Using System Dynamics to Contribute to Ecological Economics

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Purpose

- Investigate **possible contributions of SD** to **ecological economics**
  - Ecological economics is the study of interactions between ecological systems and economic systems
- The main focus is on the usefulness of **sensitivity analysis**
  - Economics has focused on **comparative statics** (*i.e.*, analyzing the behavior of a system around a steady state).

Approach: Use a Two-step Modeling Process

- Build a base model using **economic theory**
- Incorporate adaptation using **system dynamics**
  - Hill-climbing approach that solves first order conditions numerically
  - Allows for out-of-equilibrium states

Context

- Extend a model of population-resource dynamics by Brander & Taylor (1998)
  - Published in the **American Economic Review**
- Reflect some of the suggestions from Nagase & Uehara (2011)
  - Population growth fn. (**Demographic Transition**)
  - Input substitutability (**CES function**)
  - Capital accumulation (**Man-made capital**)
  - Modeling approach (**Economics & System Dynamics**)

Mathematical Spec. of the BT Model

General equilibrium version of the Gordon-Schaefer Model, using a variation of the Lotka-Volterra predator-prey model

Static optimization (for given resource stock size S and population L)

Consumers: $\max_{\{h,\, m\}} \; u = h^{\beta} m^{1-\beta}$ s.t. $ph + m = w$

Producers: $H = \alpha S L_H$; α: tech parameter

$M = L_M$

$L_H + L_M = L$

$\Downarrow$

Equations of Motion (Predator-prey framework)

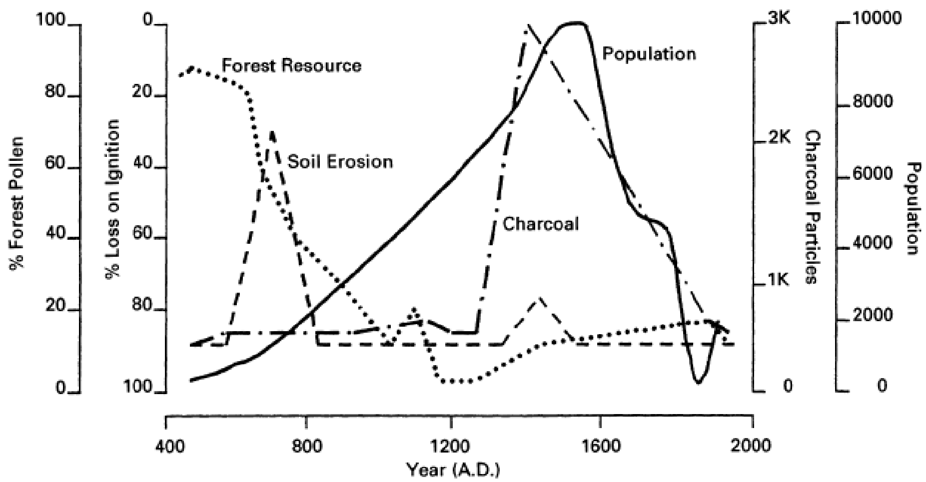
$dL/dt = (b - d + \phi h^*)L$

$dS/dt = G(S) - H^* = rS(1 - S/K) - H^*$ where K: Carrying Capacity

Reference Mode: pattern of behavior of the system to be modeled

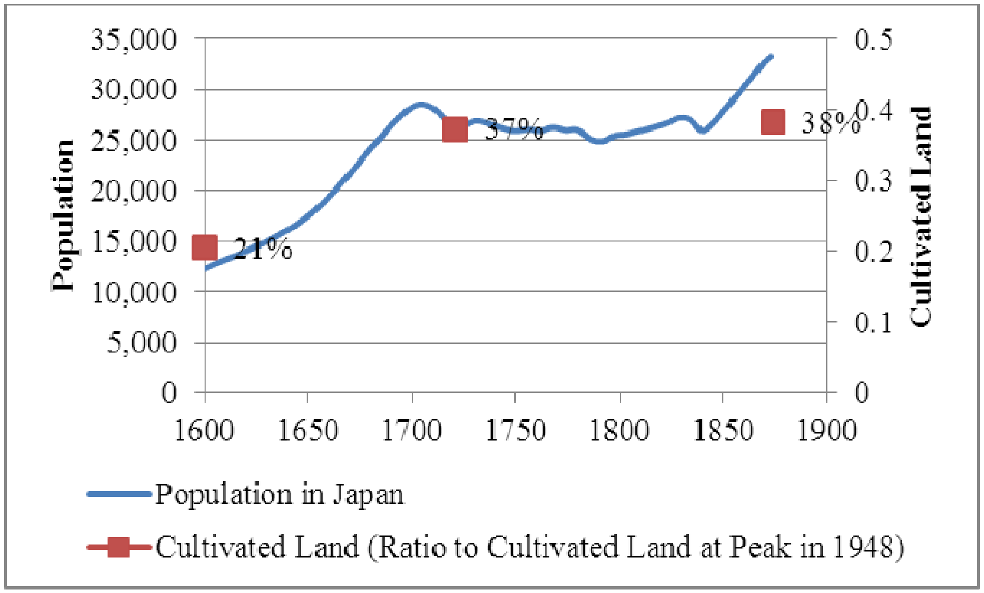
Boom and Bust

--OR--



Easter Island dynamics from archaeological study by Bahn and Flenley (1992)

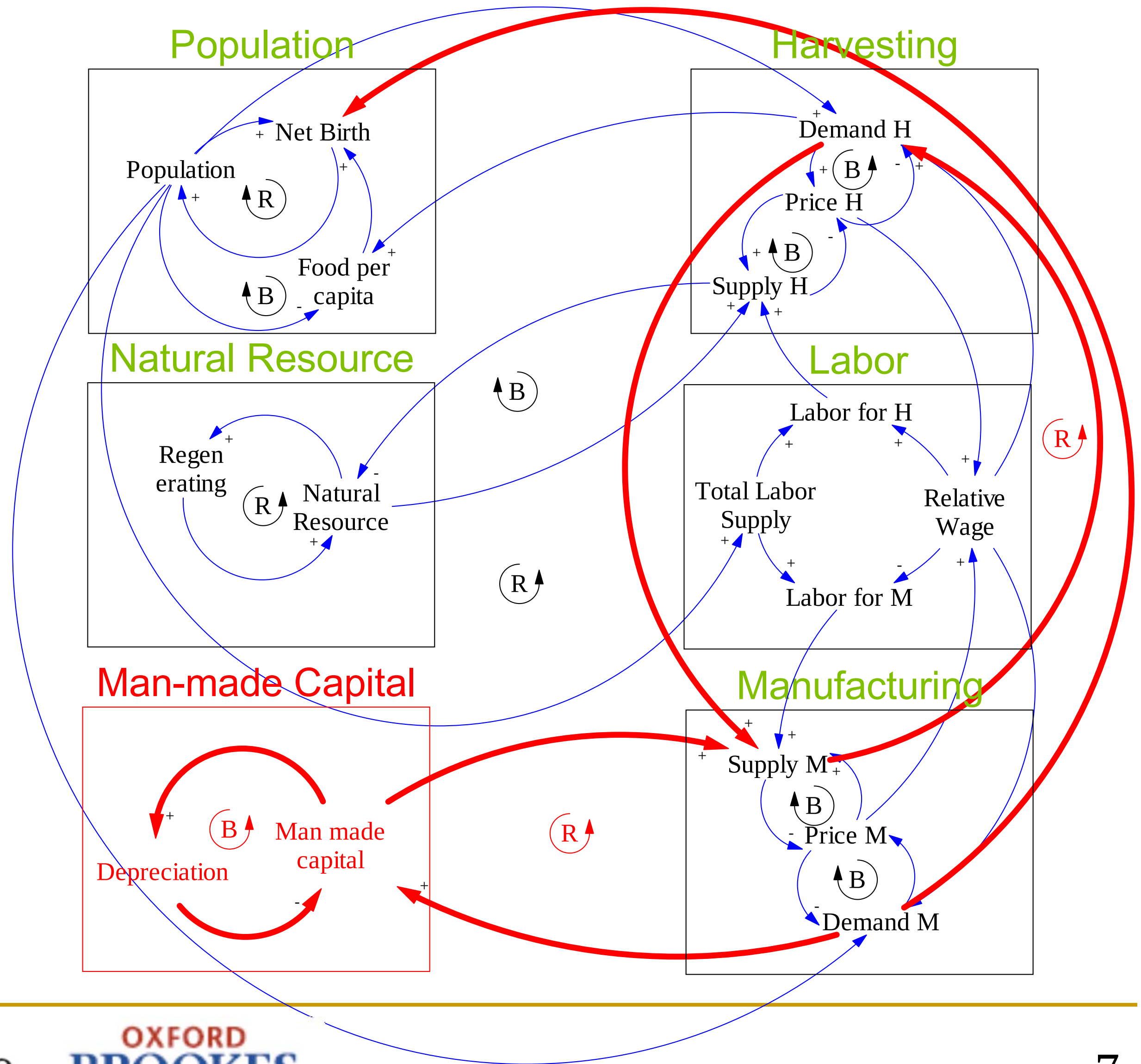
Stabilization



Population and Cultivated Land in Japan during *Edo* Era (1603-1868). Source: Wikipedia and Kito (1996)

Model Description: Causal Loop Diagram

- Main feedback loops
- Red texts and thick arrows indicate newly added items.

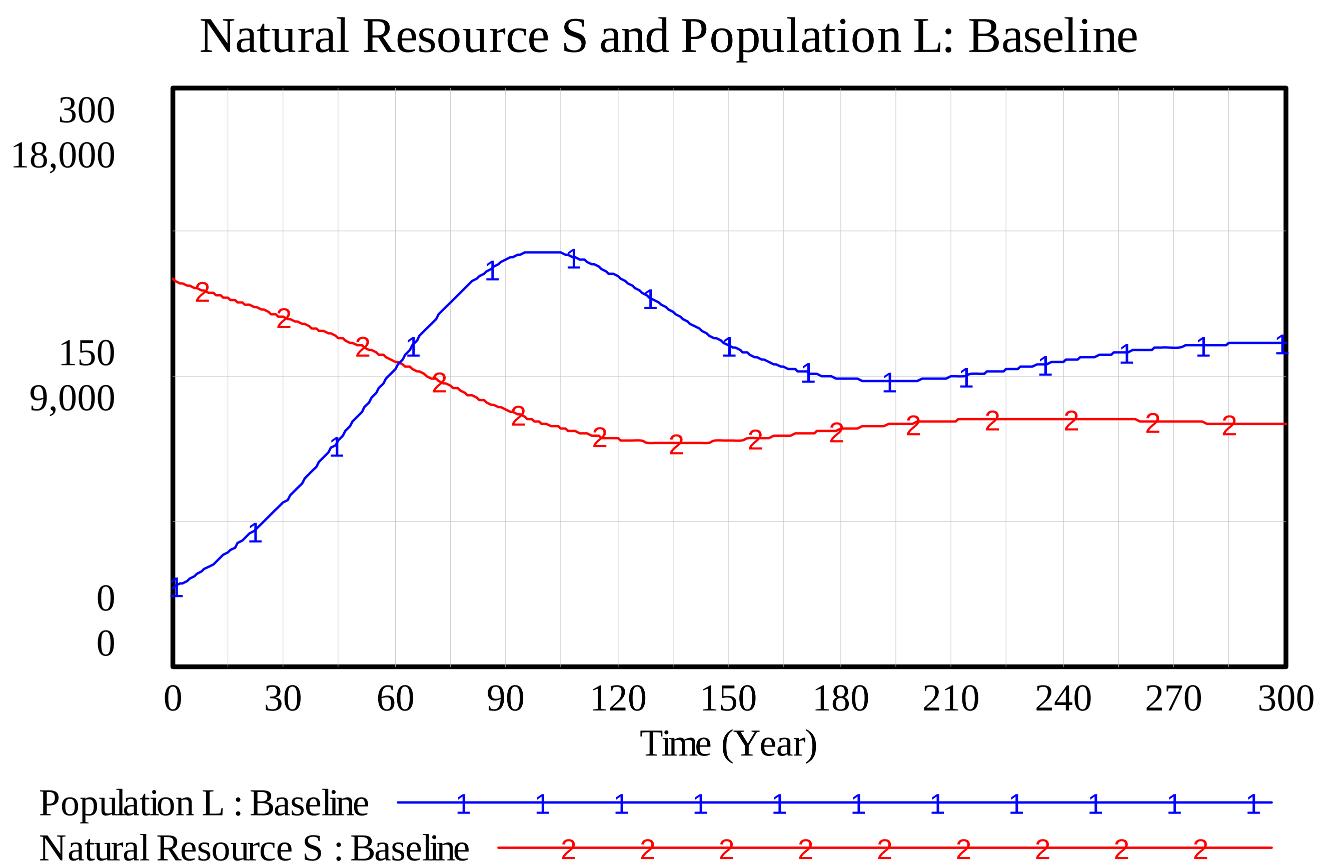


Model Description: Boundary

Endogenous	Exogenous	Excluded
Population - Population (L) - Birth Rate (b) - Death Rate (d) Natural Resource - Resource stock (S) - Growth of S (G) - Harvesting of S (H_S) Harvesting - Inventory of H - …	Population - Initial population (L_0) - Impact of H and M on population (b_1, b_2, d_1, d_2) - Maximum fertility rate (b_0) - Maximum mortality rate (d_0) Natural Resource - Initial natural Resource (S_0) - Regeneration rate of natural resource (η) - Carrying capacity (S_{max}) - …	- Non-renewable resources - Negative externalities of production (pollution) - International relationships (exports, imports, immigration, emigration) - Unemployment

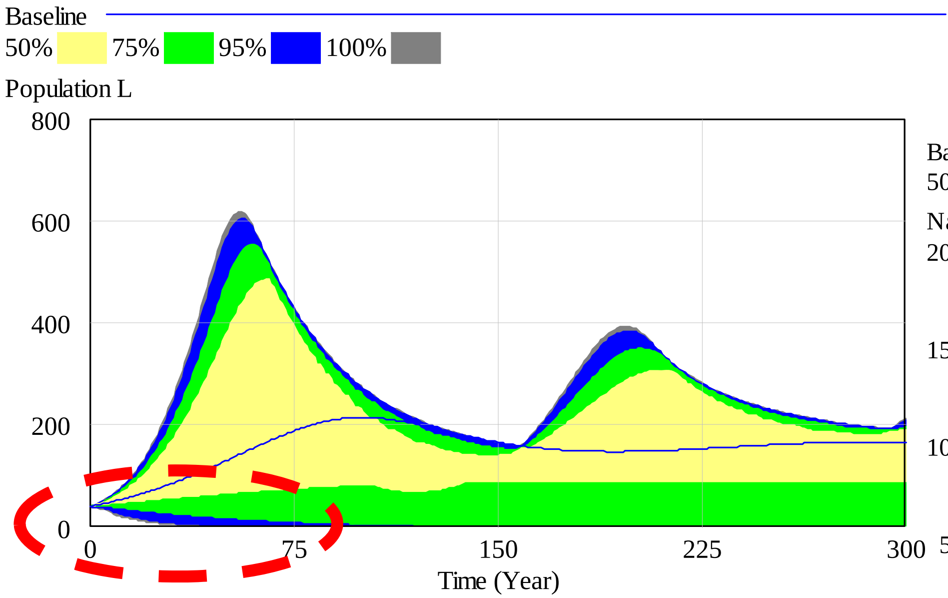
Results: Baseline

- Calibrated to be consistent with chosen reference mode

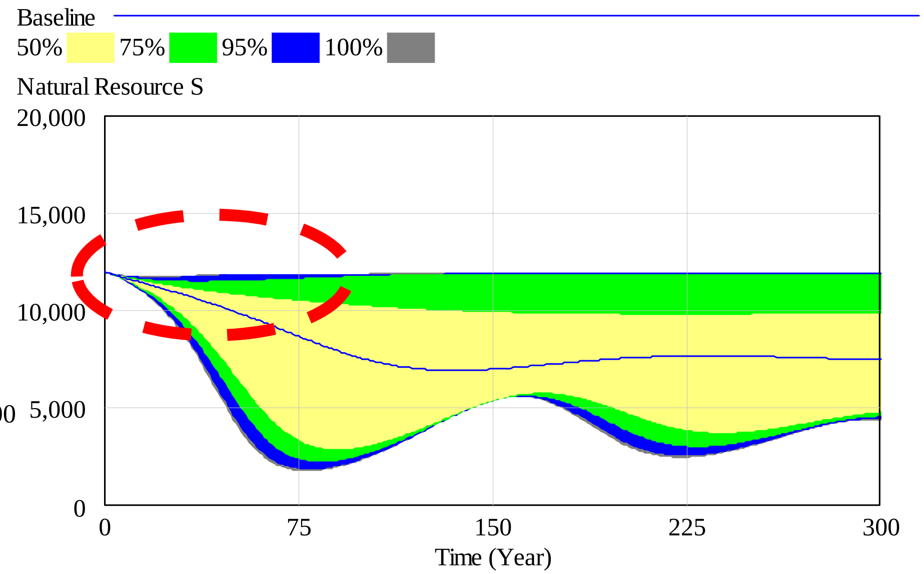


Results: Consumer Preference *b*

- Exogenous consumer preference leads to implausible results
- Either **exogenous preference** with careful choice or **endogenous preference** may solve the problem



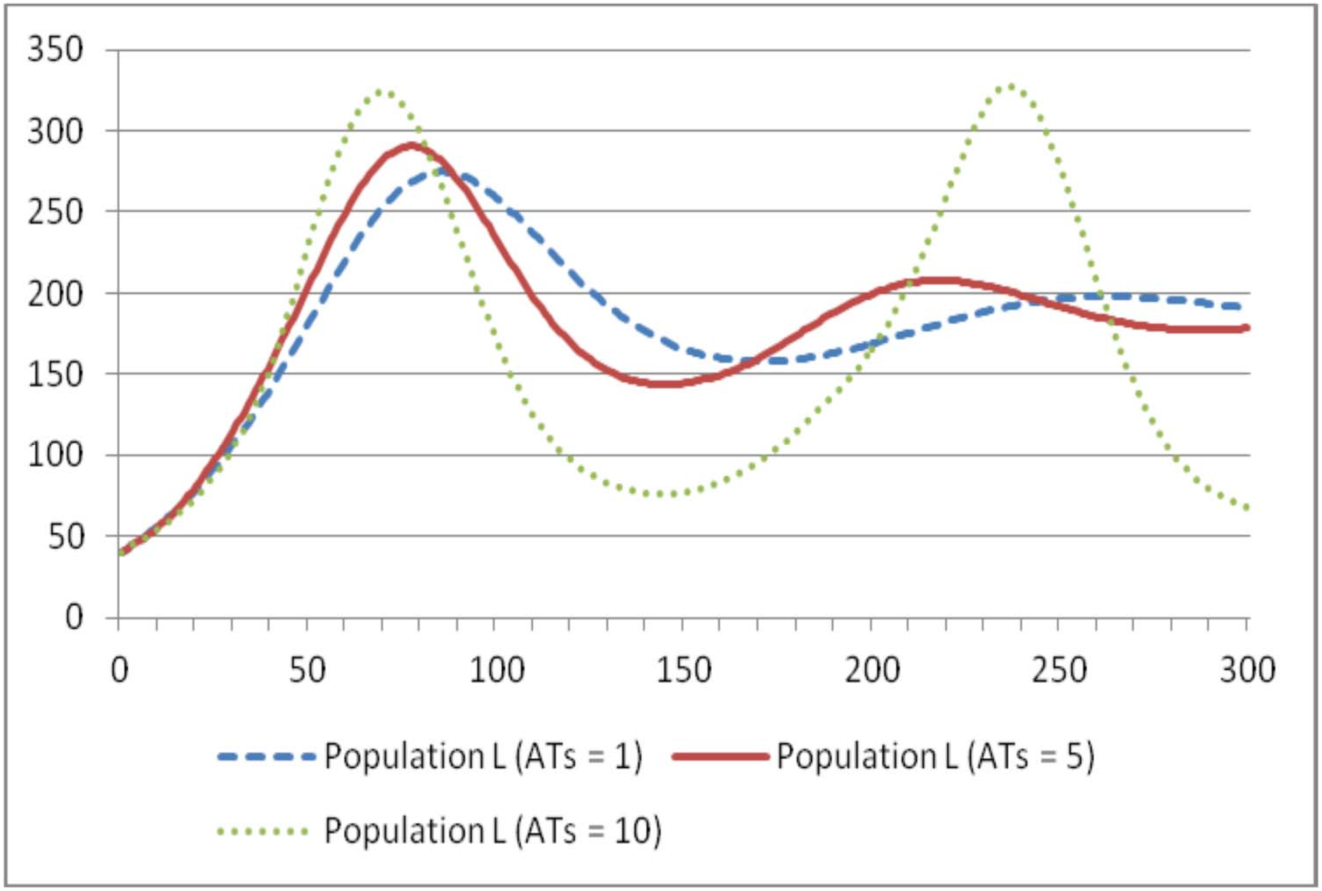
Sensitivity of L to various β



Sensitivity of S to various β

Results: Adaptation Processes

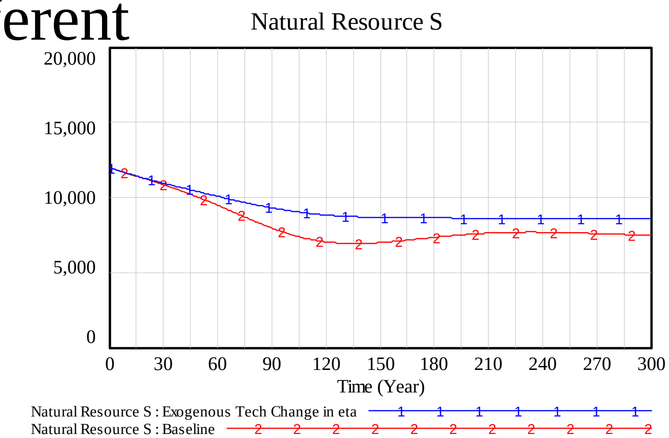
- Adaptation time constants significantly affect the numerical results, but not the qualitative results (shape of curve)

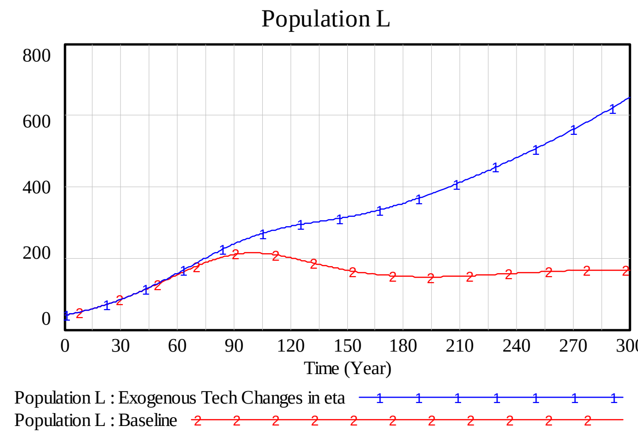


Results: S_{max} (carrying capacity) and η (resource regeneration rate)

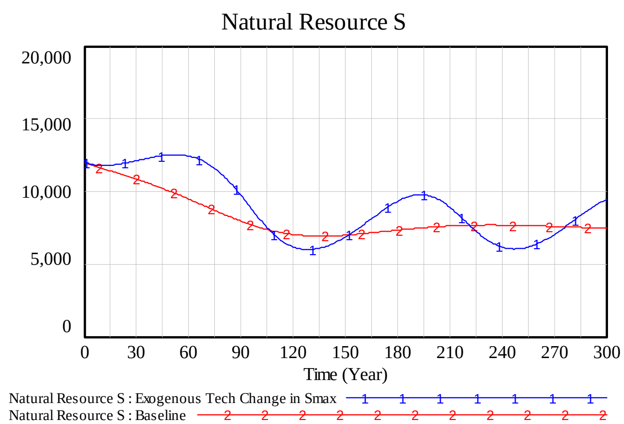
- While the impacts of S_{max} and η on $G(S)$ are both positive ($dG/dS_{max}>0$ and $dG/d\eta>0$), their impacts on the system are quite different

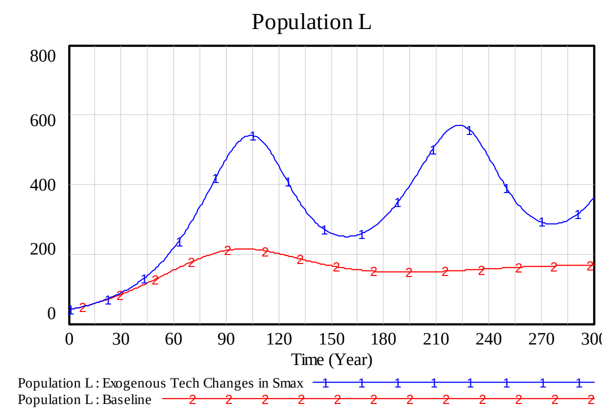
Impacts of Changes in η





Impacts of Changes in S_{max}





Discussion: Consumer Preferences

- **Neoclassical economists** are "very reticent" to talk the origin of preferences and assume that they are unchanging over time (Stern, 1997)
- **Heterodox economists** (e.g., ecological economists) argue for the importance of changing preference for sustainability issues.
- There is **no well established approach** in economics.
- **SD** could offer an approach to endogenize consumer preferences

Discussion: Adaptation

- Adaptation has been paid attention to in ecological economics only recently (e.g., Common and Stagl, 2005)
- And, while its importance has been raised, **no well established modeling approach for adaptation is available in economics**
  - Learning in macroeconomic theory (e.g., Evans and Honkapohja, 2011) could be one possibility
  - **SD** could offer an approach to incorporate adaptation in an appropriate manner

Discussion: S_{max} and η

- System Dynamics view: A system oscillates if
  - S_{max} is **not constant** and the system involves **delays** to keep seeking a new steady state (cf., Sterman, 2000).
- Economics view; from Brander and Taylor (1998):
  - The system converges to a steady state **with oscillations** if
    $$\eta(d - b)/(S_{max}\phi\alpha\beta) + 4\,((\mathrm{d} - \mathrm{b}) - S_{max}\phi\alpha\beta\,) < 0$$
  - The system converges **monotonically** to a steady state if
    $$\eta(d - b)/(S_{max}\phi\alpha\beta) + 4\,((\mathrm{d} - \mathrm{b}) - S_{max}\phi\alpha\beta\,) > 0$$
  - **$\mathrm{d}\eta/\mathrm{d}t > 0$** may **change** the left-hand side **from negative to positive** but **$\mathrm{d}S_{max}/\mathrm{d}t > 0$ reinforces the negativity**

Conclusion

- Making consumer preferences endogenous and incorporating adaptation are quite important for an ecological economic model, but these ideas are relatively new to economics and not yet well addressed
- **SD** has a rich experience and theory in making variables endogenous and modeling adaptation processes