SAND Number 2011-4204

Complex Adaptive System of Systems (CASoS) Engineering Initiative
http://www.sandia.gov/CasosEngineering/

Modeling Systems of Interacting Specialists

Walter E. Beyeler
RJ Glass, PD Finley, TJ Brown, MD Norton, M Bauer, M Mitchell, and JA Hobbs
Sandia National Laboratories

Eighth International Conference on Complex Systems
Quincy, MA
June 26 – July 1, 2011

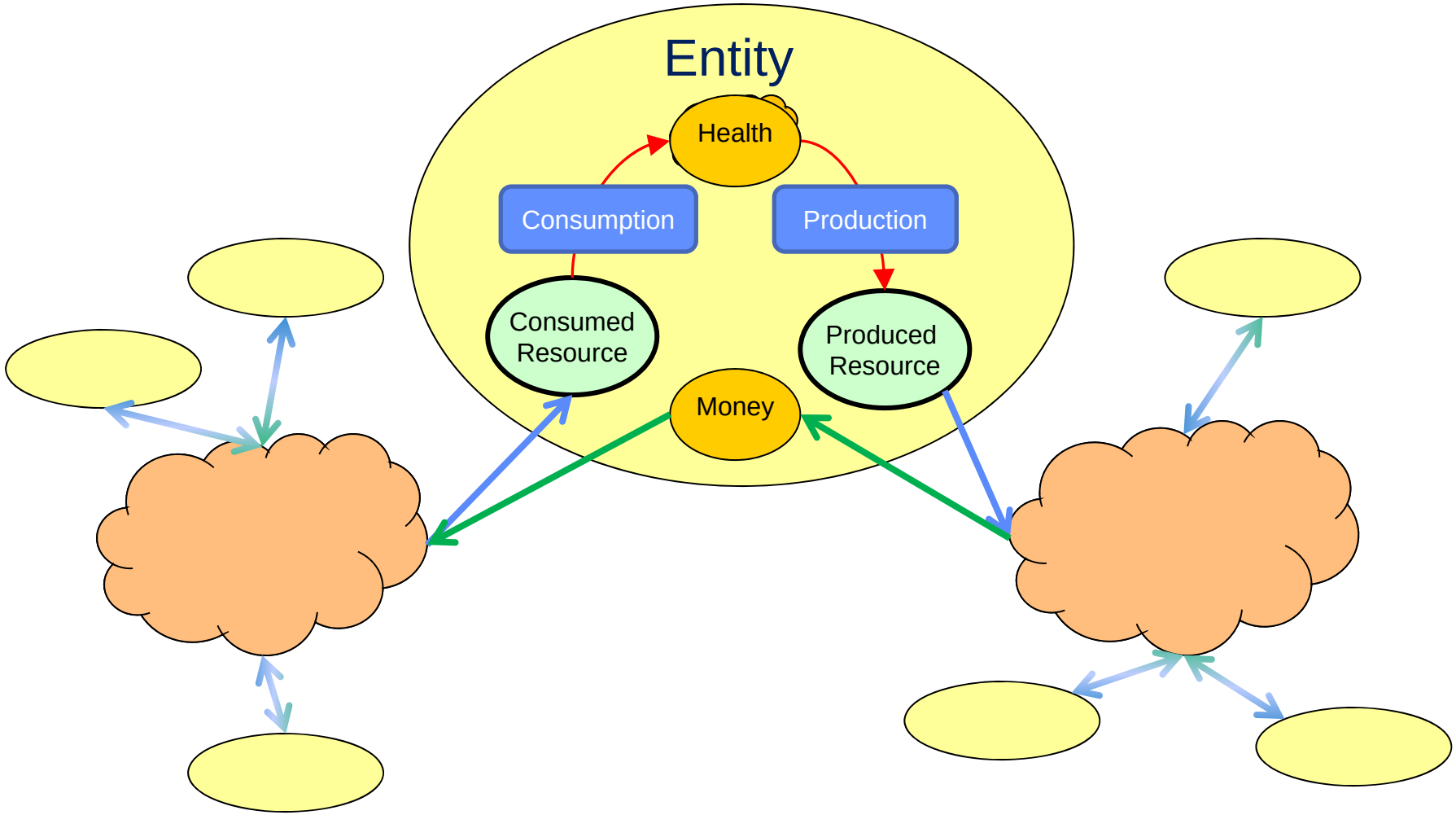
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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

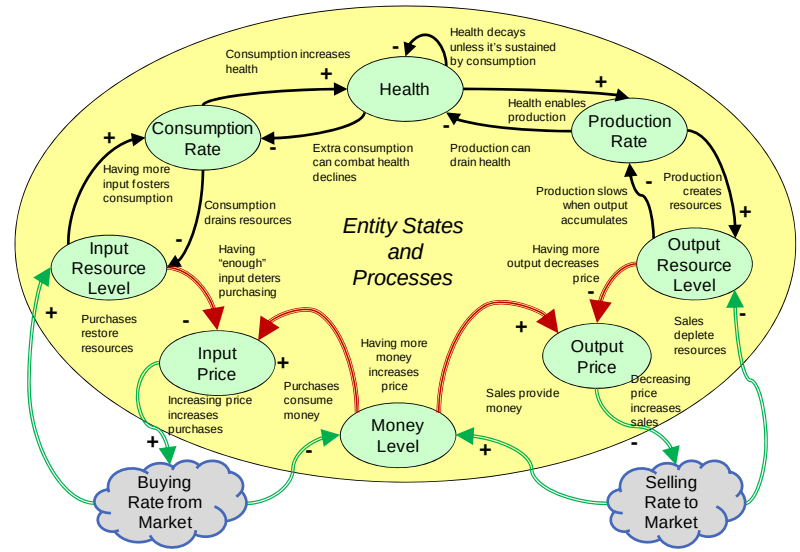
- Entities that manage resource for their own benefit, and that interact to acquire resources they need.
- Closure: all resources come from somewhere, and that source has its own requirements
- Basic questions:
  - How does the system react to disruptions (loss of resources, producing entities, interconnection)?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

Essential Exchange Model Elements

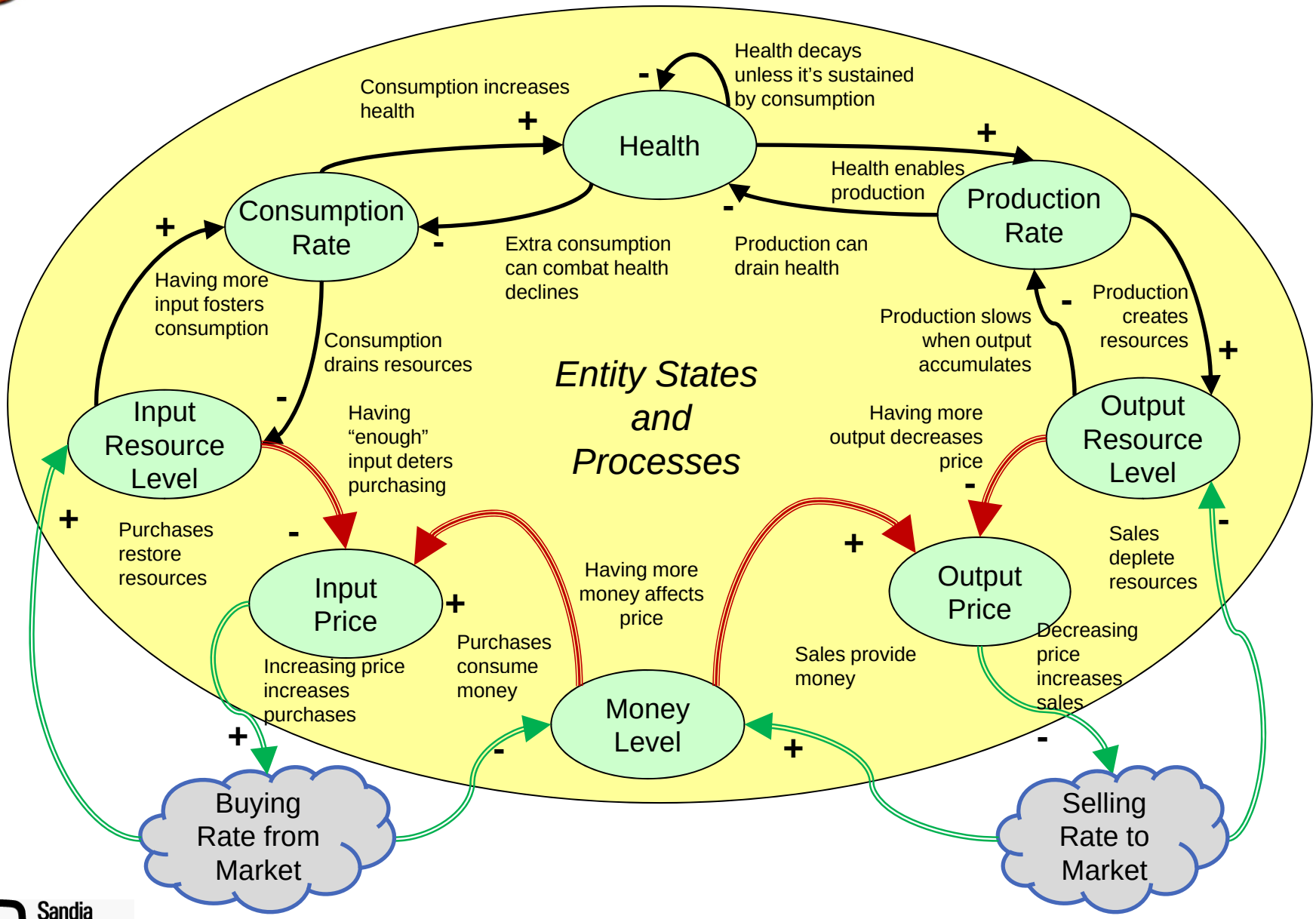


Causal Loop Diagram

- The major reinforcing loop around the outside creates the drive for growth
  - More consumption makes you healthier, leading to more production, more sales, more inputs, and more production.
- Growth is *automatically regulated* by flows through the market.
  - When input can't be obtained health and production slides.
  - When output can't be sold inputs can't be acquired.

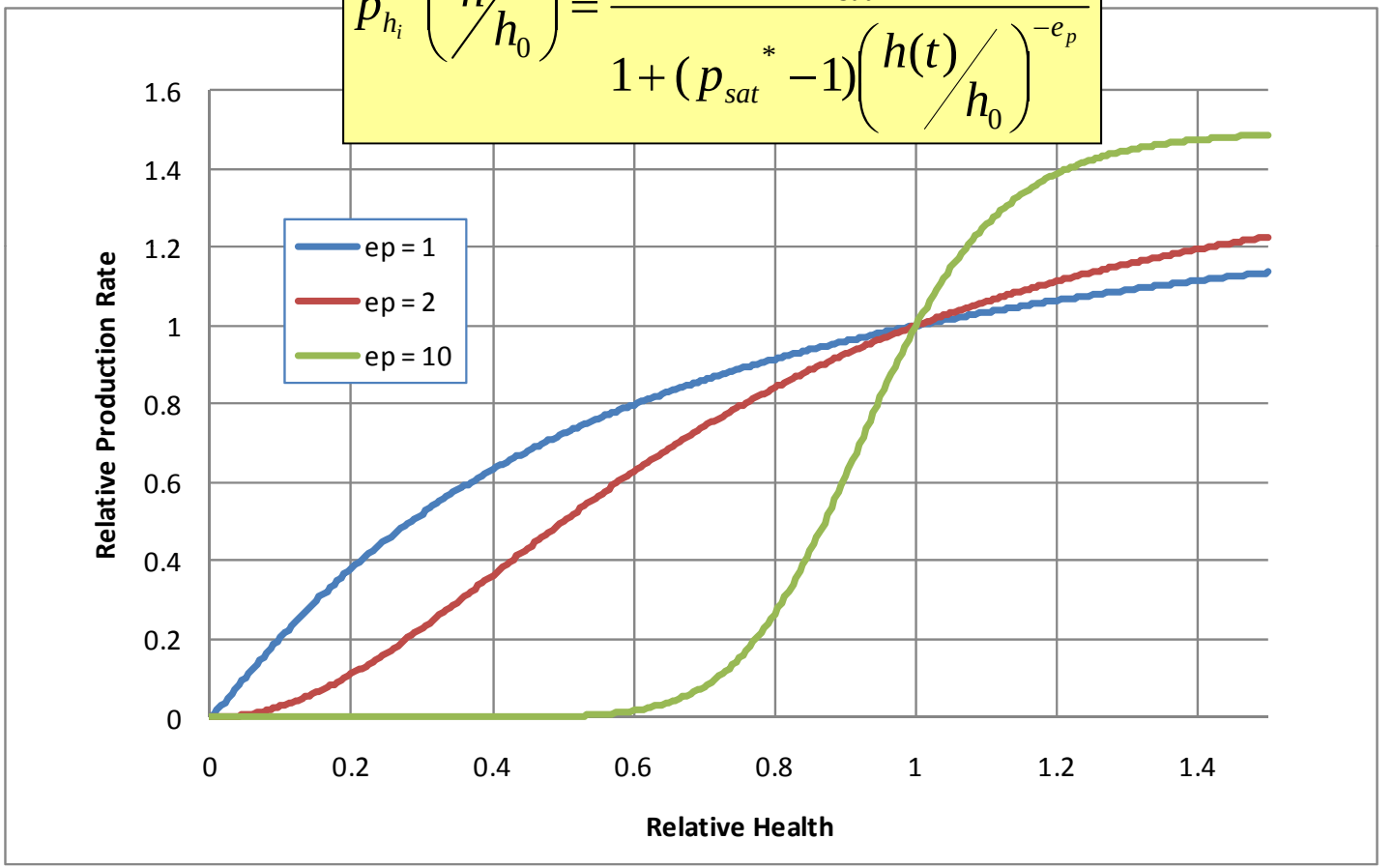


Causal Loop Diagram



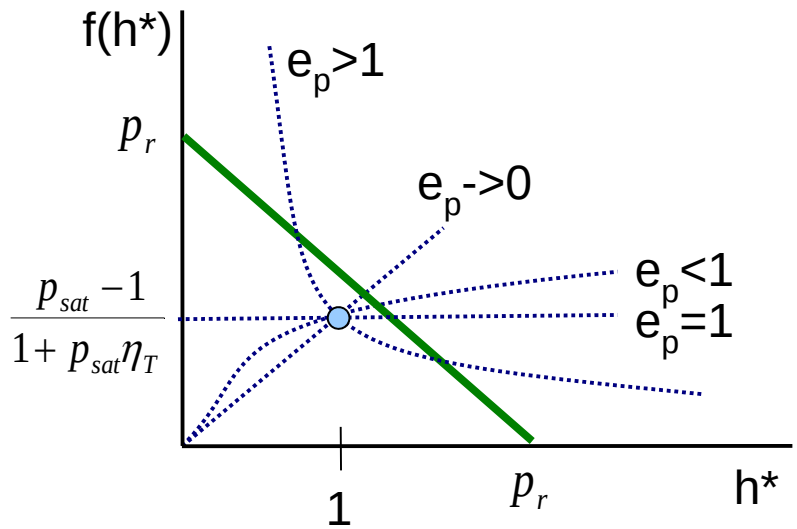
Effect of Health on Potential Production Rate

$$p_{h_i}^{*}\left(h/h_0\right) = \frac{p_{sat}^{*}}{1+\left(p_{sat}^{*}-1\right)\left(h(t)/h_0\right)^{-e_p}}$$

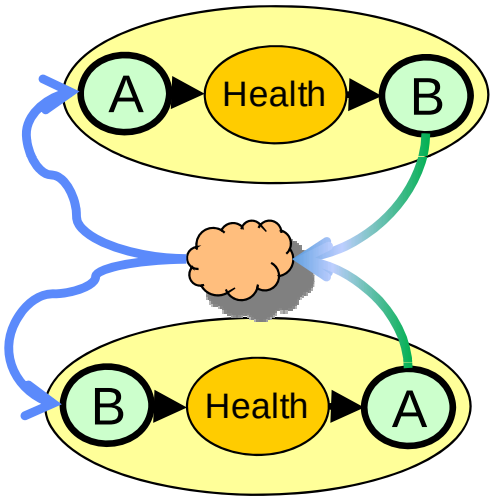


Stability Analysis for an Island Entity

$$p_r - h^* = \frac{p_{sat} - 1}{1 + p_{sat}\eta_T} h^{*1-e_p}; \qquad p_r \equiv p_{sat} \frac{p_0}{c_0} \frac{1+\eta_T}{1+p_{sat}\eta_T}$$

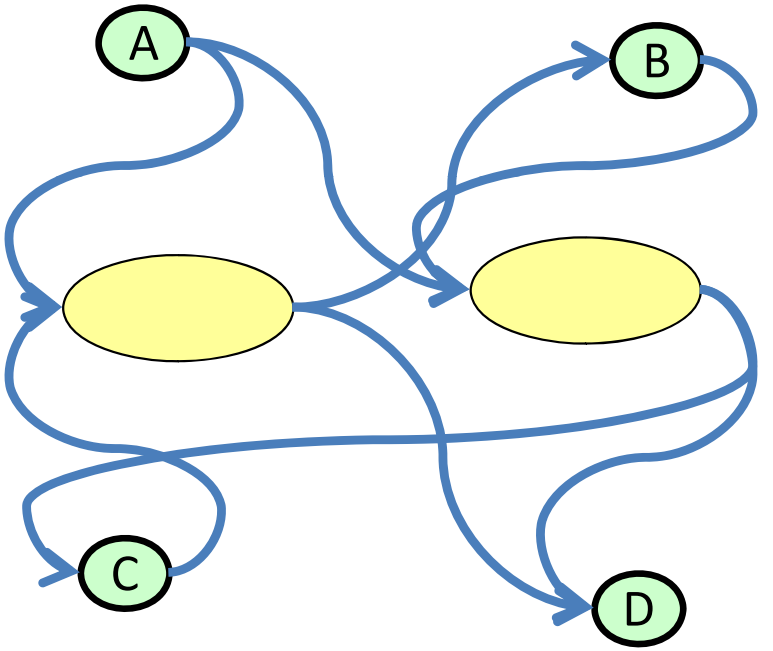


Complete Interdependency



Some equilibrium results can be derived; Sensitivity to exchange process can be studied…

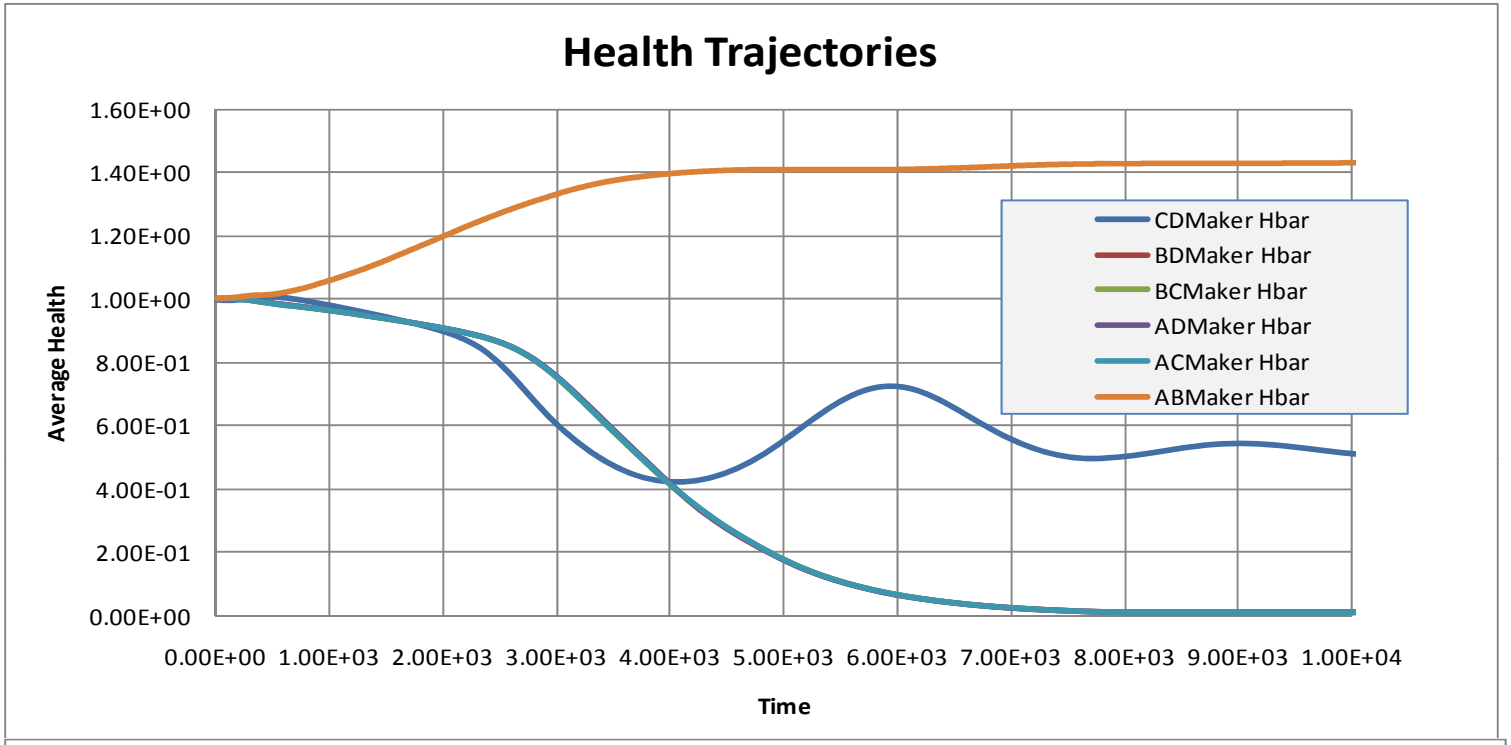
Using four resources minimally allows for input substitution and output specialization



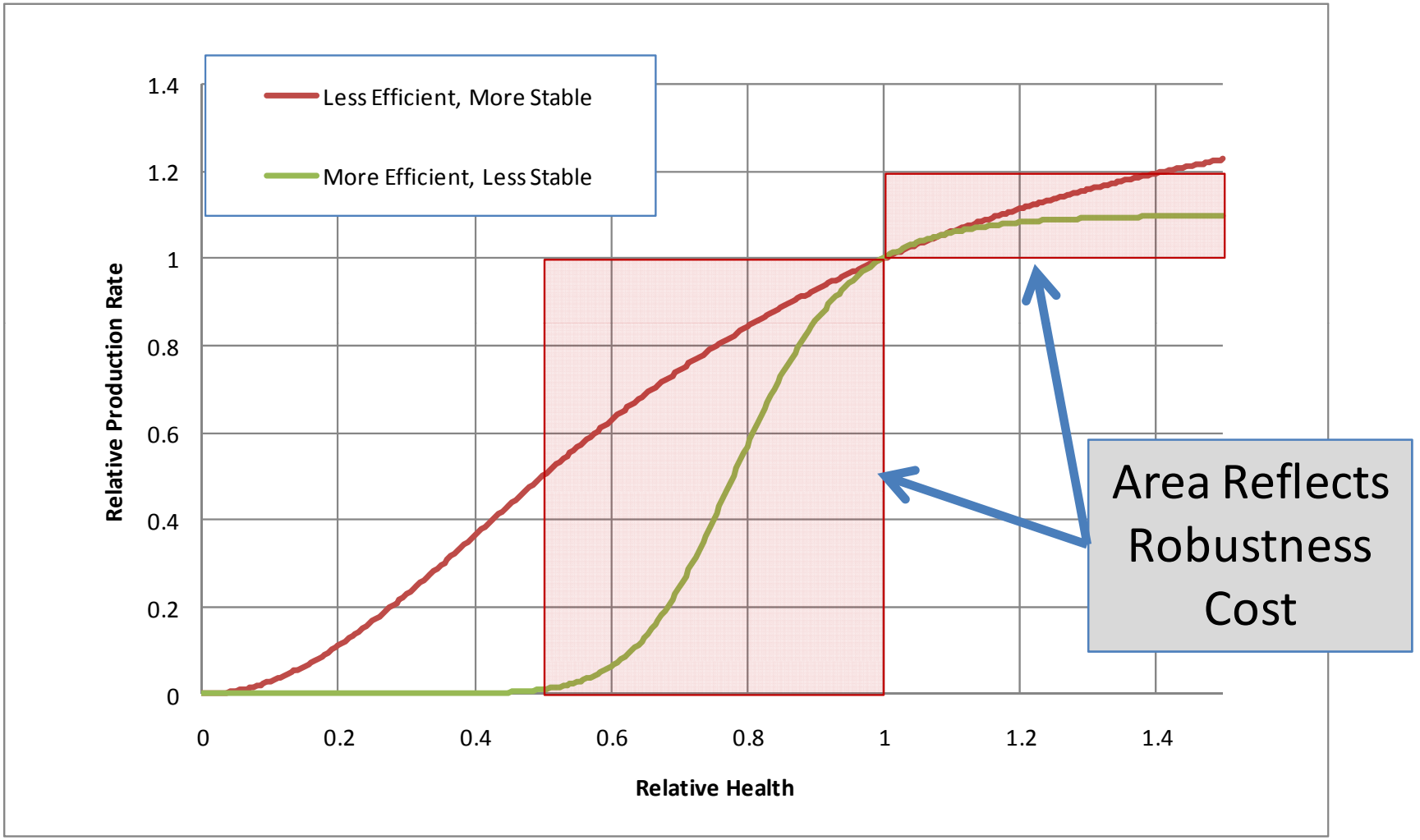
Six distinct input/output patterns are possible

What happens when one type is especially productive?

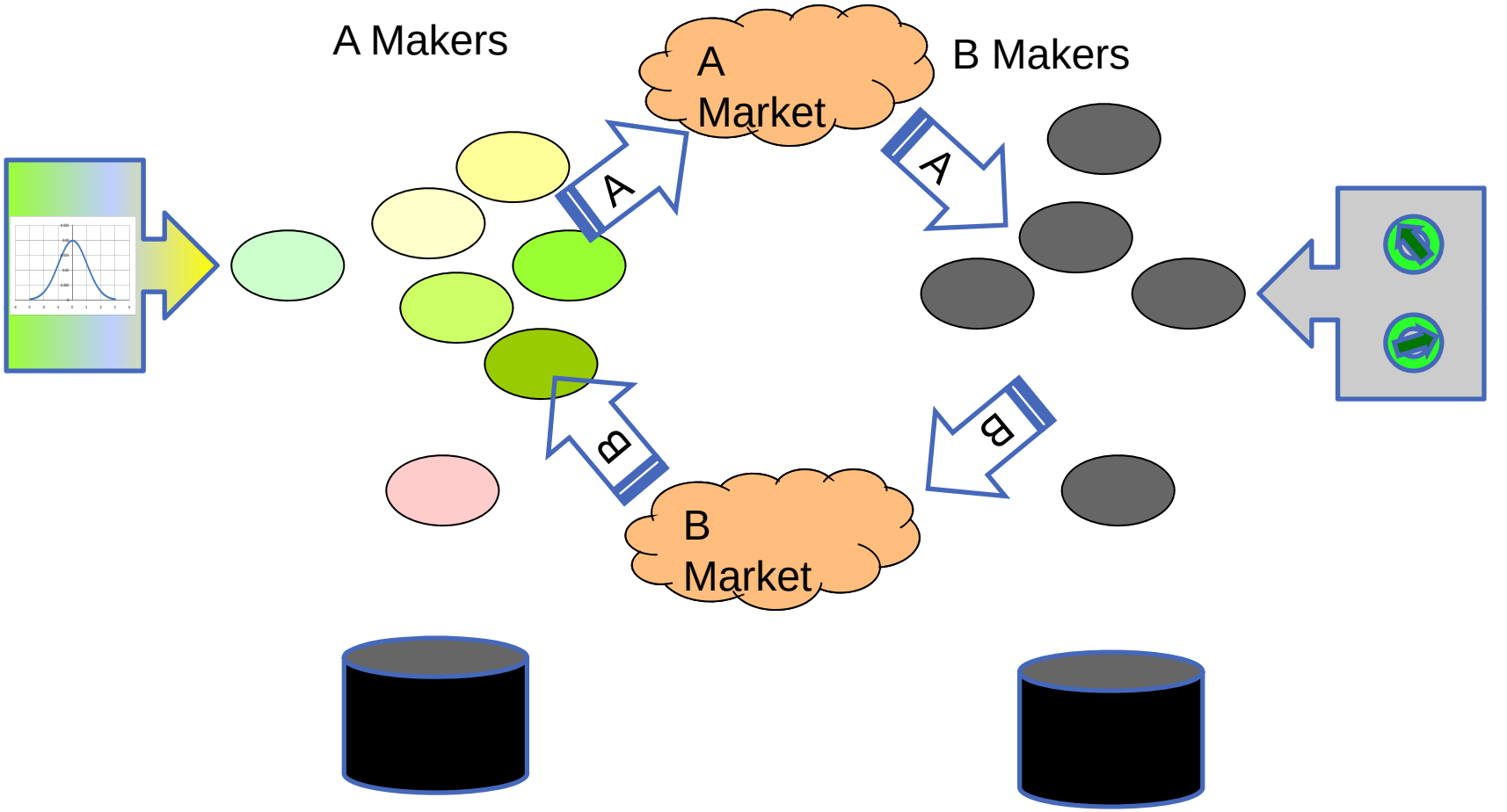
Competitive Exclusion



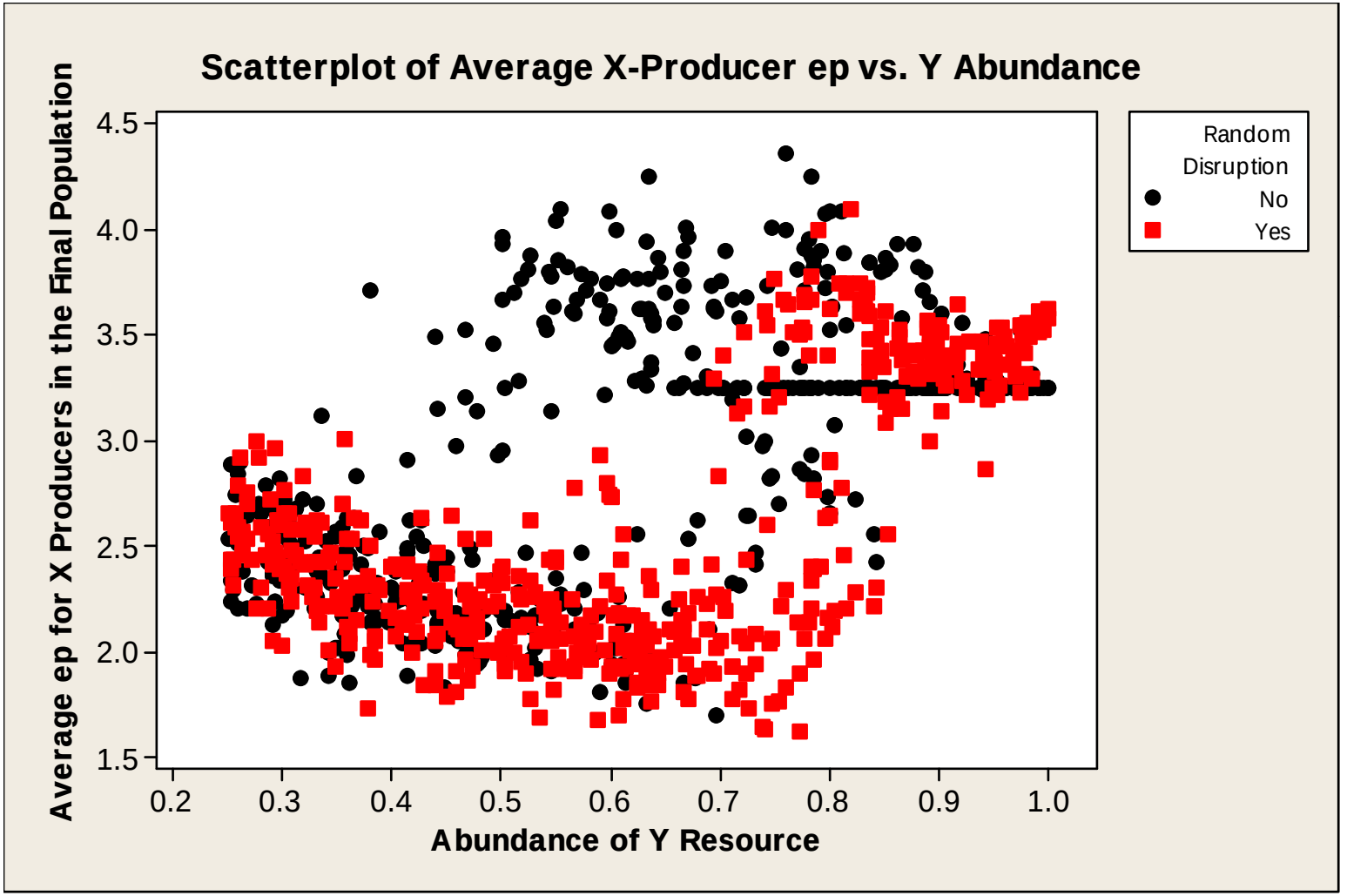
Robustness/Efficiency Tradeoff



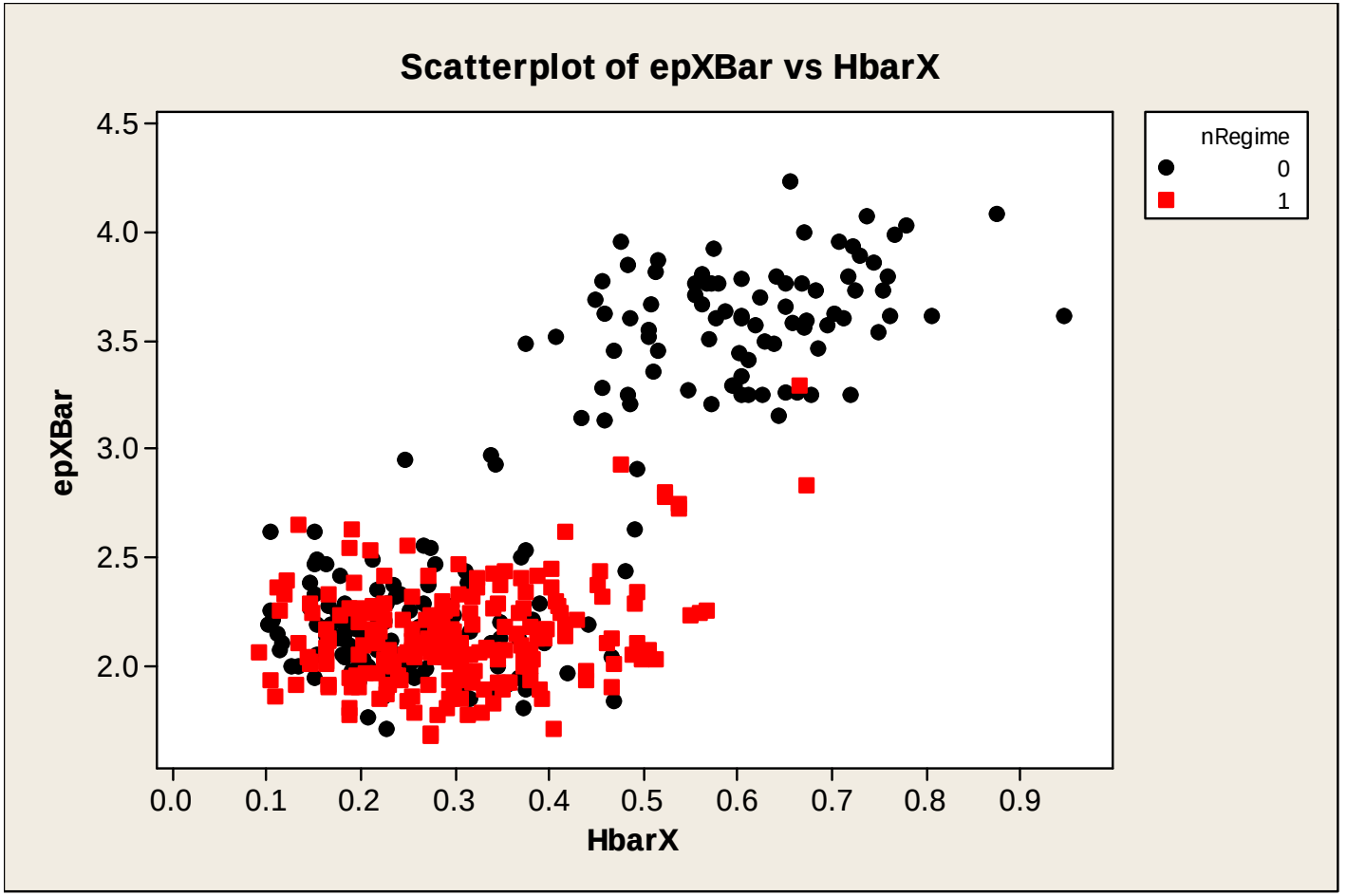
Robustness/Efficiency Configuration



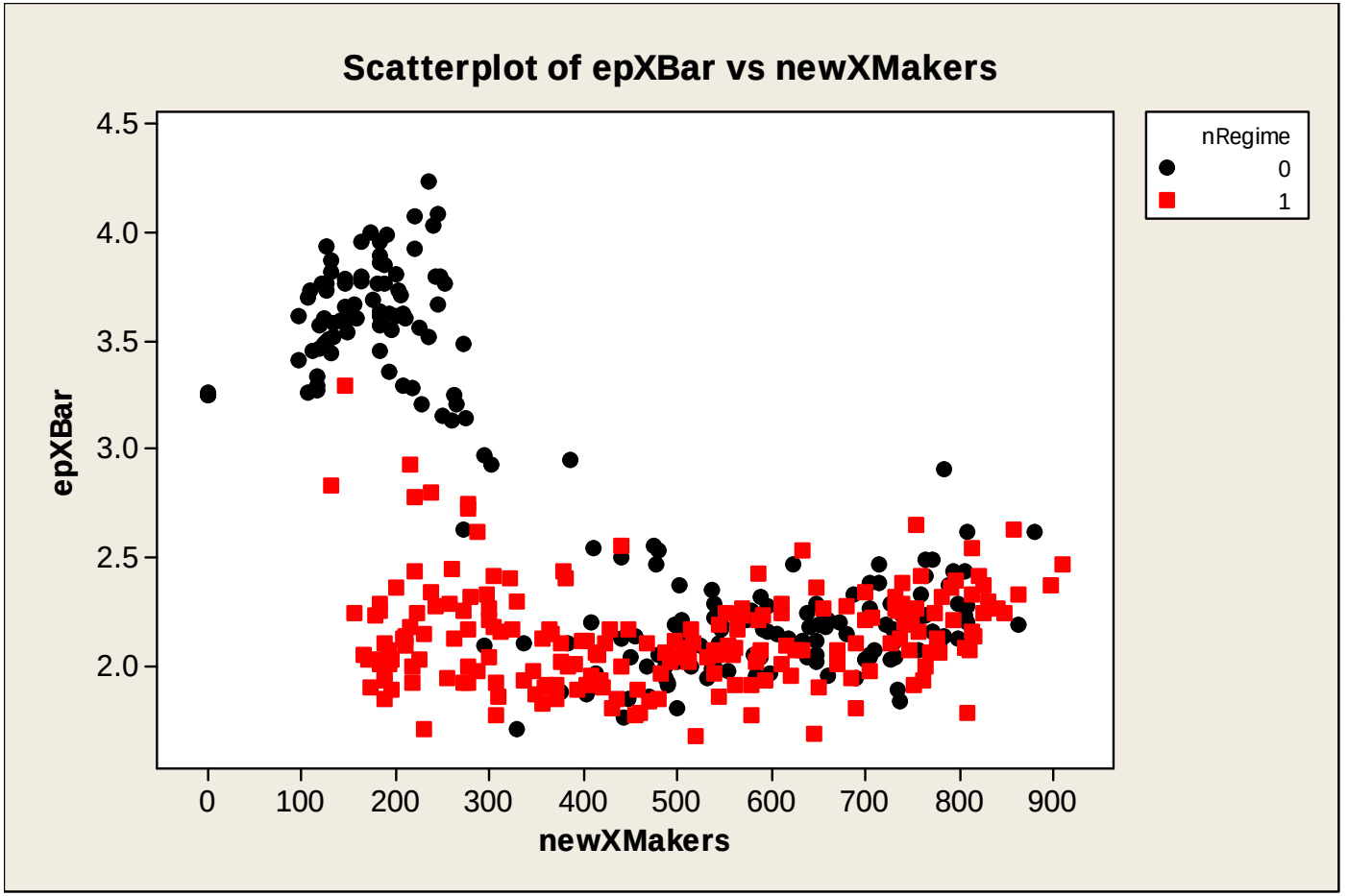
Robustness/Efficiency Tradeoff



Robustness/Efficiency Tradeoff



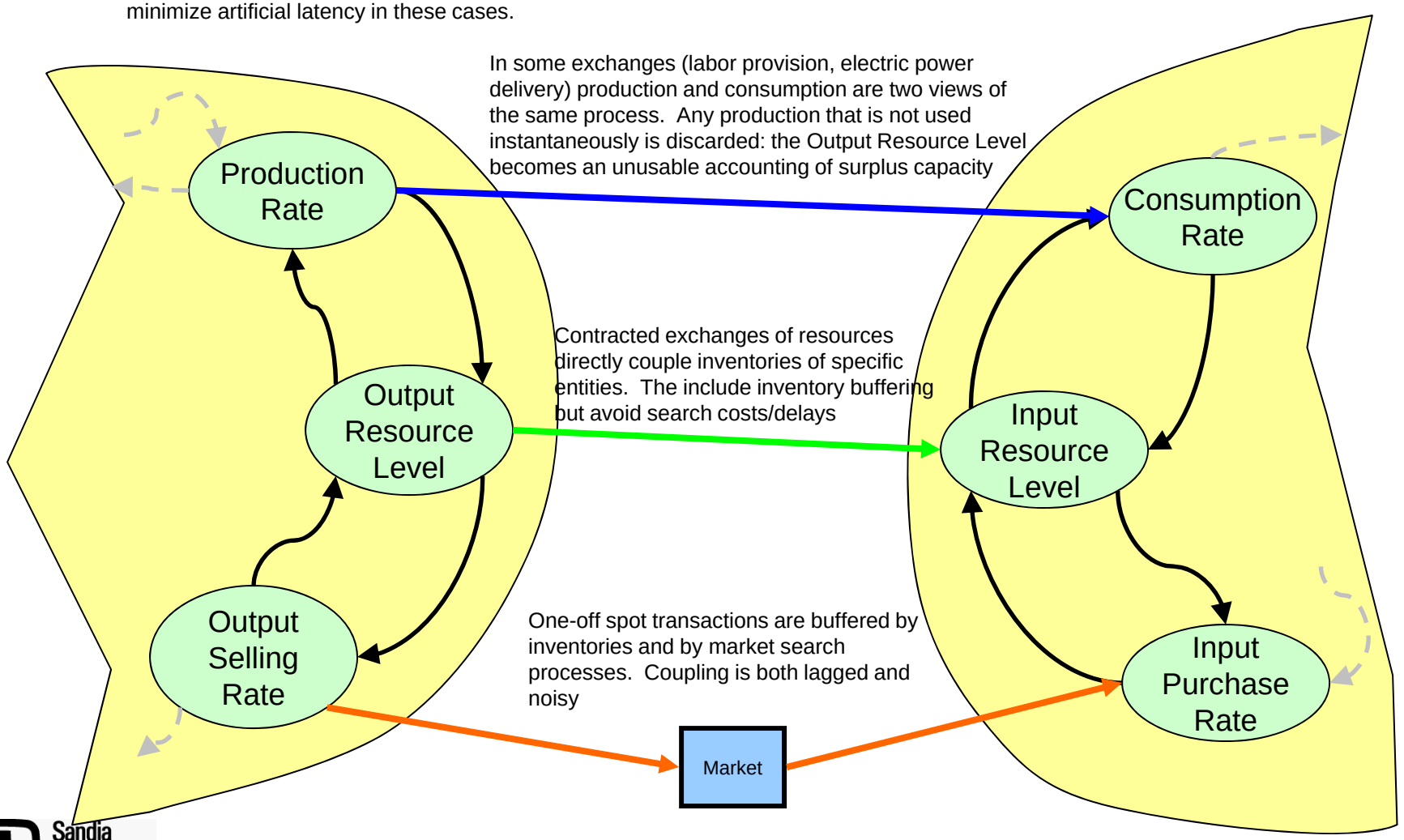
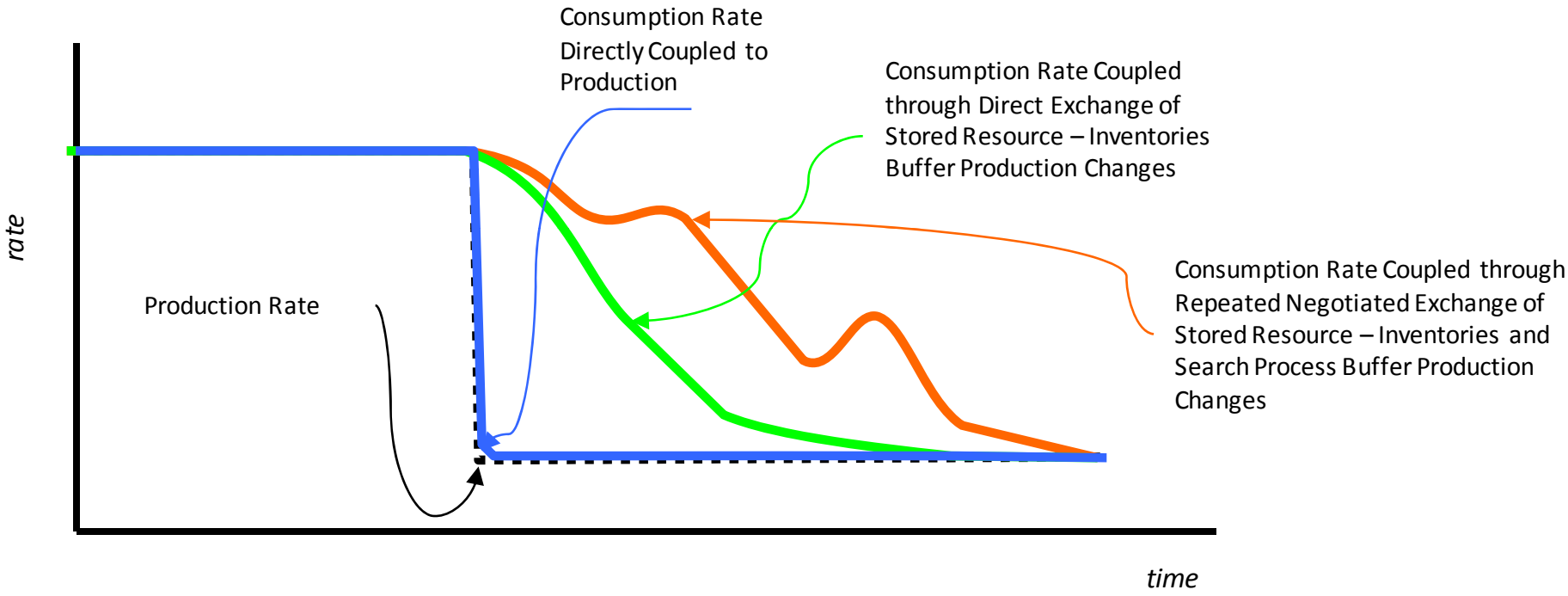
Robustness/Efficiency Tradeoff



Extra Slides

Hierarchy of Entity-to-Entity Interconnection

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