Resource Exchange Model

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April 21, 2011
Modeling Approach

• Consider the diverse problems we confront involving systems composed of adapting interacting components (infrastructures, ecosystems, producers of goods and services...)
• Find the most basic features and processes that are common to all systems, and that dictate their ability to function as individuals and as viable parts of an interacting system
• Build and understand a formal model that captures these features and processes
• Approach the motivating problems through this common formal structure

• Entities that manage resource for their own benefit, and that interact to acquire resources they need.
• Closure: all resources come from somewhere, and that source has its own requirements
• Basic questions:
  – How does the system react to disruptions (loss of resources, producing entities, interconnection)?
  – How do remediations change these reactions?
  – Are there general insights that derive from specific system studies?
Essential Exchange Model Elements
Causal Loop Diagram

The major reinforcing loop around the outside creates the drive for growth. More consumption makes you healthier, leading to more:

- Production
- Sales
- Inputs

Hence, more production

Entity States and Processes

- Health
- Consumption Rate
- Production Rate
- Input Resource Level
- Output Resource Level
- Input Price
- Output Price
- Money Level

Consumption increases health
Health decays unless it’s sustained by consumption
Health enables production
Consumption drains resources
Extra consumption can combat health declines
Production can drain health
Production slows when output accumulates
Having more output decreases price
Production creates resources
Having more money decreases price
Production can drain health
Having "enough" input deters purchasing
Purchases consume money
Decreasing price increases sales
Purchases restore resources
Sales deplete resources
Extra consumption can combat health declines
Purchases consume money
Growth is automatically regulated by flows through the market.

Buying Rate from Market
Selling Rate to Market

When input can’t be obtained health and production slides.
When output can’t be sold inputs can’t be acquired.
Effect of Health on Potential Production Rate

\[ p_{h_i}^* \left( \frac{h}{h_0} \right) = \frac{p_{sat}^*}{1 + (p_{sat}^* - 1) \left( \frac{h(t)}{h_0} \right)^{-e_p}} \]
Stability Analysis for an Island Entity

\[ p_r - h^* = \frac{p_{sat} - 1}{1 + p_{sat} \eta_T} h^{1-e_p} ; \quad p_r \equiv p_{sat} \frac{p_0}{c_0} \frac{1+\eta_T}{1 + p_{sat} \eta_T} \]
Some equilibrium results can be derived; Sensitivity to exchange process can be studied...

Using four resources minimally allows for input substitution and output specialization

Six distinct input/output patterns are possible

What happens when one type is especially productive?
Competitive Exclusion

**Health Trajectories**

- A: CDMaker Hbar
- B: BDMaker Hbar
- C: BCMaker Hbar
- D: ADMaker Hbar
- E: ACMaker Hbar
- F: ABMaker Hbar

**Price Trajectories**

- A: A Price
- B: B Price
- C: C Price
- D: D Price
Robustness/Efficiency Tradeoff

- **Less Efficient, More Stable**
- **More Efficient, Less Stable**

Area Reflects Robustness Cost
Robustness/Efficiency Tradeoff

Scatterplot of Average X-Producer ep vs. Y Abundance

- x-axis: Abundance of Y Resource
- y-axis: Average ep for X Producers in the Final Population
- Legend:
  - Random Disruption
  - No
  - Yes

Note: The scatterplot shows the relationship between the abundance of the Y resource and the average ep of X producers in the final population, with different markers indicating the presence or absence of random disruption.
Robustness/Efficiency Tradeoff

Scatterplot of epXBar vs HbarX

- epXBar
- HbarX

Legend:
- nRegime
  - 0
  - 1
Robustness/Efficiency Tradeoff

Scatterplot of $epXBar$ vs $newXMakers$

- $nRegime$: 0 (black circles) and 1 (red squares)
We can define three general patterns of interconnection between entities. These patterns can be thought of as creating increasingly close coordination between the production process and consumption process. Our initial implementation will be limited to the “loosest” pattern involving spot exchanges of lumps of stuff. This is a good pattern for many resources but a poor pattern for some services (such as labor or electric power) in which the resource is consumed as it is produced. We can reduce inventory times to minimize artificial latency in these cases.
Latency of Different Coupling Mechanisms

- Consumption Rate Directly Coupled to Production
- Consumption Rate Coupled through Direct Exchange of Stored Resource – Inventories
- Consumption Rate Coupled through Repeated Negotiated Exchange of Stored Resource – Inventories and Search Process Buffer Production Changes

Graph showing production rate over time with different coupling mechanisms.