Easter Island's Collapse: a Tale of Population Race

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Easter Island and Tikopia: maps

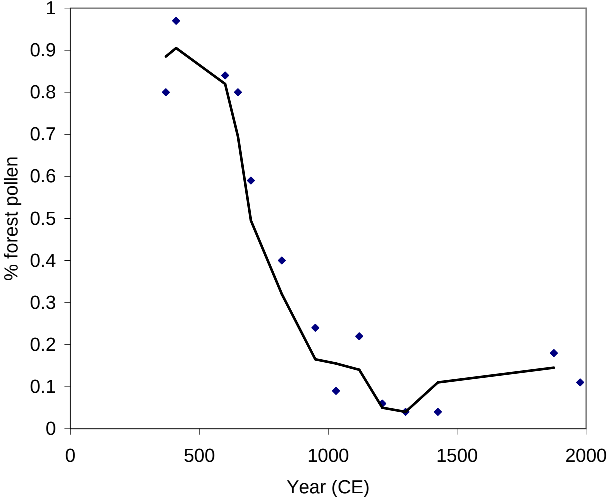
Chronology of the rise and fall

- 400 CE. First settlers, likely Polynesians (Marquesas Islanders, less than 100 units)
- 600 CE. Beginning of deforestation.
- 1000-1500 CE. *Moai* building by competing clans. (more than 800 in total, each weighting up to 80 tons)
- 1500 CE. Population's peak at about 10000 (but other estimates come up to 20'000)
- 1500-1700 CE. Appearance of new weapons, cannibalism, movements into fortified dwellings: *conflicts*. Deforestation completed. Population crash.
- 1722 CE. Discovery by Dutch explorers. Estimated population: less than 3000. No tree.

Easter island, Earth Island

Monuments of Easter Island, 1775 CE, by William Hodges

Easter Island: An Ecological Catastrophe

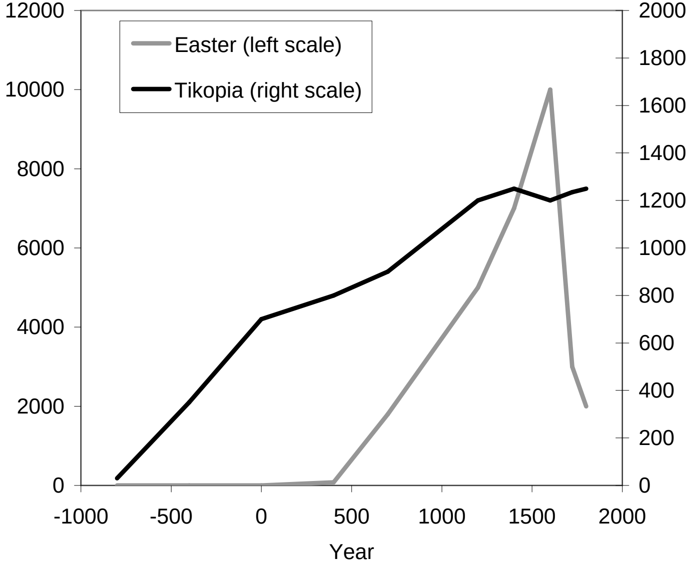


(data: John Flenley)

A counter-example: Tikopia

- 900 BCE; First settlers from Eastern Polynesia; second wave from Eastern Polynesians tribes later.
- Population achieved 1200 units by 1100 CE and then remained roughly steady over centuries
- Control over population growth through several practices (cult of virginity, infanticides, celibacy, sea voyaging by young males, abortion, contraception, expulsion of segments of population in excess, fono (an annual address by the chief)

Population in Easter and Tikopia



Literature

- Brander & Taylor (AER, 1998): Population-resources interaction. Fertility determined by nutrition (Malthus).
  Extensions to account for abrupt decrease: Pezzey and Anderies (JDE, 2003), Erickson and Gowdy (LE, 2000), Reuveny and Decker (EE, 2000).
- Conflicting groups: groups may conflict to encroach crop. A (static) problem of optimal allocation between working and fighting. Malthusian fertility.
  Myopic behaviors often implicitly postulated.
  Maxwell and Reuveny (JEBO, 2005; 2001), Lasserre and Souberyan (JEBO,2003), Prskawetz *et al.*(EMA,2003).

What we Do

We are not satisfied with the way fertility is modeled.

Also, assuming myopic behavior is unsatisfactory.

We propose a first model with endogenous fertility decisions to include strategic complementarities between groups.

Outline of the model

- Utility Maximizing Fertility
- Absence of strong property rights: crop distribution among clans follows a non cooperative bargaining
- Bargaining power depends on the threat of fighting a war
- Success in conflict depends on the relative size of groups
- Incentive to increase clan's population? ⇒ *Population Race*

The economy

- OLG where agents live for 2 periods. Every agent belongs to a clan. 2 clans.
- N_{it} young individuals at time t in clan i.
- The young work, rear children, support parents (and fight in case of conflict).
- The old consume out of a portion of their sons' income.
- Child rearing has a disutility cost
- Timing of clans' decisions:
  1. choice of own fertility rate as a social norm, considering the others' as given, and having perfect foresight,
  2. bargaining on crop sharing.

- Old age support: Share of income paid to old parents *decreasing in the number of siblings*:

$$\frac{\tau}{1+n_{i,t}}, \qquad 0<\tau<1.$$

- Utility: (for simplicity) Linear

$$U_i = c_{i,t} + \beta d_{i,t+1} - \lambda n_{i,t}$$

Budget constraints:

$$c_{i,t} = \left(1 - \frac{\tau}{1+n_{i,t-1}}\right) y_{i,t} \qquad (1)$$

$$d_{i,t+1} = n_{i,t} \frac{\tau}{1+n_{i,t}} y_{i,t+1} \qquad (2)$$

where:

c_{it}	:	1st period consump	d_{it+1}	:	2nd period consumption
y_{it}	:	income of a young	$n_{i,t}$	:	number of children
$\beta > 0$	:	discount factor	$\lambda \geq 0$	:	child-rearing disutility

- Population Dynamics:

$$N_{it+1} = n_{it} N_{it} \tag{3}$$

- Production: $Y_t = A_t L^{\alpha}(N_{1,t} + N_{2,t})^{1-\alpha}$
  L: Land (fixed: $\Rightarrow L = 1$);
  A_t: TFP depending on stock of resources R_t:

$$A_t = A(R_t)$$

- Resources Dynamics (Matsumoto 2002):

$$R_{t+1} = \left(1 + \delta - \delta \frac{R_t}{K} - b(N_{1,t} + N_{2,t})\right) R_t \tag{4}$$

	δ:	natural regeneration growth rate
where:	K:	carrying capacity
	b:	coefficient on human impact

The Clan's Problem

- $\theta \equiv$ group 1's crop-share

$$
\begin{aligned}
y_{1t} &= \theta_t Y_t / N_{1t} \\
y_{2t} &= (1-\theta_t) Y_t / N_{2t}
\end{aligned}
$$

- **Step 2**: Given $n_{i,t}$, θ results from bargaining:

$$(U_1 - \bar{U}_1)^{\gamma} (U_2 - \bar{U}_2)^{1-\gamma}$$

with γ : group 1's exogenous contractual force
$\bar{U}_i$: fall back utility

- **Step 1**: Clans maximize U_i over $n_{i,t}, c_{i,t}, d_{i,t+1}$ s.t. budget constraints

Fall back utility

$\bar{U}_i$: expected pay-off in case of war:

$$\begin{aligned} \bar{U}_{1t} &= \pi_t \hat{U}_{1,t} + (1-\pi_t)\check{U}_{1,t} \\ \bar{U}_{2t} &= (1-\pi_t)\hat{U}_{2,t} + \pi_t \check{U}_{2,t} \end{aligned}$$

where $\pi_t = p(N_{1,t}, N_{2,t})$: group 1's probability to win,
$\hat{U}_{i,t}$ $(\check{U}_{i,t})$: utility if war is won (lost).

Assumptions about war

- War involves destruction of a portion $\omega \in [0,1)$ of total product.
- War entails no human loss.
- The winner encroaches the whole available crop.
- The bigger group has more chances to win: $p'_{N_1} > 0$ and $p'_{N_2} < 0$.
- An explicit form satisfying desirable properties (Skaperdas, ET 1996):

$$p = \frac{N_{1,t}^{\mu}}{N_{1,t}^{\mu} + N_{2,t}^{\mu}} \in (0,1)$$

where μ: sensitivity to size of the clan

Step 2: Bargaining Outcome

Proposition (1)

Nash bargaining solution:

$$\theta_t = \gamma\omega + \frac{N_{1,t}^{\mu}}{N_{1,t}^{\mu} + N_{2,t}^{\mu}}(1-\omega)$$

The obtained share is endogenous and depends on group size.

The role of endogenous fertility

Channels through which fertility affects utility:

- Costs:
  - Disutility cost from child-rearing
  - Next period crop to be divided among more persons
- Benefits:
  - Greater old age support
  - Positive effect on bargaining power: (θ_{t+1})

    children $\uparrow \Rightarrow$ threat point tomorrow $\uparrow$ (perfect foresight)

    $\Rightarrow$ share of crop tomorrow $\uparrow$

    $\Rightarrow$ income when old $\uparrow$

Step 1: Fertility Choice - Reaction Functions

- Fertility is chosen taking as given the other group's one $\Rightarrow$ fertility reaction functions. Mutual dependency? Positive slope?
- No explicit general solution can be found analytically. Analytical study under Assumption 1. General case studied numerically.

Assumption (1)

Parameters satisfy: $\mu = 1, \omega = 0, \lambda = 0, \alpha = 1$

implying: $\theta_t = \frac{N_{1,t}}{N_{1,t}+N_{2,t}}$ and "coconuts"-type crop.

Proposition (2)

- *The fertility reaction functions have positive slopes*

$$n_{i,t} = \sqrt{\frac{N_{j,t}}{N_{i,t}} n_{j,t}}$$

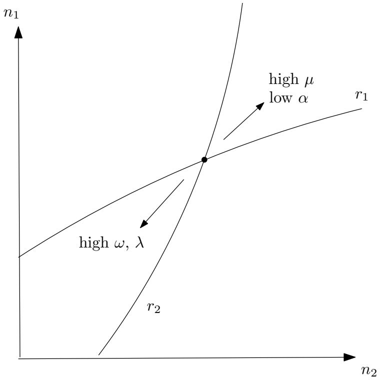
- *The Nash equilibrium is:*

$$n_{1,t}^{*} = \sqrt[3]{\frac{N_{2,t}}{N_{1,t}}}, \quad n_{2,t}^{*} = \sqrt[3]{\frac{N_{1,t}}{N_{2,t}}} \tag{5}$$

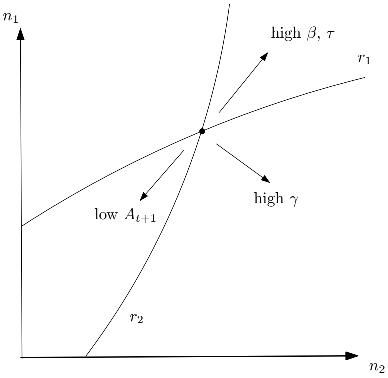
- *The Nash Equilibrium is stable.*

Comparative Statics

Corollary 1



Corollary 2



Dynamics

Proposition (3)

- *If a strictly positive Resources Steady State exists, then it is stable*

$$\bar{R} = K\left(1 - \frac{b(\bar{N}_i + \bar{N}_j)}{\delta}\right)$$

- *Under Assumption 1*
  - *A positive s.s. exists if and only if initial populations are not too high:*

$$2b\sqrt{N_{1,0}}\sqrt{N_{2,0}} < \delta$$

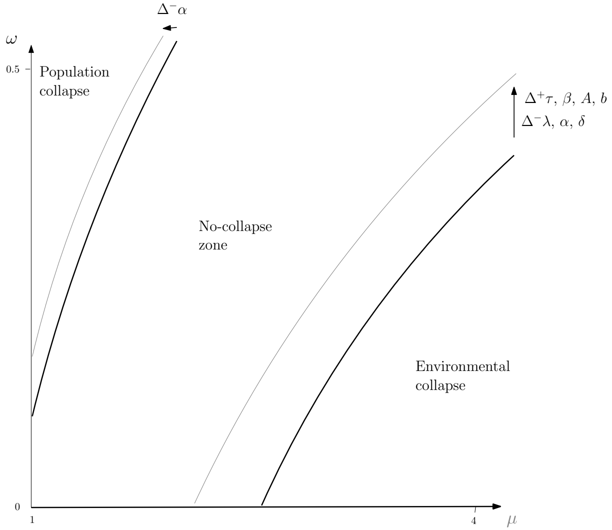
  - *If so, population converge to* $\bar{N}_i = \bar{N}_j = \sqrt{N_{1,0}}\sqrt{N_{2,0}}$
  - θ *and* π *converge to* $1/2$.

Resources and Population Dynamics

- Numerical Simulations detecting 3 regions in the $\{\mu; \omega\}$ space:
  - *Environmental Collapse*: Resources exhausted by high population, implying eventual extinction of people. (Easter Island case)
  - *Population Collapse*: Fertility below replacement value. Population goes to 0, resources to K.
  - *No collapse*: Long run positive population and resources stock. (Tikopia case). Need $\lambda > 0$.
- Effect of *ceteris paribus* perturbation of parameters on the regions:

  $\Rightarrow$ Parameters spurring fertility enlarge the scope for environmental collapse.

Collapse zones



Factors affecting the occurrence of environmental trap

Environmental Collapse more likely with:

- low cost of war: low ω
- high decisiveness of groups' (relative) size: high μ
- low cost of child rearing: low λ
- not severe decreasing returns: low α
- greater importance of old age support: high τ, high β
- high total factor productivity: high A
- low natural resource growth rate: low δ
- high human impact on resources: high b

Differences between Easter Island and Tikopia

- Colder and dryer climate in Easter. Easter poor in volcanic fallout and other determinants of soil fertility.
  $\Rightarrow$ difference in δ
- Remoteness of Easter and its settlers' habits likely implying greater human impact on natural resources.
  $\Rightarrow$ difference in b
- Tikopia hit by periodic cyclones. Tikopia's fields requiring almost constant labor ($\neq$ in Easter).
  $\Rightarrow$ high ω in Tikopia (A)
- Tikopia's terrain more difficult to walk because of a razor-sharp rock (*makatea*) $\Rightarrow$ relative advantage for defensive position in conflicts $\Rightarrow$ low μ (Hirshleifer, JPE 1995)
  $\Rightarrow$ low μ in Tikopia (B)

(A)+(B): social factors which could explain the difference between the two Islands

Concluding remarks

- Beyond Malthusian fertility dynamics.
- New factors for literature on fragile eco-system.
- A new way of looking at fertility choices.
- Allegory for today world?
- "Rationale" for social problems being increased instead of being solved: positional rent seeking and clash of interests.
- Possible extensions to modern episodes of conflicts involving poor societies: allow for endogenous mortality