Advanced Macroeconomics
12. Population & Resources:
# Malthus and the Environment

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Malthus and Resources

- The Malthusian model may seem of interest today only to explain the world before the Industrial Revolution.

- Recall, however, that Malthus's views focused on how increasing numbers of people placed pressures on the allocation of scarce resources, particularly food.

- Are concerns about scarce resources necessarily a thing of the past?

- With global population passed 7 billion, it is reasonable to ask whether energy sources, agricultural land and climate can continue to withstand the strain of increasing population.

- Here, we look at a model that combines a Malthusian approach to population dynamics with modelling changes in a renewable resource base.

- First presented by Brander and Taylor in their 1998 paper "The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use."

The World's Most Remote Place
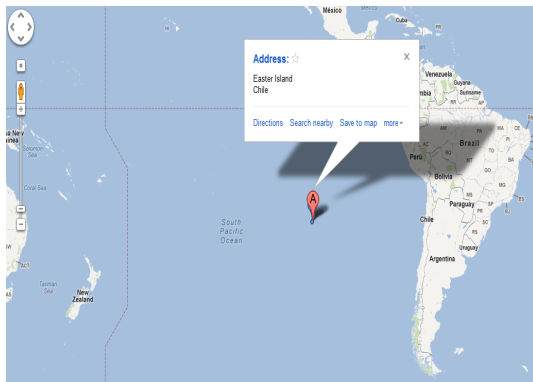
Easter Island Statues

Standing and Toppled Statues

Model of Resources: Population and Harvests

- The model economy has N_t people.

- They sustain themselves by collecting a harvest, H_t from a renewable resource stock denoted by S_t.

- The model consists of three elements:

- **The Change in Population**: This depends positively on the amount of harvest per person and on an exogenous factor $d > 0$ (without a harvest, there is a certain percentage reduction in population).

$$\frac{dN_t}{dt} = -dN_t + \theta H_t$$

- **The Harvest**: The harvest reaped per person is a positive function of the size of the resource stock.

$$\frac{H_t}{N_t} = \gamma S_t$$

Model of Resources: Stock of Resources

- The final element in the model is the change in the resource stock.

- We are describing a resource stock that is renewable. It doesn't simply decline when harvested until it is all gone.

- Instead, it has its own capacity to increase. For example, stocks of fish can be depleted but will increase naturally again if fishing is cut back.

- So, our equation for the change in resources is

$$\frac{dS_t}{dt} = G\left(S_t\right) - H_t$$

- The second term on the right-hand-side captures that the resource stock is reduced by the amount that is harvested.

- The first element describes the ability of the resource to grow.

Renewal of the Stock of Resources

- Brander and Taylor use a logistic function to describe how the resource stock renews itself

$$G\left(S_t\right) = rS_t\left(1 - S_t\right)$$

- The maximum level of resources is $S_t = 1$: At this level, there can no further increase in S_t.

- If $S_t = 0$ so the resource base has disappeared, then it cannot be regenerated.

- For all levels in between zero and one, we can note that

$$\frac{G\left(S_t\right)}{S_t} = r\left(1 - S_t\right)$$

- So the amount of natural renewal as a fraction of the stock decreases steadily as the stock reaches its maximum value of one. If the stock gets very low, it can grow at a fast rate if there is limited harvesting.

Dynamics of Population

- We are going to use a *phase diagram* to describe the joint dynamics of N_t and S_t.

- Inserting the equation for the harvest into the equation for the change in population we get

$$\frac{dN_t}{dt} = -dN_t + \theta\gamma S_t N_t$$

- This equation shows us that population growth is a positive function of the resource stock.

- This means there is a particular value of the resource stock, S^*, for which population growth is zero. When resources are higher than S^* population increases and when it is lower than S^* population declines.

- The value of S^* can be calculated as

$$-dN_t + \theta\gamma S^* N_t = 0 \Rightarrow S^* = \frac{d}{\theta\gamma}$$

Phase Diagram: Population Dynamics

- The figure on the next slide shows how we illustrate the dynamics with a phase diagram.

- We put population on the x-axis and the stock of resources on the y-axis.

- Population dynamics can then be described as follows:

  1. Unchanged population corresponds to a straight line at S^*.
  2. For all values of resources above S^* population is increasing: Thus in the area above the line, we show an arrow pointing right, meaning population is increasing.
  3. In the area below this line, there is an arrow pointing left, meaning population is falling.

Population Dynamics

Resource Dynamics

- Combining logistic renewal with harvest equation, resource stock dynamics are

$$\frac{dS_t}{dt} = rS_t \left(1 - S_t\right) - \gamma N_t S_t$$

- The stock of resources will be unchanged for all combinations of S_t and N_t that satisfy

$$rS_t \left(1 - S_t\right) - \gamma N_t S_t = 0 \Rightarrow N_t = \frac{r \left(1 - S_t\right)}{\gamma}$$

- This means that there is downward sloping line in $N - S$ space along each point of which the change in resources is zero.

Phase Diagram: Resource Dynamics

- The upper point crossing the S axis corresponds to no change because $S = 1$ and there are no people.

- As we move down the line we get points that correspond to no change in the stock of resources because while there are progressively larger numbers of people, the stock gets smaller and so can renew itself at a faster pace.

- Growth rate of resources depends negatively on the level of the stock:

  1. Every point that lies above the downward-sloping $\frac{dS}{dt} = 0$ line has a higher level of resources than the point on line below it. So S_t is declining for every point above the line and increasing for every point below it, hence arrow pointing down.

  2. In the area below this line, there is an arrow pointing up, meaning the stock of resources is increasing.
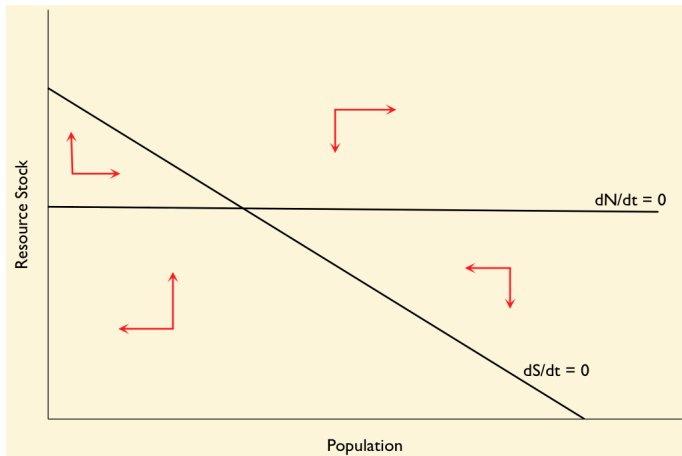
Resource Dynamics
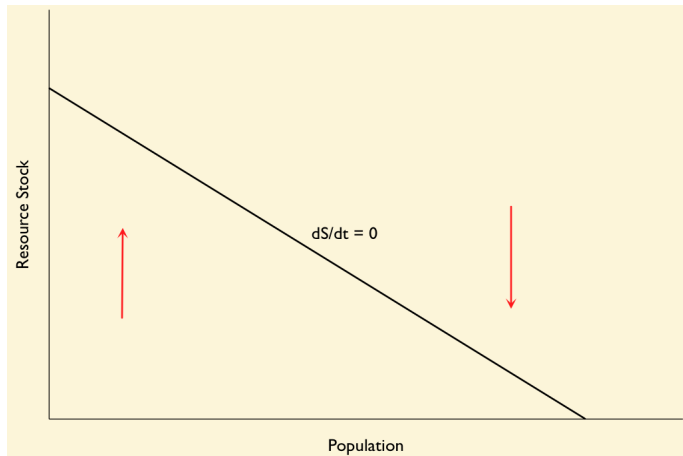
Joint Dynamics of Population and Resources

- In the next figure, we put together the four arrows drawn in the two previous figures.

- The joint dynamics of population and resources can be divided up into four different quadrants.

- We can also see that there is one point at which both population and resources are unchanged.

- We know already from equation (9) that the level of the resource stock at this point is $S^* = \frac{d}{\theta\gamma}$.

- The level of population associated with this point is:

$$N^* = \frac{r\left(1 - \frac{d}{\theta\gamma}\right)}{\gamma} = \frac{r\left(\theta\gamma - d\right)}{\theta\gamma^2}$$

Combining Population and Resource Dynamics

Joint Dynamics of Population and Resources

- This point is clearly some kind of "equilibrium" in the sense that once the economy reaches this point, it tends to stay there.

- But is the economy actually likely to end up at this point?

- Yes: From any interior point (i.e. a point in which there is a non-zero population and resource stock) the economy eventually ends up at (N^*, S^*).

- I don't prove this in the notes but you can show that

$$
\begin{aligned}
\frac{1}{N_t} \frac{dN_t}{dt} &= \theta\gamma (S_t - S^*) \\
\frac{1}{S_t} \frac{dS_t}{dt} &= \gamma (N_t - N^*) + r (S_t - S^*)
\end{aligned}
$$

so the dynamics of both population and the resource stock are both driven by how far the economy is from this equilibrium point.

Harvesting and Long-Run Population

- How does more intensive harvesting (higher γ) affect the long-run equilibrium level of population N^*?

- In the notes, we show that

$$\frac{dN^*}{d\gamma} = \frac{r}{\gamma^2}(2S^* - 1)$$

- The right-hand side here may be greater than or less than zero.

- Whether an increase in γ raises or reduces the equilibrium population depends on the size of the equilibrium level of resources.

    1. If $S^* > 0.5$ then a more intensive rate of harvesting raises the population even though it reduces the total amount of resources.
    2. If $S^* < 0.5$ then a more intensive rate of harvesting reduces the population because it reduces the total amount of resources.

- Easter Island devastation scenario (ending with very low resource stock) more like the latter case.

Back to Easter Island

- Let's go back to Easter Island and imagine the island in its early days with a full stock of resources and very few residents. What happens next?

- For many years, the population expands and resources decline.

- Then, when it moves into the bottom right quadrant, population falls and resources keep declining.

- It moves though the quadrants and ends up at equilibrium with $S = S^*$ and $N = N^*$

- Our theoretical Easter Island sees its population far overshoot its long-run equilibrium level before collapsing below this level and then oscillating around the long-run level and then finally settling down.
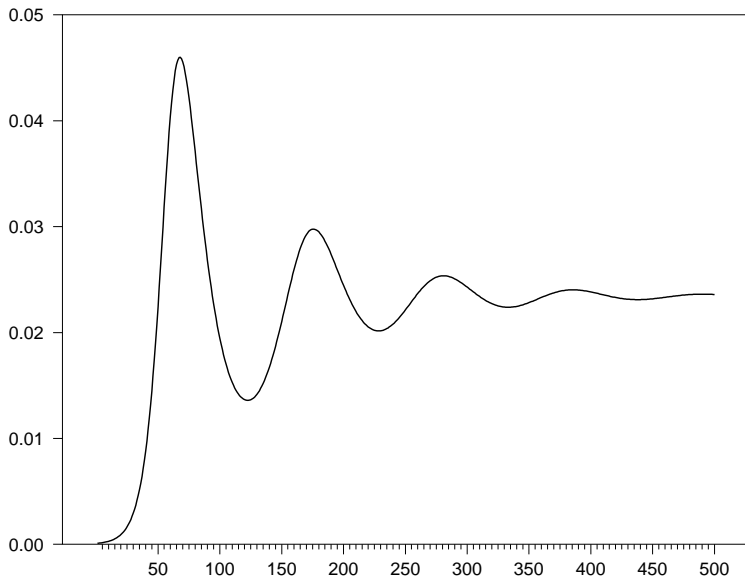
Illustrative Dynamics Starting from Low Population and High Resources
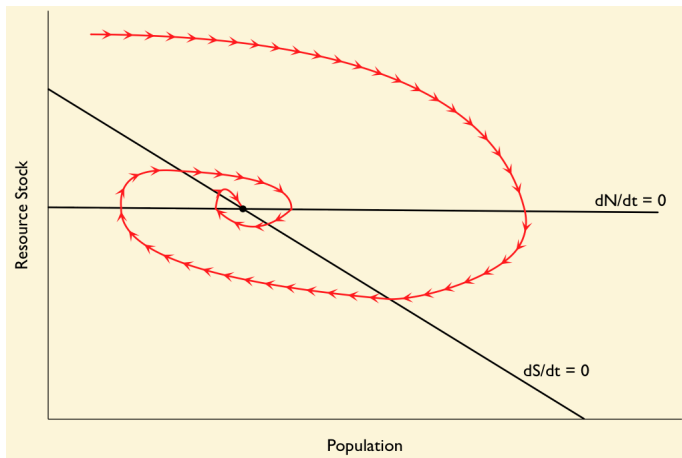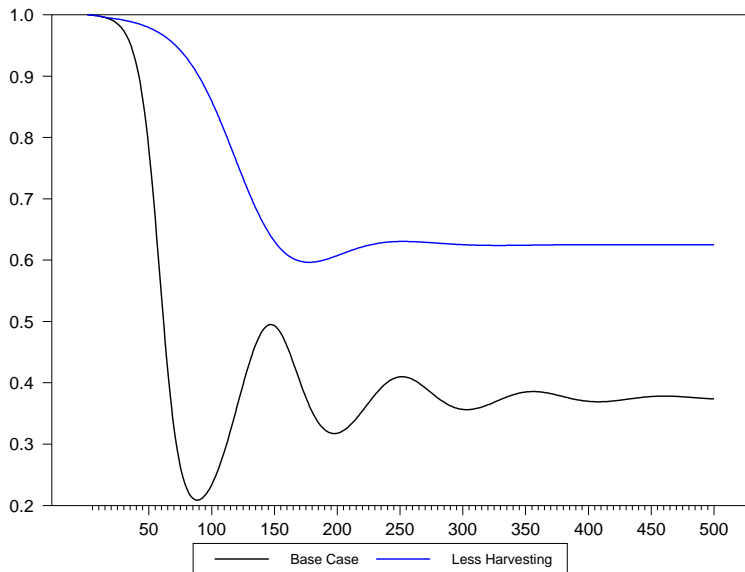
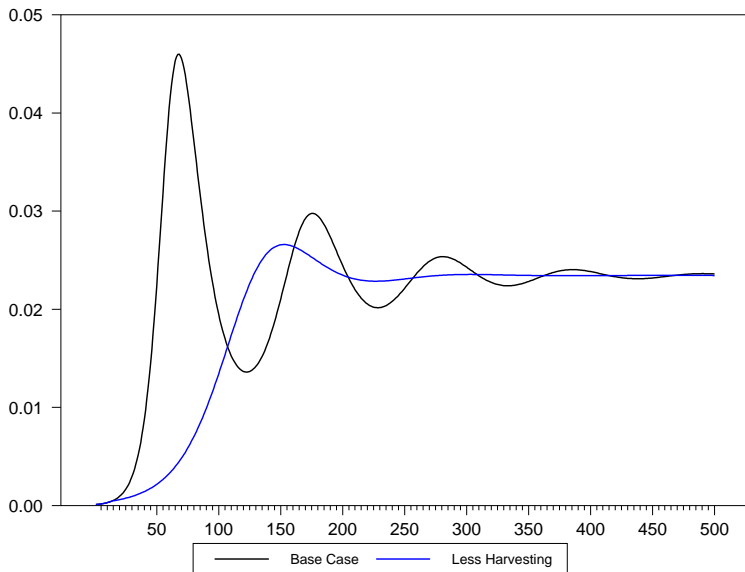# Resources in a Simulated Easter Island Economy
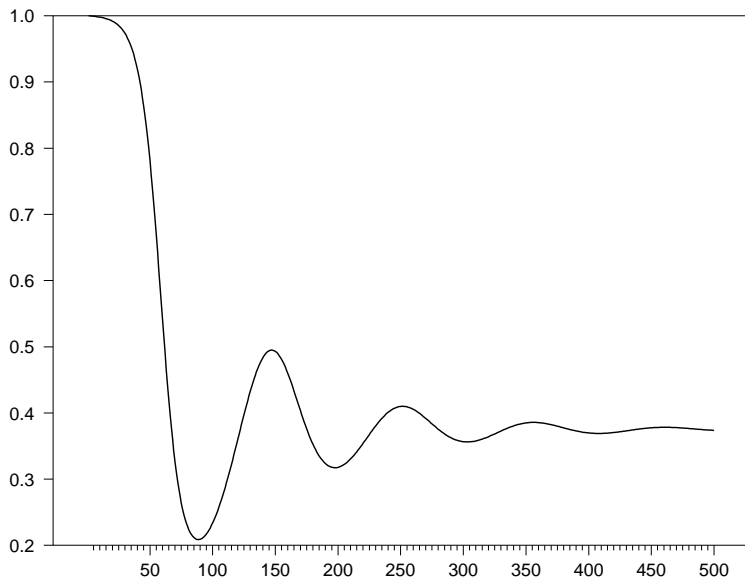
Population in a Simulated Easter Island Economy

Resource Stock with Less Harvesting

Population with Less Harvesting

Why Doesn't Someone Shout Stop?

- In his book, *Collapse*, Jared Diamond discusses Easter Island and a number of other cases in which societies saw dramatic collapses, many triggered by long-term environmental damage.

- Diamond points to a number of potential explanations for why societies can let environmental damage occur up to the point where they trigger disasters.

  - **The Tragedy of the Commons**: It may simply never be in anyone's individual interests at any point in time to prevent environmental degradation. Need political institutions to take into account externalities associated with self-interested behaviour.
  - **Failure to Anticipate**: Societies may not realise exactly how much damage they are doing to their environment or what its long-term consequences will be.
  - **Failure to Perceive, Until Too Late**: Diamond notes that environmental change often occurs at such a slow pace that people fail to notice it and plan to deal with it.

- Analogies with current debate about climate change are clear.

Things to Understand From This Topic

1. A rough idea of the facts about the history of Easter Island prior to the arrival of Europeans.

2. The structure of the Brander-Taylor model.

3. How to derive the dynamics of population.

4. How to derive the dynamics of resources.

5. The long-run impacts of more intensive harvesting.

6. How to draw the phase diagram.

7. The likely dynamics starting from low population and high resources.

8. Why environmental disasters are not prevented.