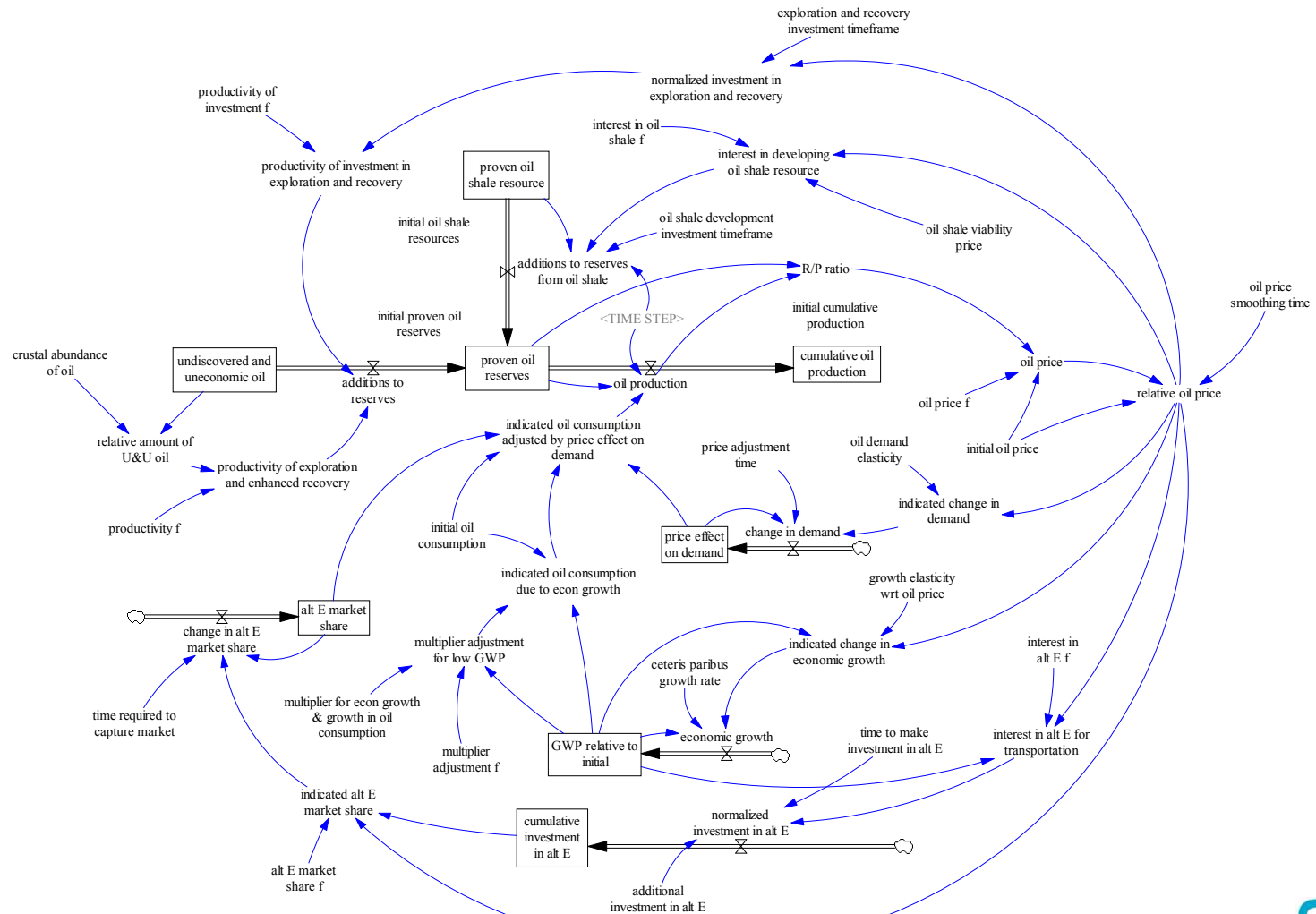
# Application

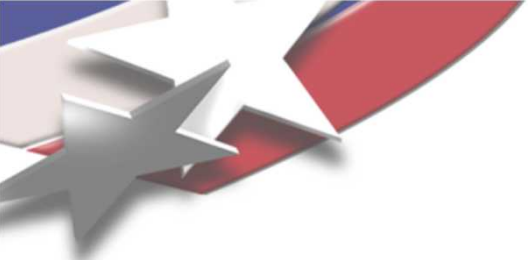
## World Peak Oil Issues Utilizing System Dynamics\*

- In the past, in the world's energy evolution performance, not scarcity, was the driver  
Wood → Coal  
Coal → Oil
- For the first time, we are driven by scarcity. Oil → ???
- Will the next generation of transportation fuels be available when oil production begins to decline?

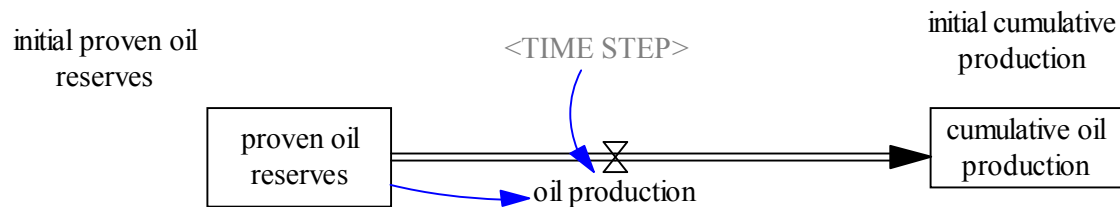
\* from Conrad, Blankenship, and Madrid, *World Oil: A Simple Dynamic Model*

# The Whole Enchilada (only about 55 variables)

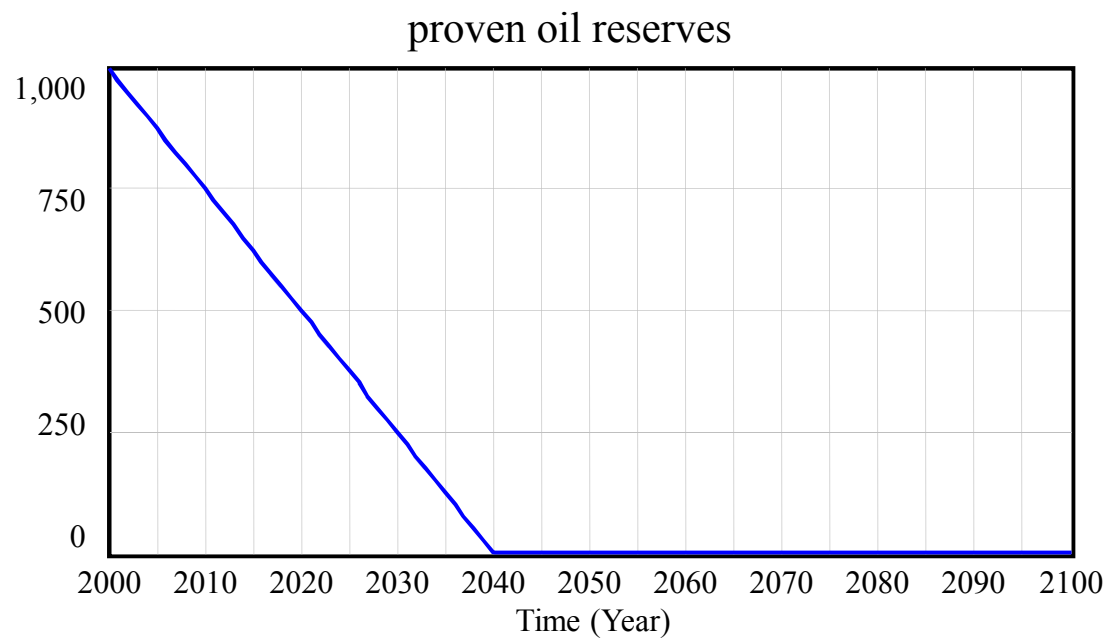




# In the beginning: We start with constant reserves and constant demand

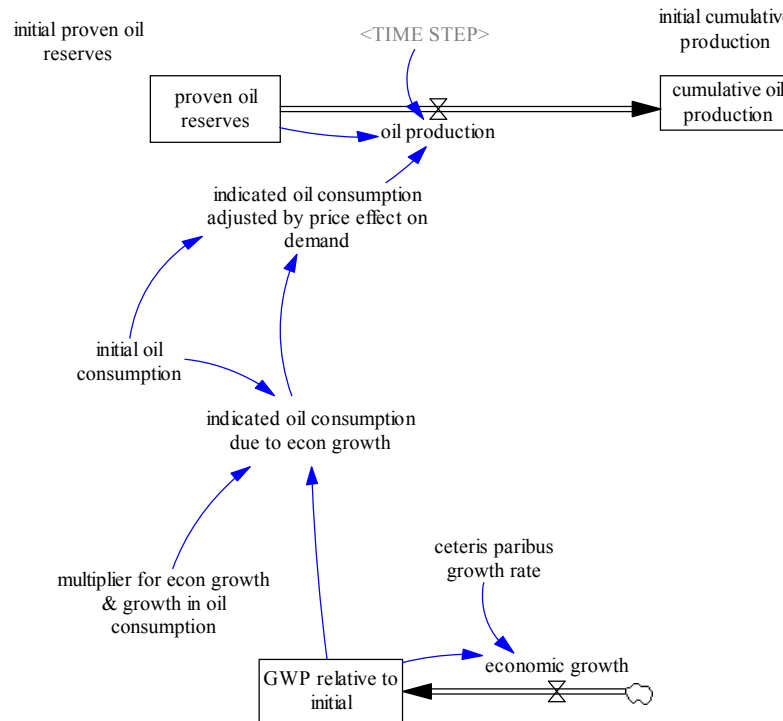


# Depletion of reserves

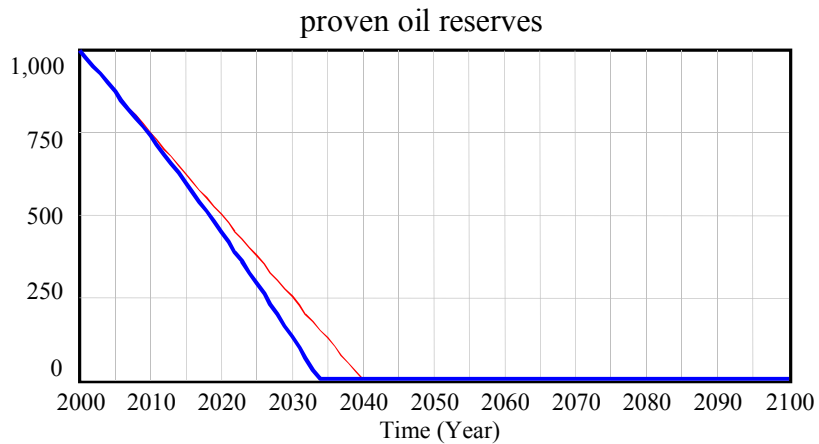


proven oil reserves : initial ————— Bbbl

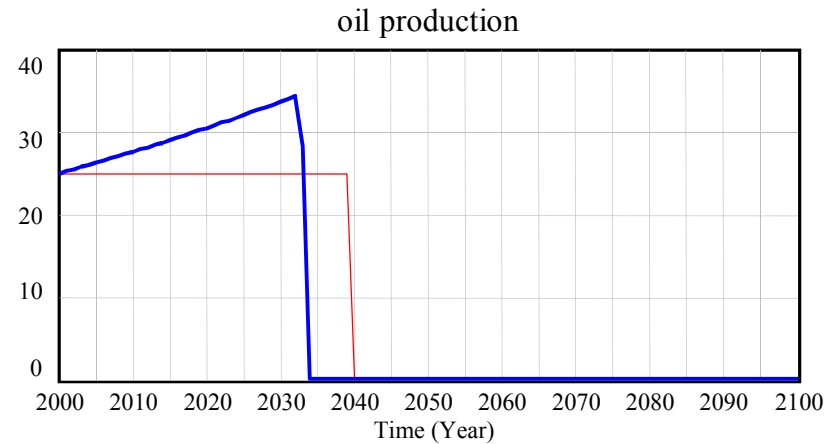
# First, we allow demand to increase over time



# Reserves are depleted faster



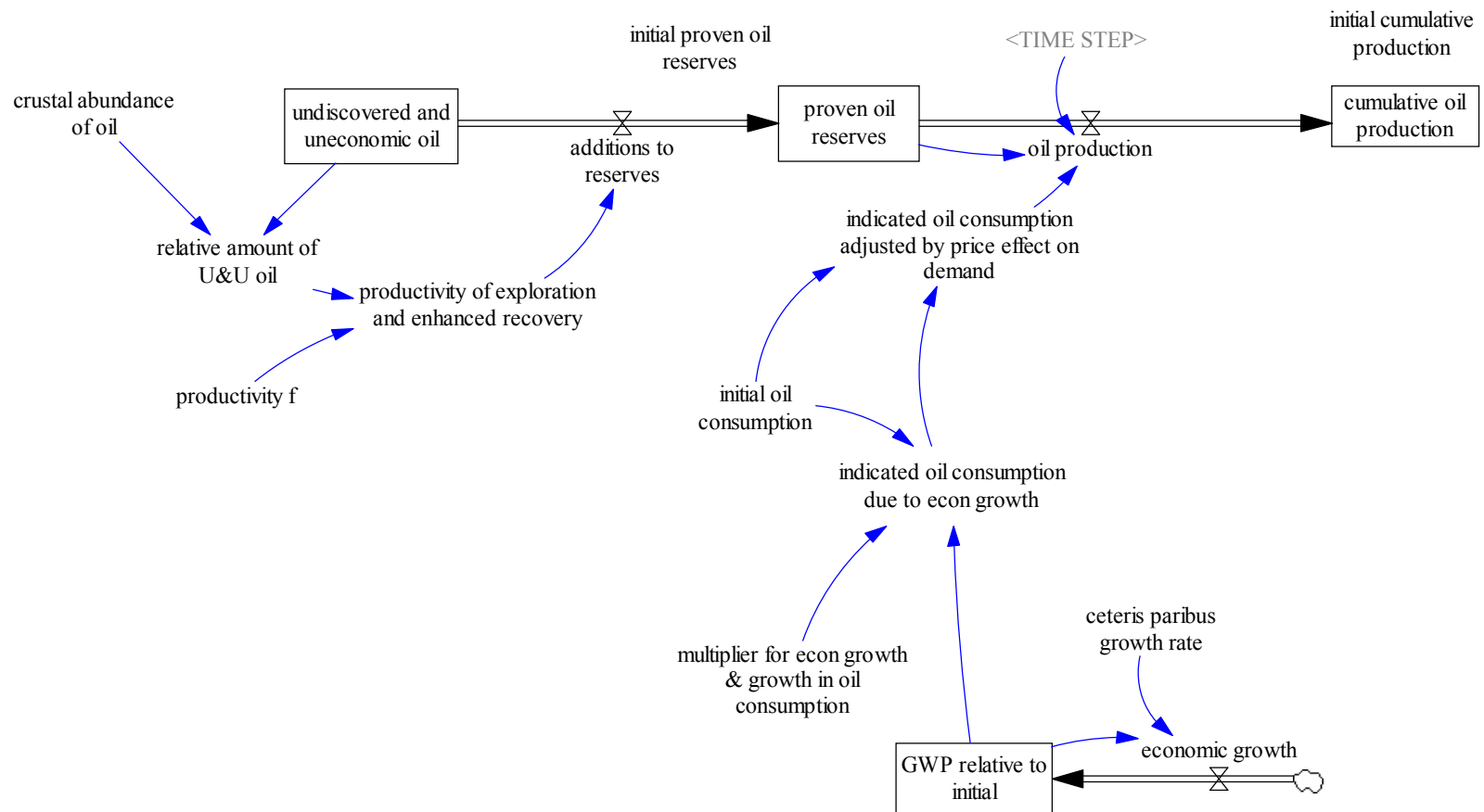
proven oil reserves : inc demand growth — Bbbl  
proven oil reserves : initial — Bbbl



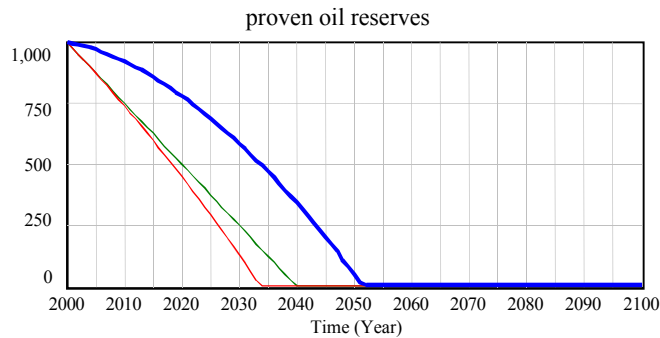
oil production : inc demand growth — Bbbl/Year  
oil production : initial — Bbbl/Year



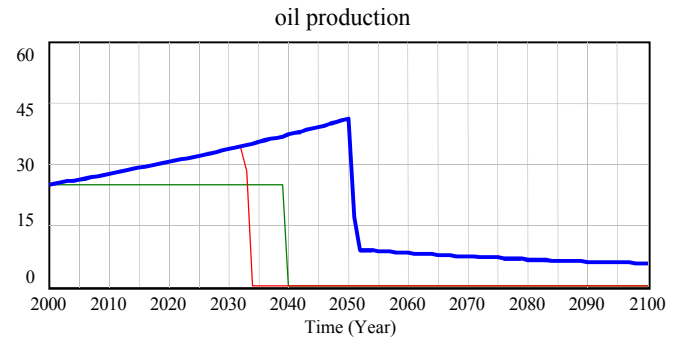
# But we know that continued discovery and advances in recovery will add to reserves



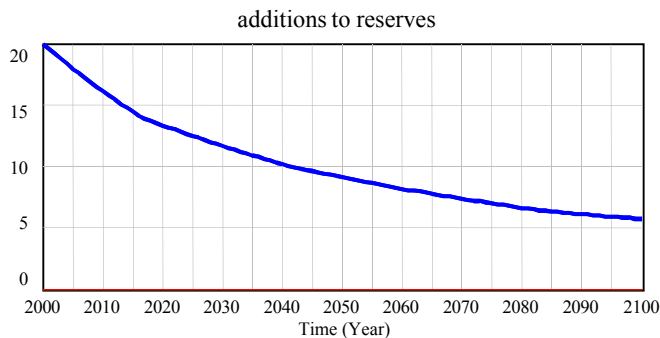
# Reserves now last a bit longer



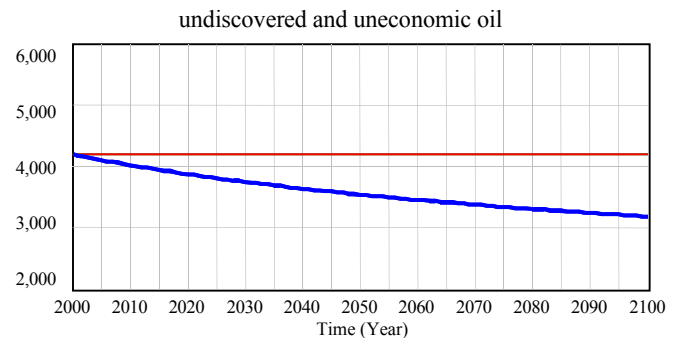
proven oil reserves : discovery adds reserves — Bbbl  
 proven oil reserves : inc demand growth — Bbbl  
 proven oil reserves : initial — Bbbl



oil production : discovery adds reserves — Bbbl/Year  
 oil production : inc demand growth — Bbbl/Year  
 oil production : initial — Bbbl/Year

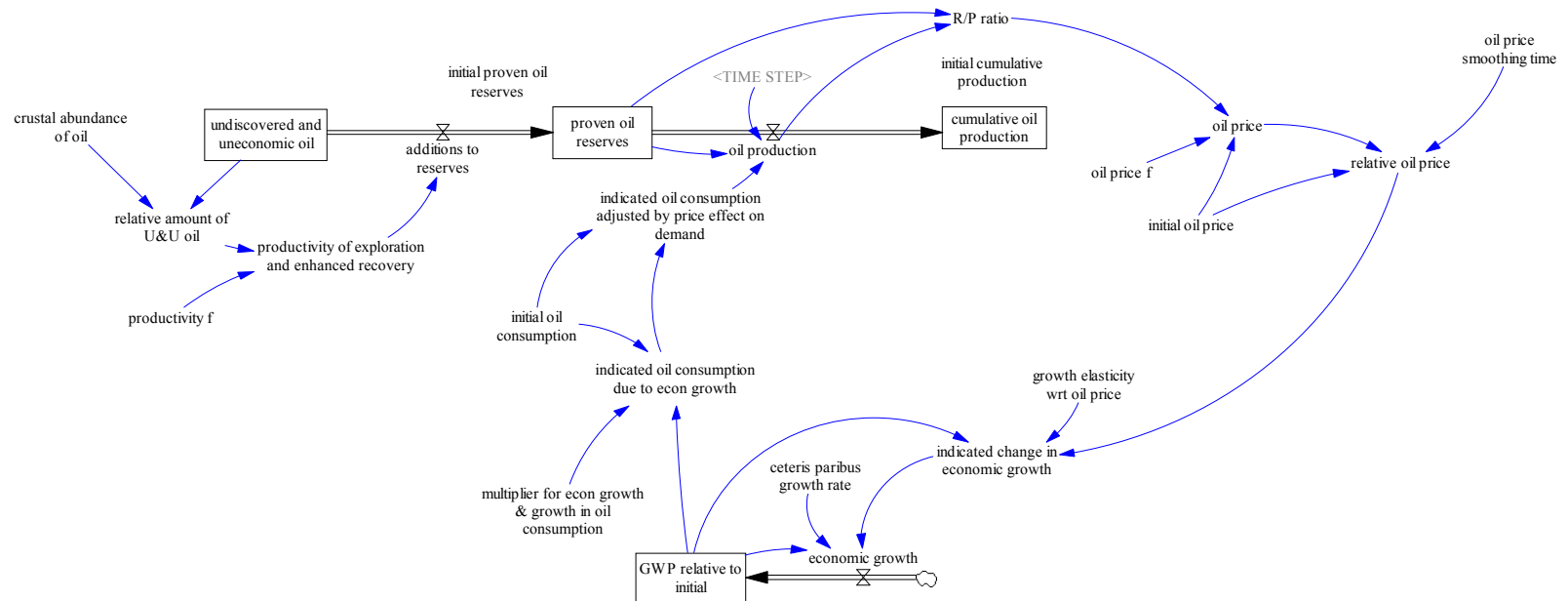


additions to reserves : discovery adds reserves — Bbbl/Year  
 additions to reserves : inc demand growth — Bbbl/Year  
 additions to reserves : initial — Bbbl/Year

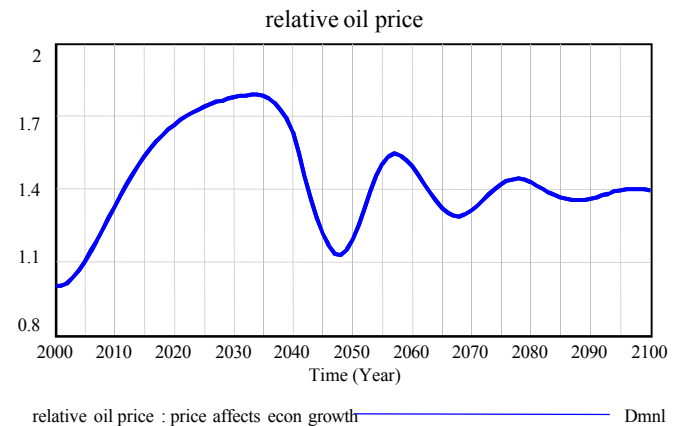
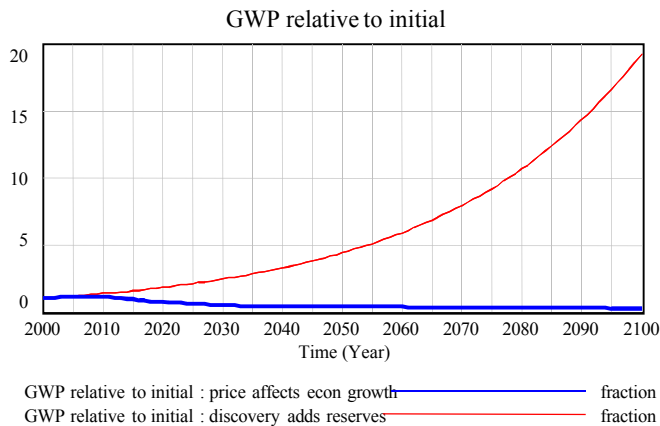
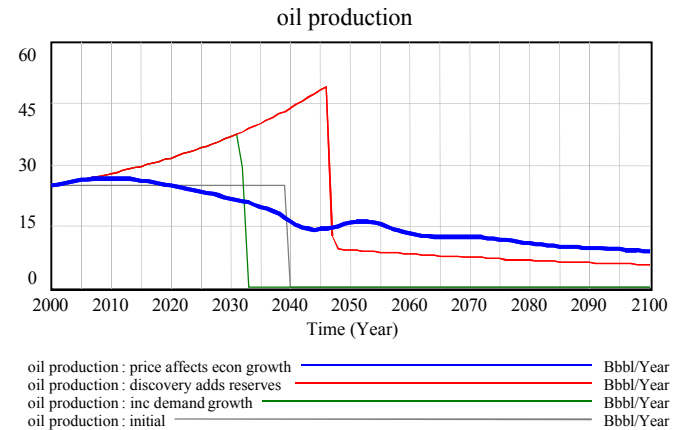
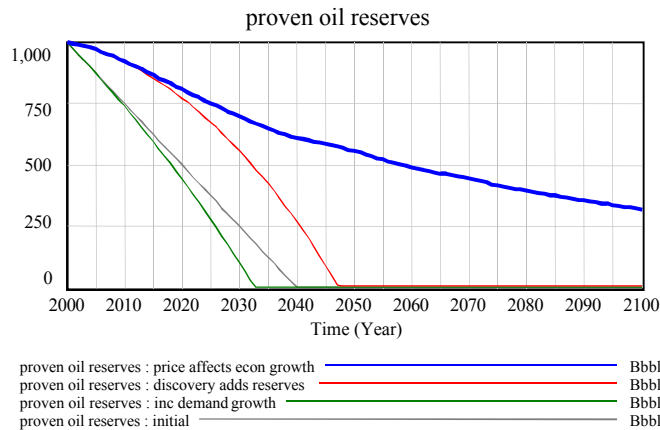


undiscovered and uneconomic oil : discovery adds reserves — Bbbl  
 undiscovered and uneconomic oil : inc demand growth — Bbbl  
 undiscovered and uneconomic oil : initial — Bbbl

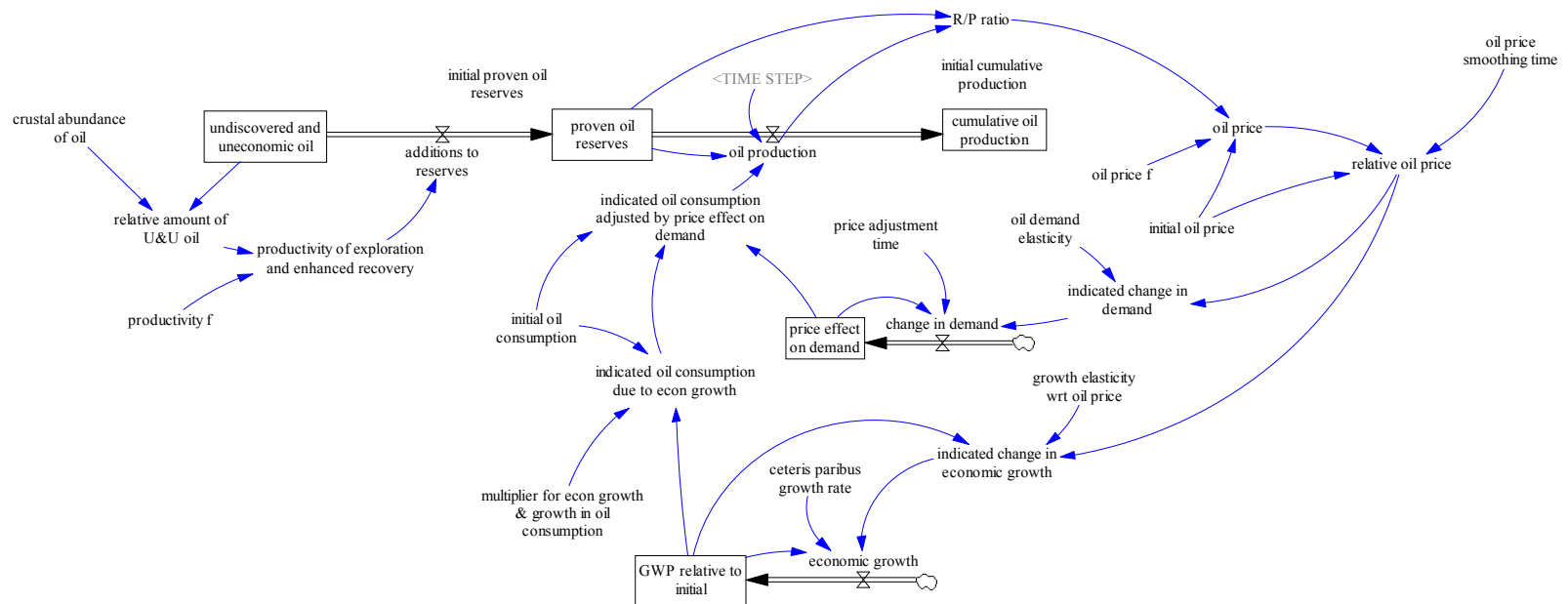
# Oil price affects economic growth, which affects the demand for oil



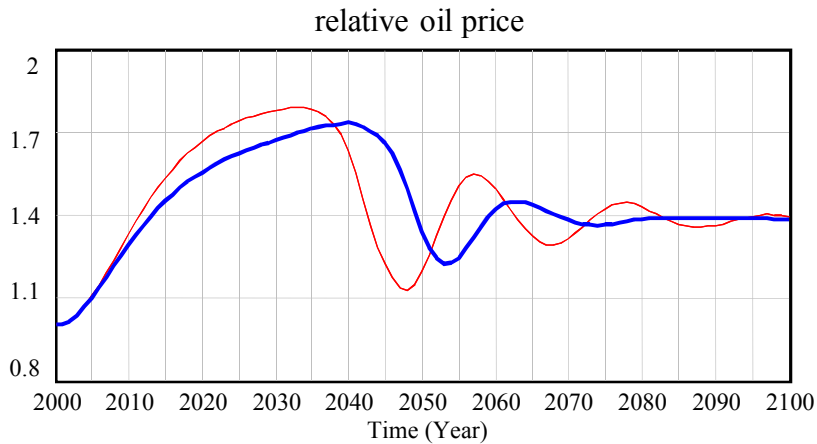
# Price response allows reserves to last, but high prices depresses GWP



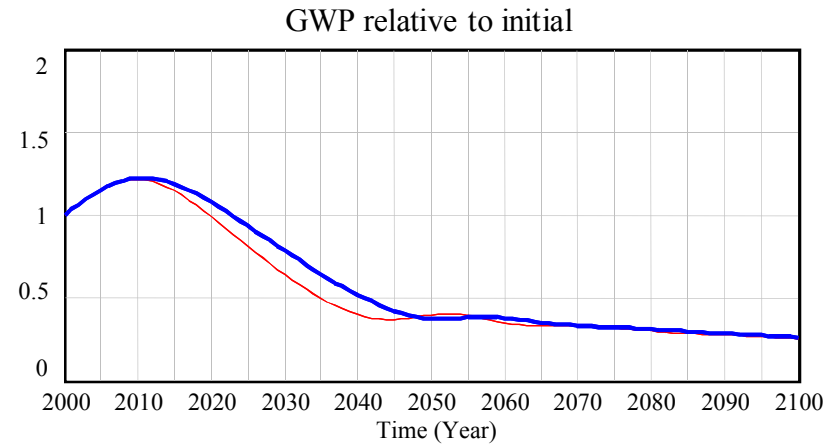
# Oil price also affects demand directly



# Relatively inelastic demand has little overall effect

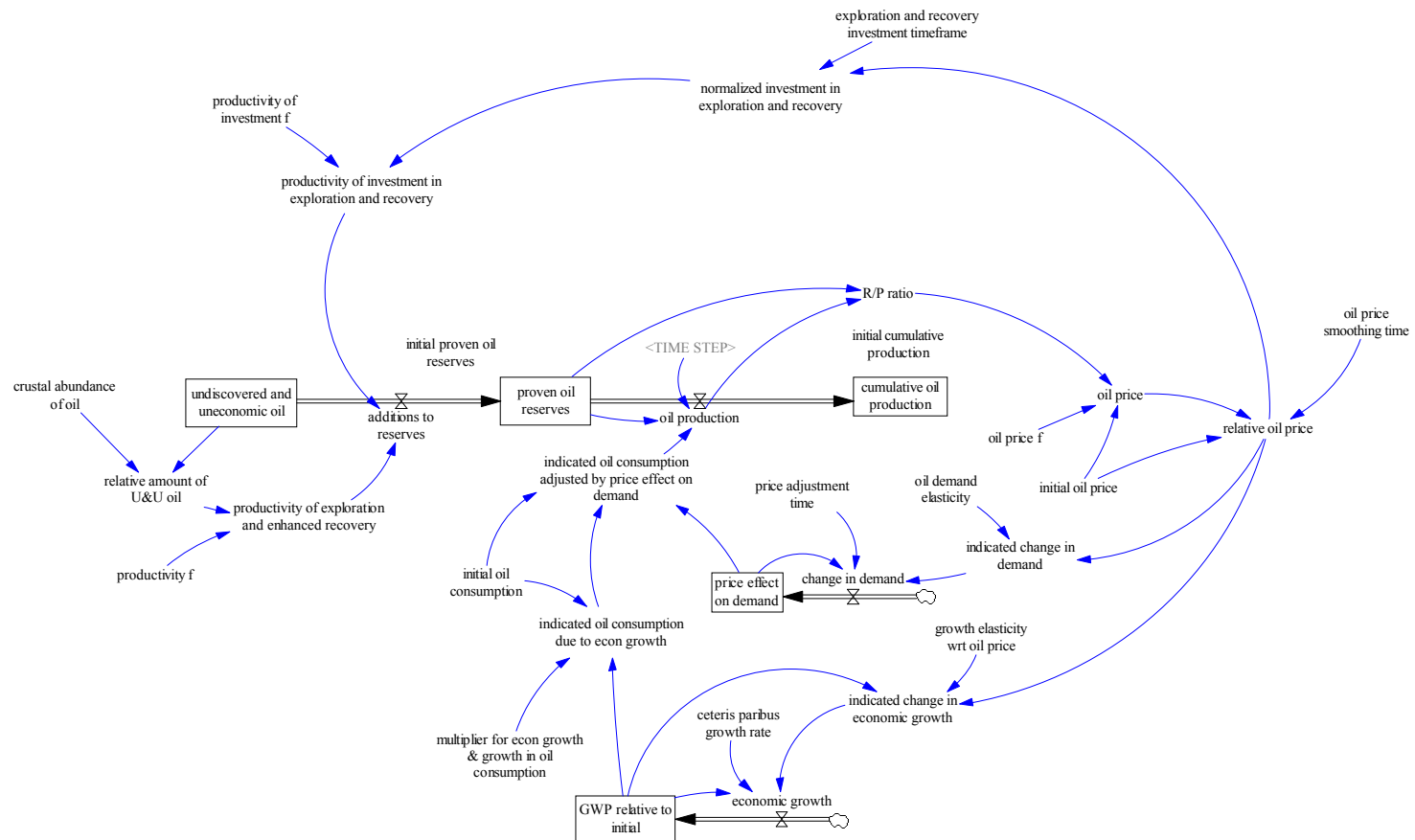


relative oil price : direct price effect on demand — Dmnl  
relative oil price : price affects econ growth — Dmnl

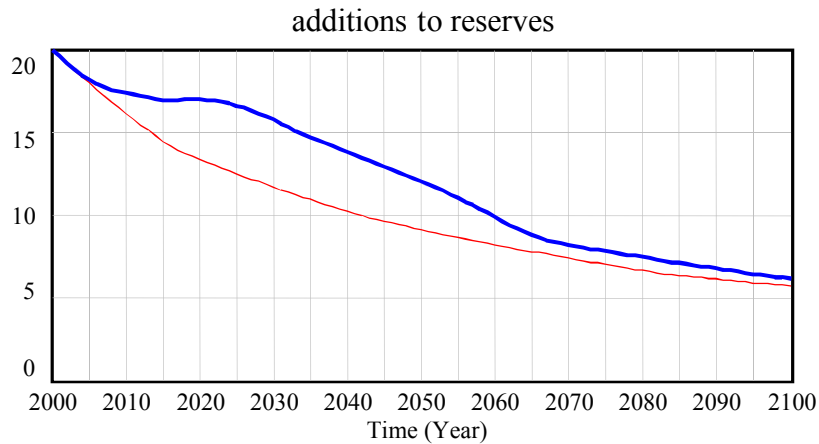


GWP relative to initial : direct price effect on demand — fraction  
GWP relative to initial : price affects econ growth — fraction

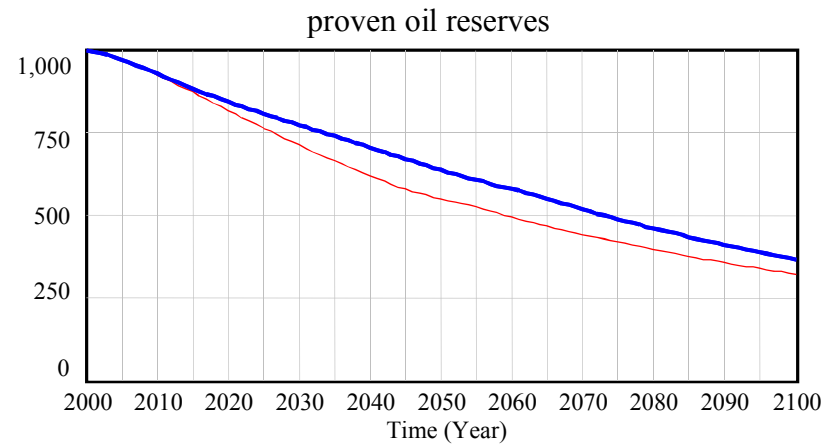
# But, oil price also spurs investment in exploration and recovery, adding to reserves



# Price spurs investment in E&R marginally adding to reserves



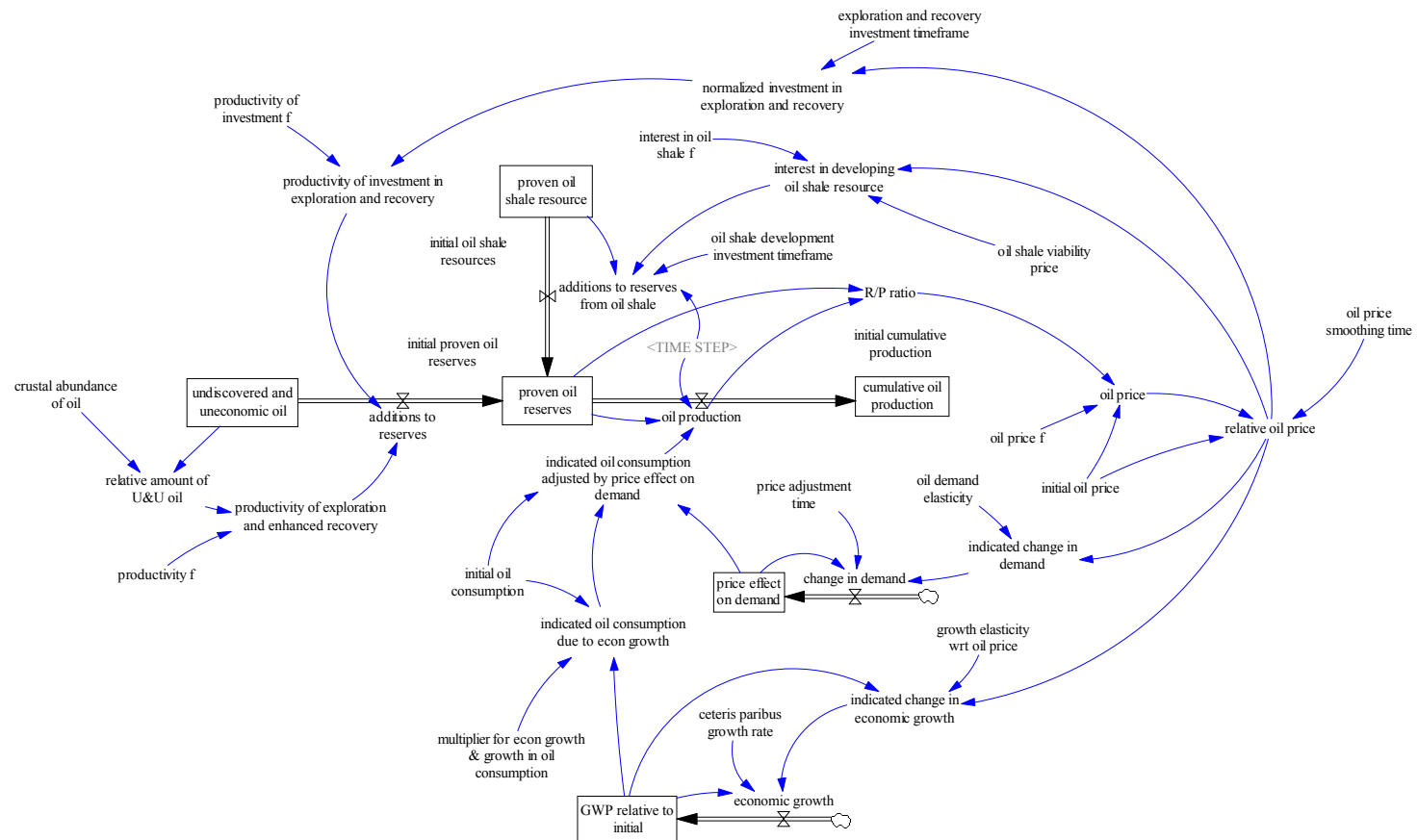
additions to reserves : price spurs investment in E&R — Bbbl/Year  
additions to reserves : direct price effect on demand — Bbbl/Year



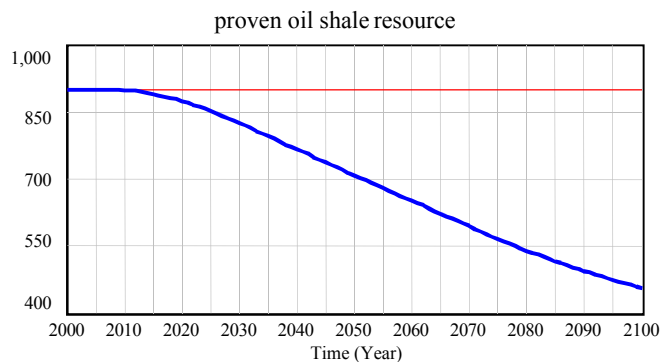
proven oil reserves : price spurs investment in E&R — Bbbl  
proven oil reserves : direct price effect on demand — Bbbl



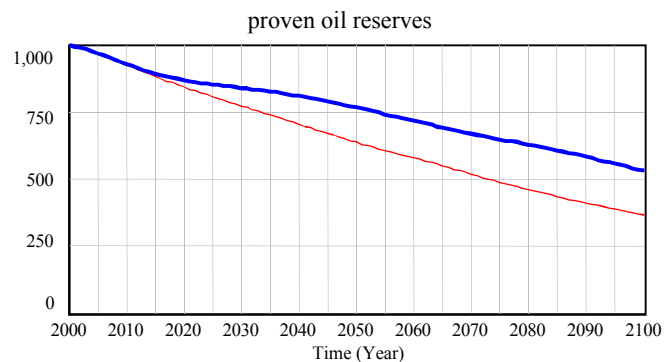
# When the price of oil gets high enough, oil shale resources begin to be developed



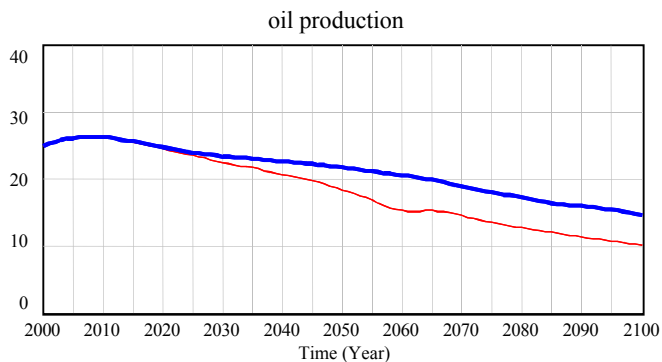
# Oil shale development helps -- somewhat



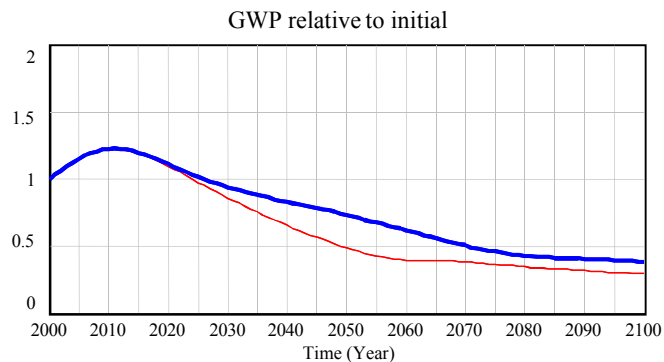
proven oil shale resource : oil shale development — Bbbl  
 proven oil shale resource : price spurs investment in E&R — Bbbl



proven oil reserves : oil shale development — Bbbl  
 proven oil reserves : price spurs investment in E&R — Bbbl



oil production : oil shale development — Bbbl/Year  
 oil production : price spurs investment in E&R — Bbbl/Year

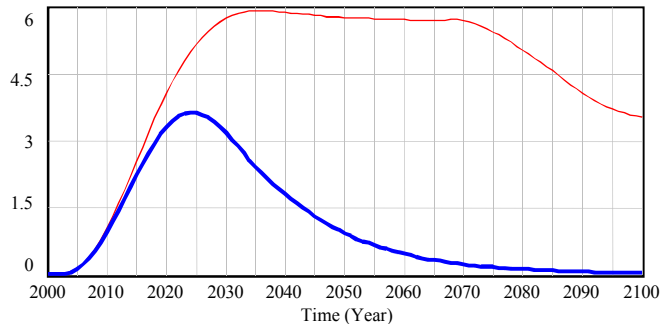


GWP relative to initial : oil shale development — fraction  
 GWP relative to initial : price spurs investment in E&R — fraction

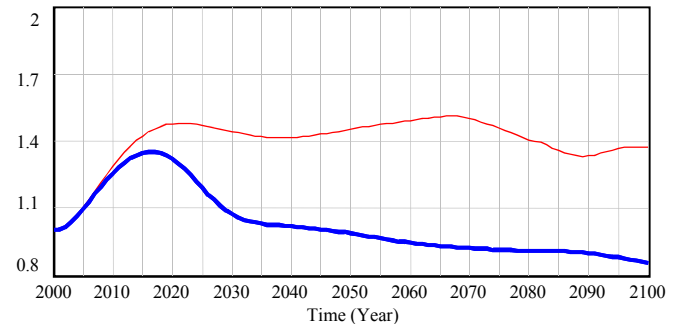


# Oil shale provides a bridge until alternate transportation fuels are able to capture significant market share

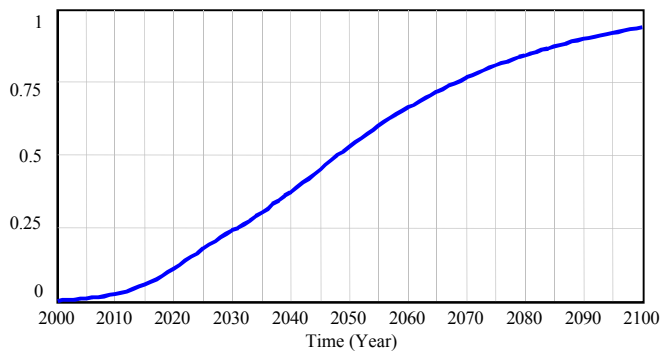
additions to reserves from oil shale



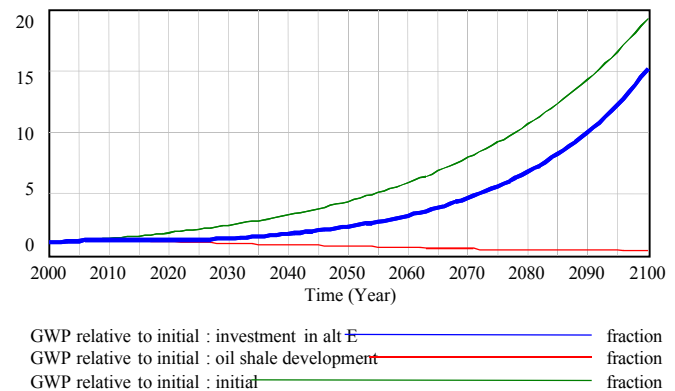
relative oil price



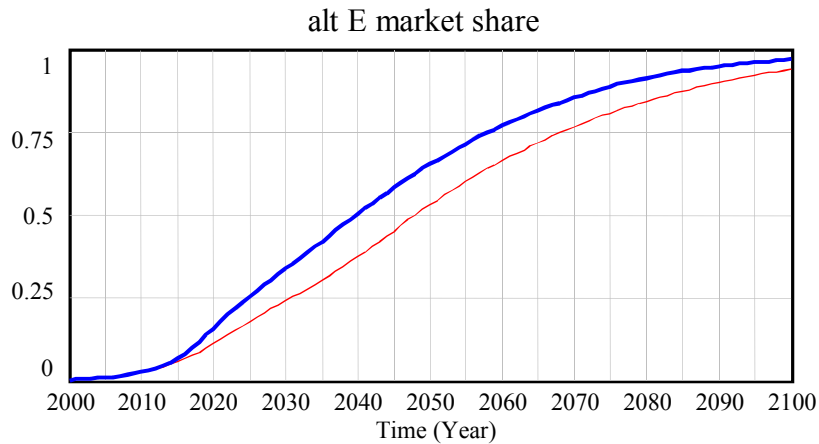
alt E market share



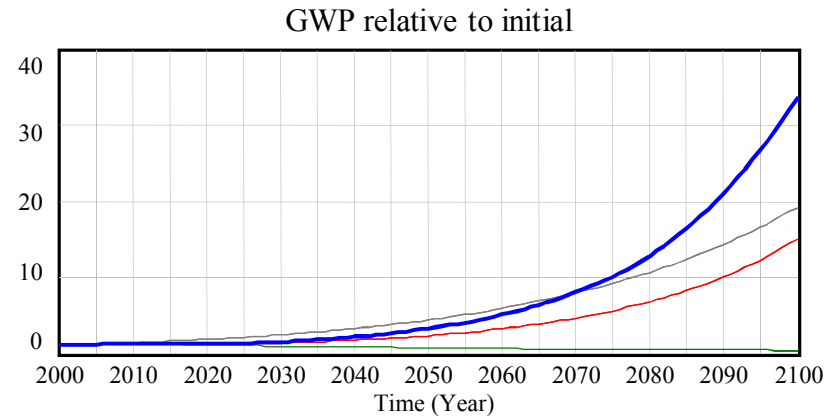
GWP relative to initial



# Doubling transportation fuel RDT&E in this decade allows for enhanced long-term economic growth



alt E market share : accelerated alt E — fraction  
alt E market share : investment in alt E — fraction



GWP relative to initial : accelerated alt E — fraction  
GWP relative to initial : investment in alt E — fraction  
GWP relative to initial : oil shale development — fraction  
GWP relative to initial : initial — fraction

# Conclusions

- **WARNING: Don't believe these results too much. There are lots of hidden parameters and response functions.**
- **The model has more value for generating insights than for generating predictions**
- There are no rosy scenarios without significant development of alternative transportation fuels.
- **Unlike both the Hubbert and EIA/USGS oil production curves, our peaks occur sooner, but decline is much more gradual.**

