
Using System Dynamics to Contribute to Ecological Economics

Takuro Uehara¹, Yoko Nagase², and Wayne Wakeland³

1. Systems Science Graduate Program and Department of Economics, Portland State University, USA
2. Department of Accounting, Finance and Economics, Oxford Brookes University, UK
3. Systems Science Graduate Program, Portland State University, USA

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:
$$\text{Max}_{\{h, m\}} u = h^\beta m^{1-\beta} \quad \text{s.t.} \quad ph + m = w$$

Producers:
$$H = \alpha SL_H; \quad \alpha: \text{tech parameter}$$

$$M = L_M$$

$$L_H + L_M = L$$



Equations of Motion (Predator-prey framework)

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

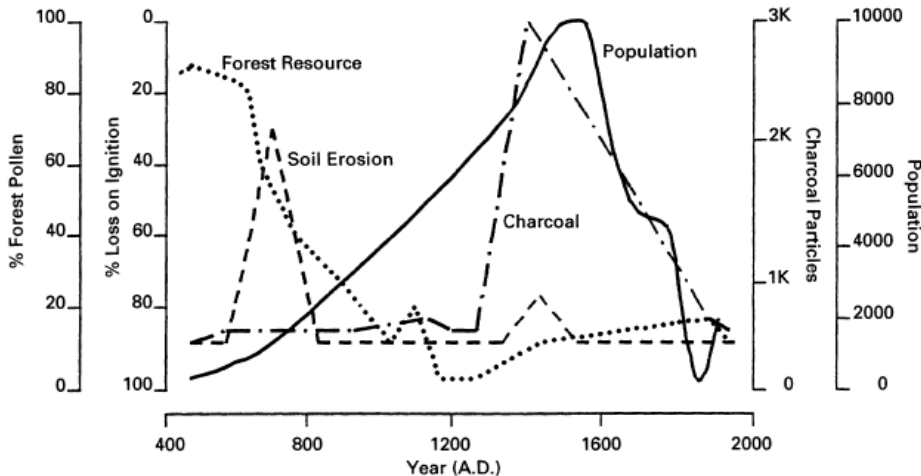


Reference Mode: pattern of behavior of the system to be modeled

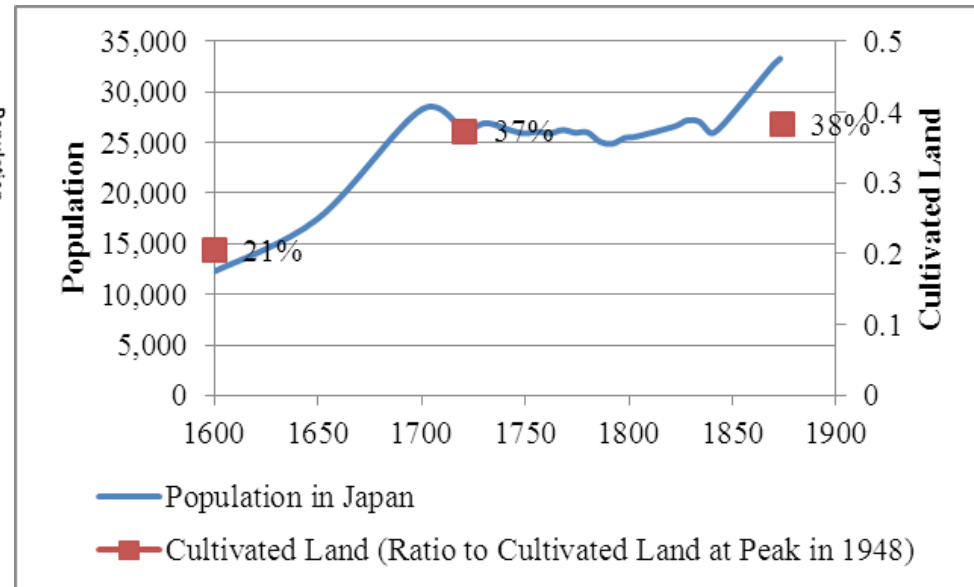
Boom and Bust

--OR--

Stabilization



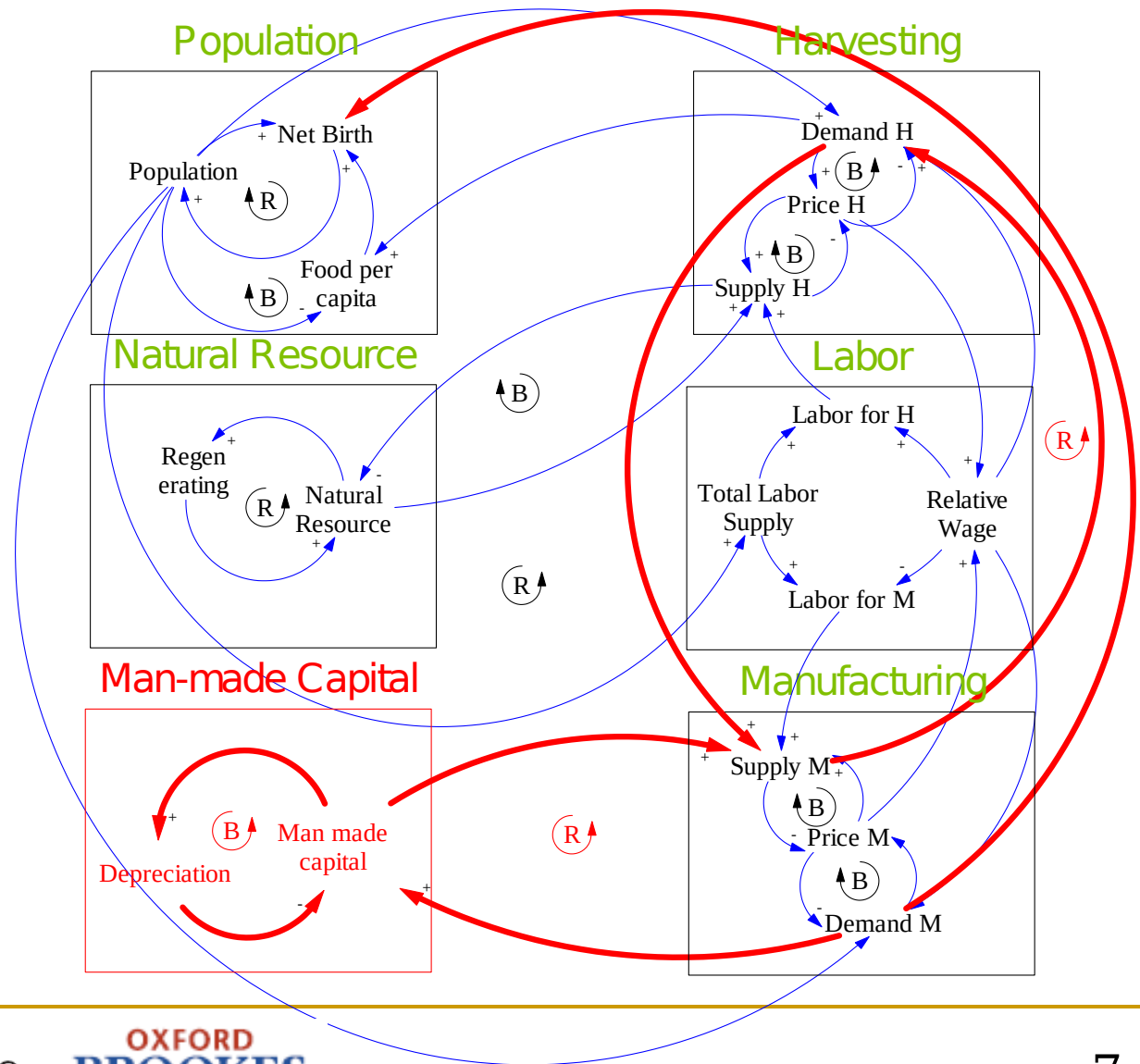
Easter Island dynamics from archaeological study by Bahn and Flenley (1992)



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.

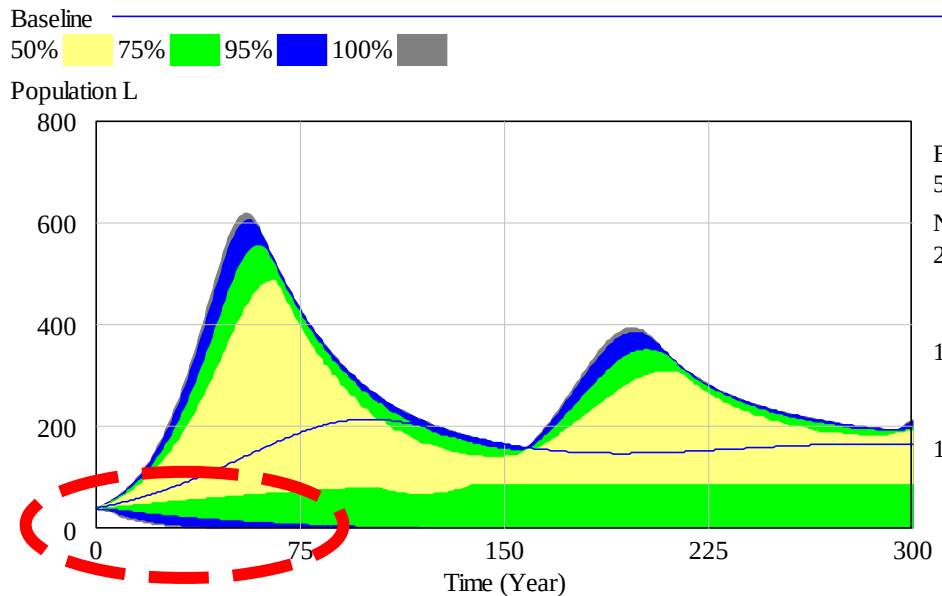


Model Description: Boundary

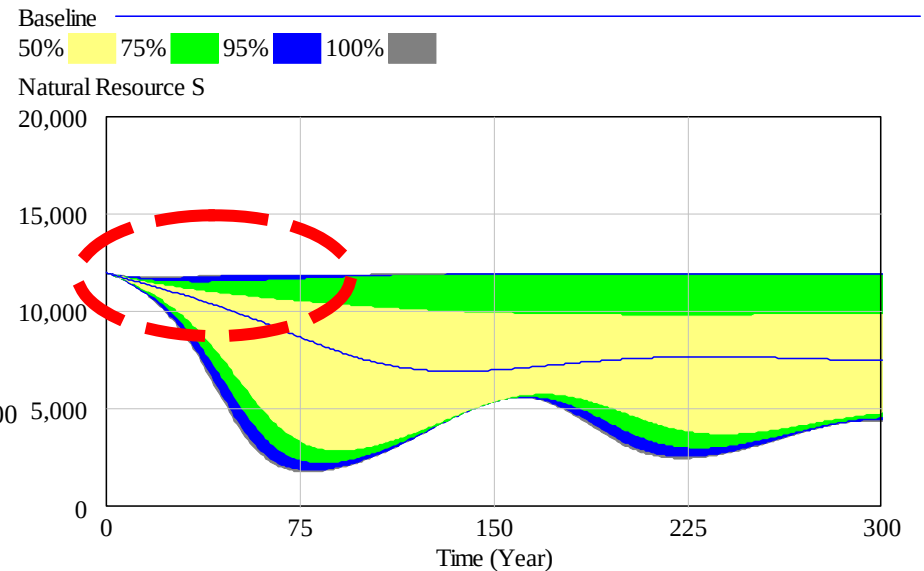
Endogenous	Exogenous	Excluded
<u>Population</u> -Population (L) -Birth Rate (b) -Death Rate (d)	<u>Population</u> -Initial population (L_0) -Impact of H and M on population (b_1, b_2, d_1, d_2) -Maximum fertility rate (b_0) -Maximum mortality rate (d_0)	- Non-renewable resources - Negative externalities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

Results: Consumer Preference b

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



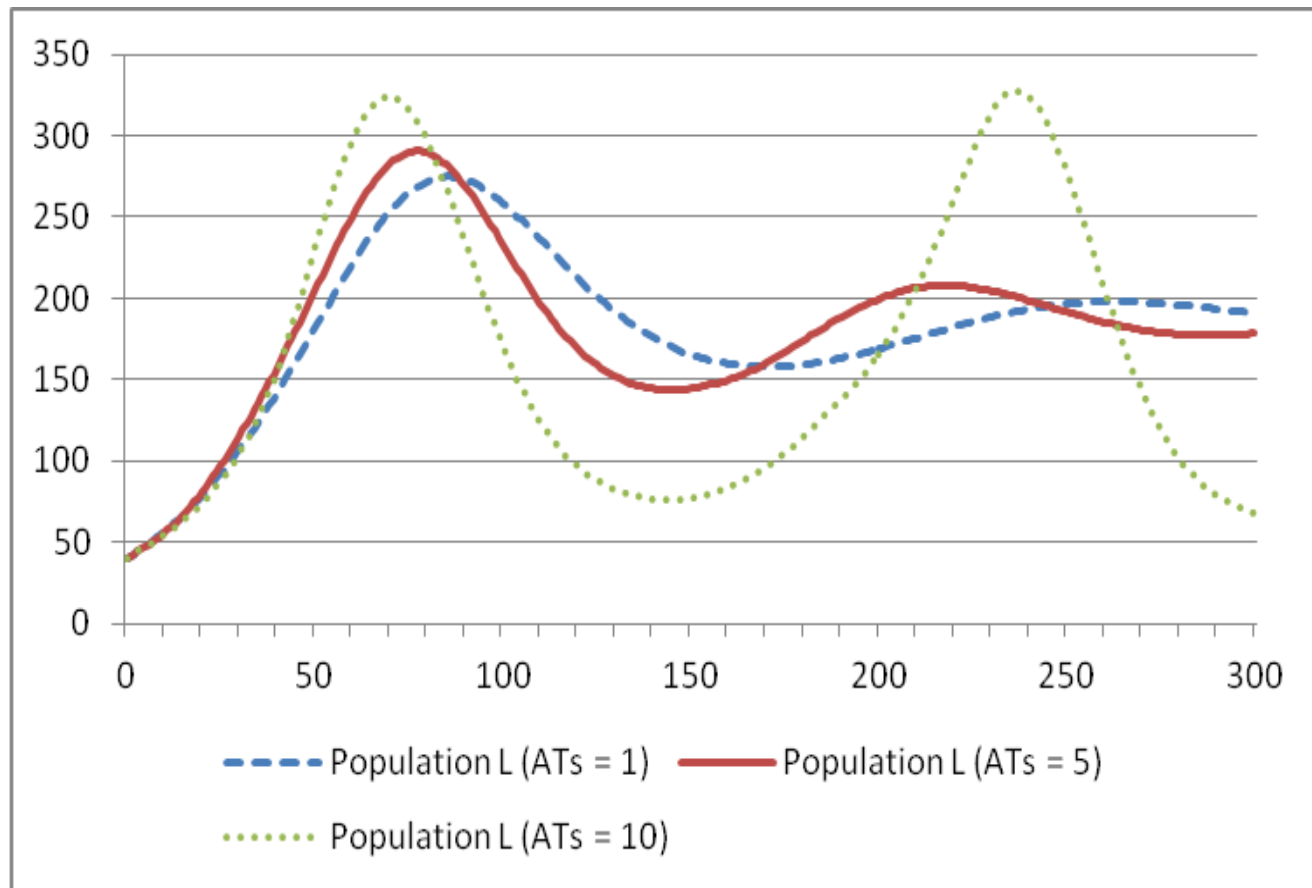
Sensitivity of L to various β



Sensitivity of S to various β

Results: Adaptation Processes

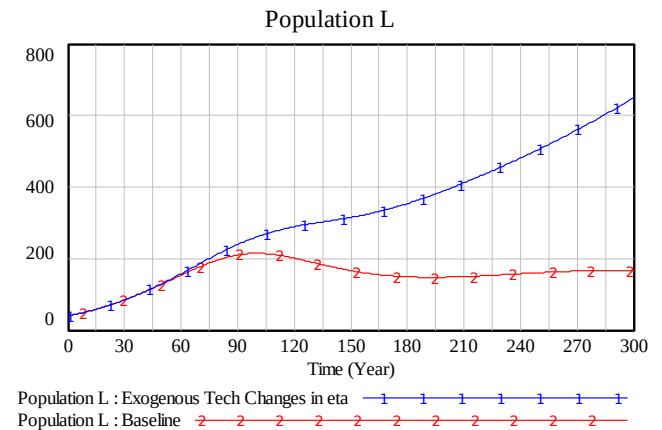
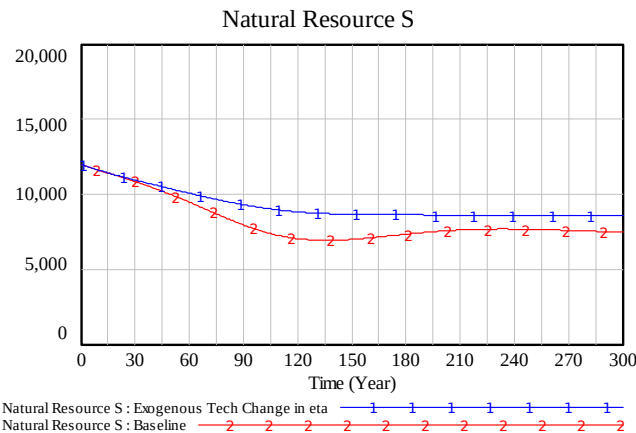
- Adaptation time constants significantly affect the numerical results, but not the qualitative results (shape of curve)



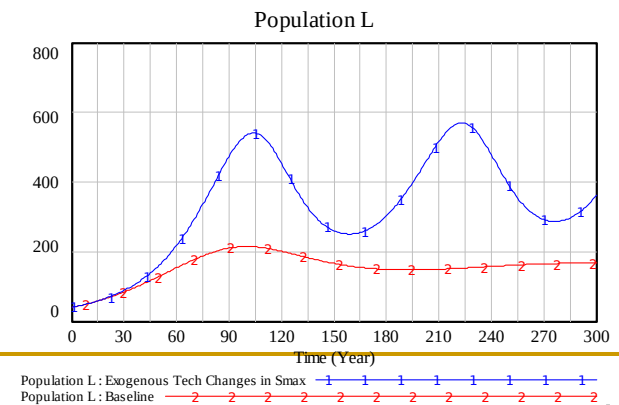
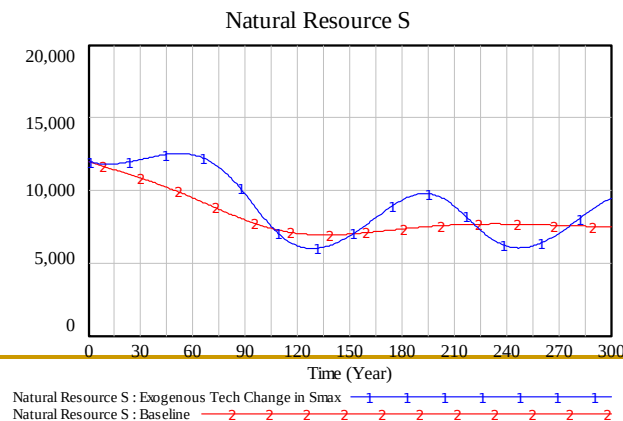
Results: S_{max} (carrying capacity) and η (resource regeneration rate)

- 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
$$\eta(d - b)/(S_{max}\phi\alpha\beta) + 4((d - b) - S_{max}\phi\alpha\beta) < 0$$
 - The system converges **monotonically** to a steady state if
$$\eta(d - b)/(S_{max}\phi\alpha\beta) + 4((d - b) - S_{max}\phi\alpha\beta) > 0$$
 - **$d\eta/dt > 0$** may **change** the left-hand side **from negative to positive** but **$dS_{max}/dt > 0$** 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