POLLUTION CONTROL
UNDER UNCERTAINTY AND SUSTAINABILITY CONCERN

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POLLUTION CONTROL

Optimal Policy intervention in order to minimize the social cost or maximize the social benefit associated with economic activity, by taking into account both economic and environmental effects.

UNCERTAINTY AND SUSTAINABILITY CONCERN

An optimal pollution control model in which:

- The dynamics of pollution is subject to **random shocks**.
- Concern for sustainability issues and future generation is taken into account via an **end-of-planning horizon cost**.

Overview
Motivation and Related Literature

- There exists a huge body of literature on pollution optimal control, but two aspects has been only marginally analyzed:

  - The implications of uncertainty on pollution and environmental policy. See Baker (2005), Athanassaglou and Xepapadeas (2012), Saltari and Travaglini (2016).
  - The relations of pollution control with sustainability and intertemporal equity. See Chichilnisky, Beltratti and Heal (1995) and Chichilnisky (1997).

Overview
Main Results

- We show that the optimal level of environmental policy is non-constant and it is clearly affected by both the degree of uncertainty and sustainability concern
- Both larger degrees of sustainability concern and larger degrees of uncertainty lead to a stricter environmental policy, reducing thus the environmental burden imposed on the society both in the short and long run.

The Model: The Economy

- Economic agents consume completely their disposable income.

$$c_t = (1 - \tau_t)y_t.$$

- c_t denotes consumption.
- y_t amounts to income.
- $\tau_t \in (0, 1)$ represents a tax rate.

The Model: The Economy

- The unique final consumption good y_t is produced competitively by firms employing capital k_t .
- The production function is linear $y_t = ak_t$.
- Capital grows exogenously at a constant rate $\gamma_k \equiv 1$ (hyp. later relaxed).

The Model: Pollution and Tax

- Economic activities generates pollution as a side product.
- The tax revenue is used to limit pollution accumulation.
- An increase in τ reduces pollution but at the same time lowers current consumption possibilities.

The Model: Social Planner and SCF

- The social planner whishes to minimize the social cost of pollution.
- The social cost function SCF is the weighted sum of two different terms
  - The expected sum of instantaneous losses (instantaneous loss function): C_t
  - Discounted environmental damage at the end of the planning horizon T: $d(p_T)$

The Model: Instantaneous loss function

- The instantaneous loss function C_t takes into account both environmental (p_t) and economic costs (τ_t).
- C_t is assumed to be increasing and convex in both its arguments: $C_t(p_t, \tau_t)$.
- C_t penalizes deviation from the no-pollution scenario and the strength of the policy intervention.

$$C_t(p_t, \tau_t) = \frac{{p_t}^2(1 + \tau_t^2)}{2}$$

The Model: EoP damage function

- **The end of planning damage function is assumed to increasing and convex in its argument**

$$\boldsymbol{d(p_T) = \frac{p_T^2}{2}}$$

The Model: Pollution Dynamics

- Pollution is a stock variable that increases with flow emissions generated by economic activity.
- Economic output generates emissions that increase the stock of pollution at a rate $\eta > 0$.
- Pollution decreases thanks to the rate of natural pollution absorption $\delta > 0$.

The Model: Pollution Dynamics

- The amount of pollution associated with economic activity can be reduced by economic regulation.
- One unit of output invested in environmental preservation reduces one unit of pollution.
- The dynamics of pollution under economic regulation is:

$$\dot{p}_t = [\eta(1 - \tau_t) - \delta]p_t$$

The Model: The control variable

- The policy instrument τ_t represents an environmental tax used to decrease environmental inefficiency in economic activities (human-induced growth rate of pollution η) .
- The previous differential equation describes the evolution of pollution in absence of uncertainty.

The Model: The Planner's Problem

$$\min_{\tau_t} SCF = \mathbb{E}\left[\vartheta \int_0^T \frac{{p_t}^2(1+\tau_t^2)}{2} e^{-\rho t} dt + (1-\vartheta)\frac{p_T^2}{2} e^{-\rho T}\right]$$

$$s.t. \quad dp_t = [\eta(1-\tau_t) - \delta] p_t dt + \sigma p_t dW_t$$

p_0 given

The Model: Intergenerational Equity

- The parameter $\vartheta \in [0, 1]$ measure the relative importance assigned by the social planner to the sum of instantaneous losses rather than the final environmental damage.
- This specification is consistent with the notion of sustainability, requiring to ensure a certain degree of intergenerational equity (Chichilnisky Criterion).

The Optimal Policy: HJB equation

- **The Planner's Problem is a Stochastic Optimal Control Problem: it is possible to obtain a closed form solution solving the associated Hamilton-Jacobi-Bellman equation.**

$$-\frac{\partial J}{\partial t} = \min_{\tau}\left\{\frac{1}{2}{p_t}^2(1+\tau_t^2)e^{-\rho t} + [\eta(1-\tau_t)-\delta]p_t\frac{\partial J}{\partial p} + \frac{1}{2}\sigma^2 p^2\frac{\partial^2 J}{\partial p^2}\right\}$$

The Optimal Policy: Closed Form

$$\tau_t^* = \frac{1}{2\eta}\left\{2(\eta-\delta)-\rho+\sigma^2+\tanh\left[\frac{\sqrt{M}(T-t)}{2}+arctanh\left(\frac{2(1-\vartheta)\eta^2-2(\eta-\delta)\vartheta+\rho\vartheta-\sigma^2\vartheta}{\vartheta\sqrt{M}}\right)\right]\sqrt{M}\right\}$$

$$p_t^* = p_0 exp\left\{\int_0^t\left[\eta(1-\tau_s^*)-\delta-\frac{1}{2}\sigma^2\right]ds+\sigma W_t\right\}$$

where

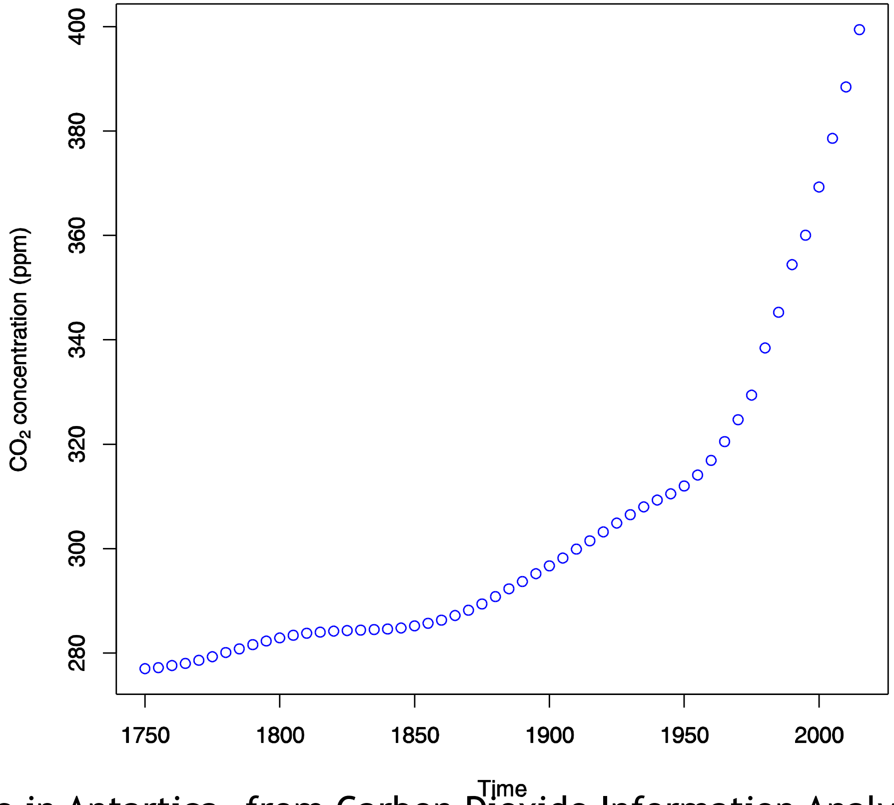
$$M = \left[2(\eta-\delta)-\rho+\sigma^2\right]^2+4\eta^2$$

Main Results

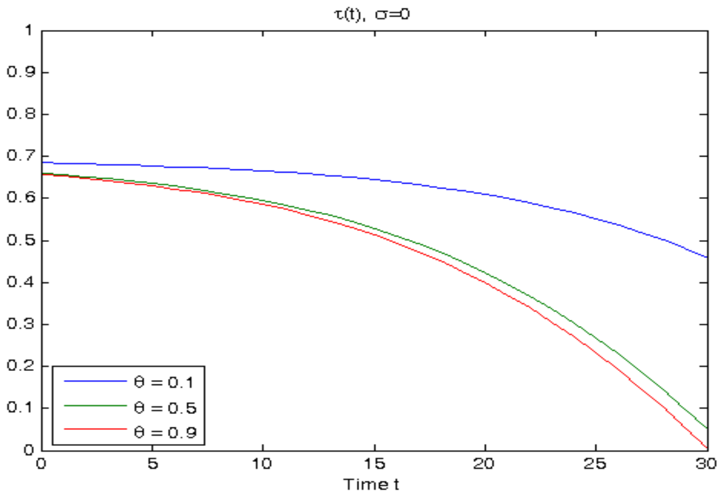
- P1: Provided that $\vartheta \in [\vartheta_{min}, \vartheta_{max}]$ holds, the optimal taxation level (i.e. τ_t^*) increases with the degree of sustainability concern (i.e., $1 - \vartheta$).

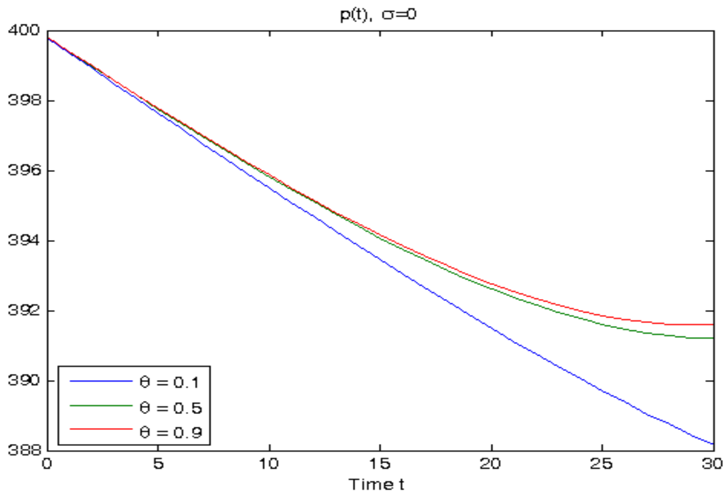
- P2: Provided that $\vartheta \in [\vartheta_{min}, \vartheta_{max}]$ holds, the optimal taxation level (i.e. τ_t^*) increases with the degree of uncertainty (i.e., σ^2), whenever $\sigma^2 \leq \rho - 2(\eta - \delta) - \frac{2\vartheta}{1-\vartheta}$

Calibration Based on Global CO_2 Data: $\eta - \delta$, net rate of pollution growth



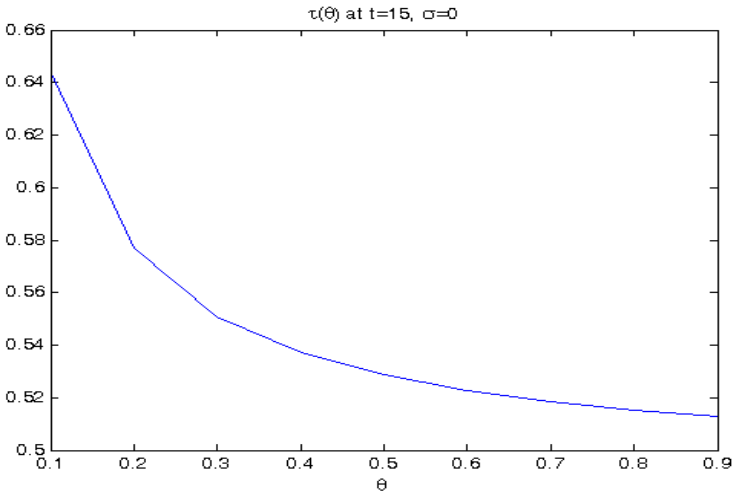
- Law Dome ice core in Antartica, from Carbon Dioxide Information Analysis Center (US Energy Dept).
- Earth System Research Laboratory, National Oceanographic and Atmosphere Administration.

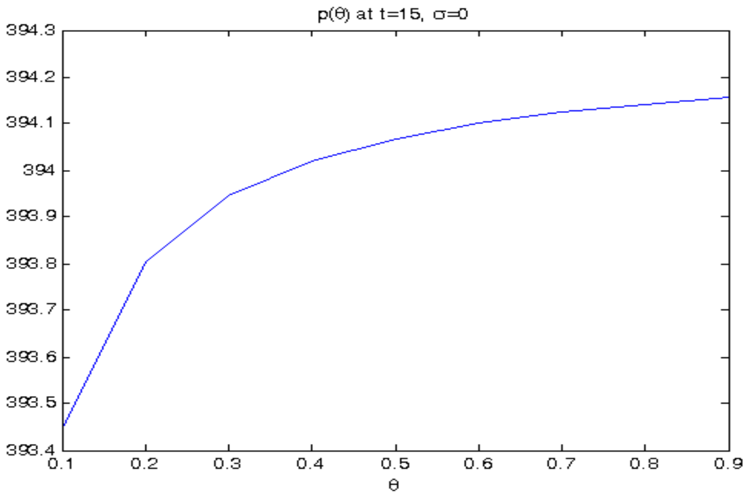




Dynamic evolution of τ_t^*, p_t^*, $\sigma^2 = 0$.

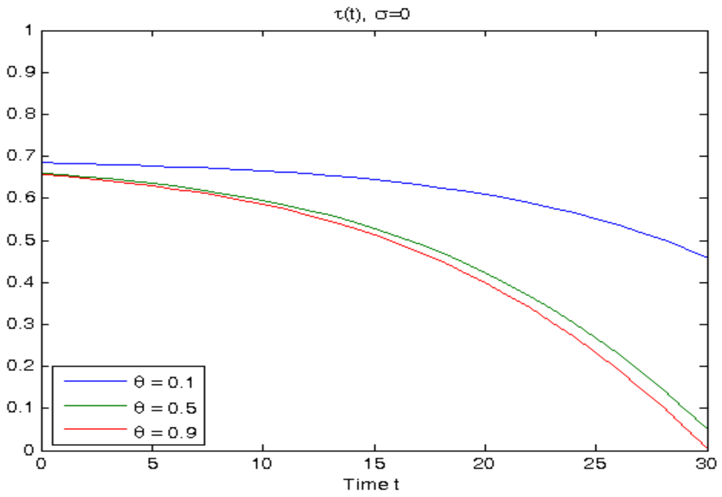
τ_t^* monotonically falls with ϑ, p_t^* monotonically rises with ϑ. The larger the weight attached to the long run level of pollution (the lower ϑ) the stricter the optimal environmental policy (the higher τ_t^*) and thus the healthier the environment (the smaller p_t^*).

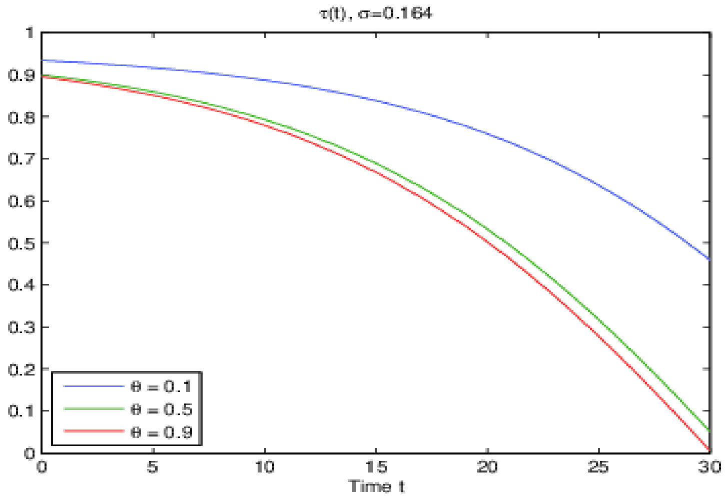




Static comparison: different degrees of sustainability concern

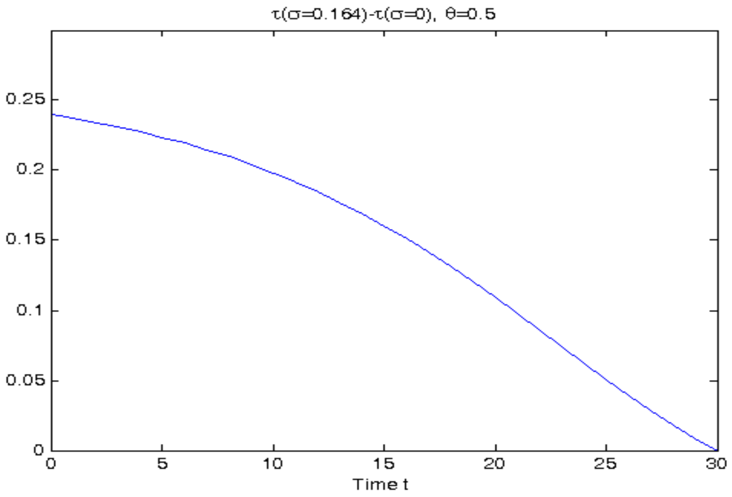
$\tau_{\bar{t}}^{*}$ decreases at its fastest pace for low values of theta ϑ. For larger value the change in $\tau_{\bar{t}}^{*}$ is barely evident. This suggest the existence of a threshold value determining the effectiveness of policies aiming to eventually promote increases in the degree of sustainability concern. Indeed, the degree of sustainability concern has to be above a certain threshold to actually translate into a leap of policy intervention.

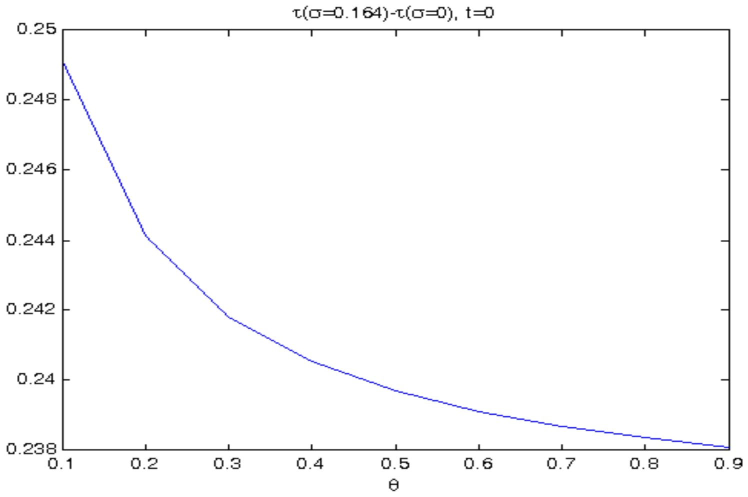




Deterministic vs Stochastic Scenario

Despite the fact that for all ϑ considered the sufficient condition P2 does not hold, the optimal taxation in the stochastic case is always greater than the deterministic one, consistently with a precautionary motive. With higher uncertainty in pollution dynamics it is convenient to adopt stricter policy.





Evolution (left) and initial (right) differences between $\tau^*_{\sigma^2>0}$ and $\tau^*_{\sigma^2=0}$

Left: the optimal policy intervention reduces the impacts of uncertainty on the pollution stock: in the very long run τ^* is determined for the largest extent by the degree of sustainability concern. Right: the uncertainty induced economic cost is higher the smaller ϑ, that is the higher the degree of sustainability concern.

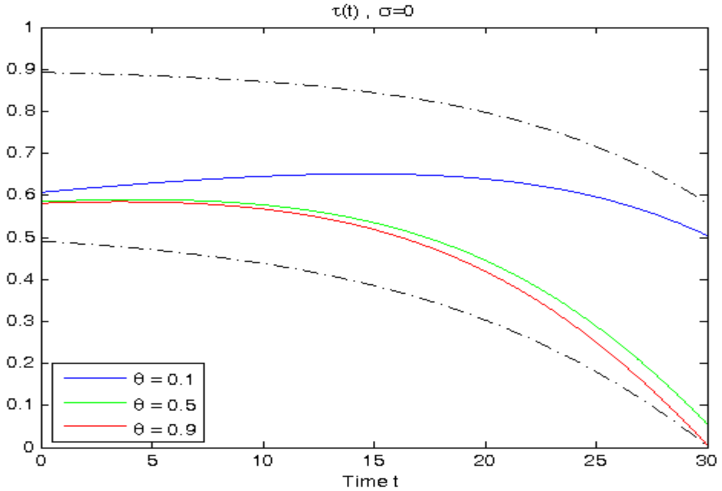
The Extended Planner's Problem

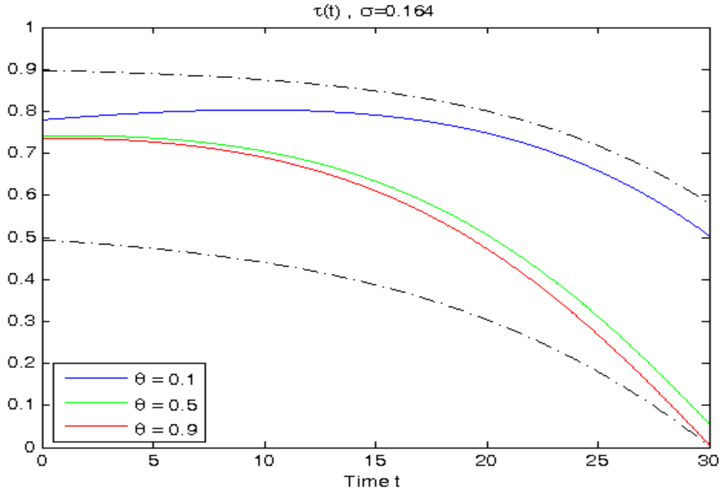
$$\min_{\tau_t} SCF = \mathbb{E}\left[\vartheta \int_0^T \frac{{p_t}^2(1+\tau_t^2)}{2} e^{-\rho t} dt + (1-\vartheta)\frac{p_T^2}{2} e^{-\rho T}\right]$$

$$s.t.\ \ dp_t = [\eta(1+\gamma_t)(1-\tau_t) - \delta]p_t \mathrm{dt} + \sigma p_t dW_t$$

$$dk_t = (1+\gamma_t)k_t \mathrm{dt}$$

$k_0 > 0$ given, $p_0 > 0$ given





Time-Varying Capital Accumulation: Extended Planner's Problem

By hypothesis $(1+\gamma) \in [\gamma_{min}, \gamma^{max}]$. We prove that also the dynamics of the optimal policy is bounded and $\tau^* \in [\tau^*_{min}, \tau^*_{max}]$. As before, τ^* increases with both $(1-\vartheta)$ and σ^2. The optimal taxation in the stochastic case is always greater than in the deterministic one, consistently with a precautionary motive.

Conclusions

- **Both larger degrees of sustainability concern and larger degrees of uncertainty lead to a stricter environmental policy, reducing thus the environmental burden imposed on the society both in the short and long run.**

Conclusions

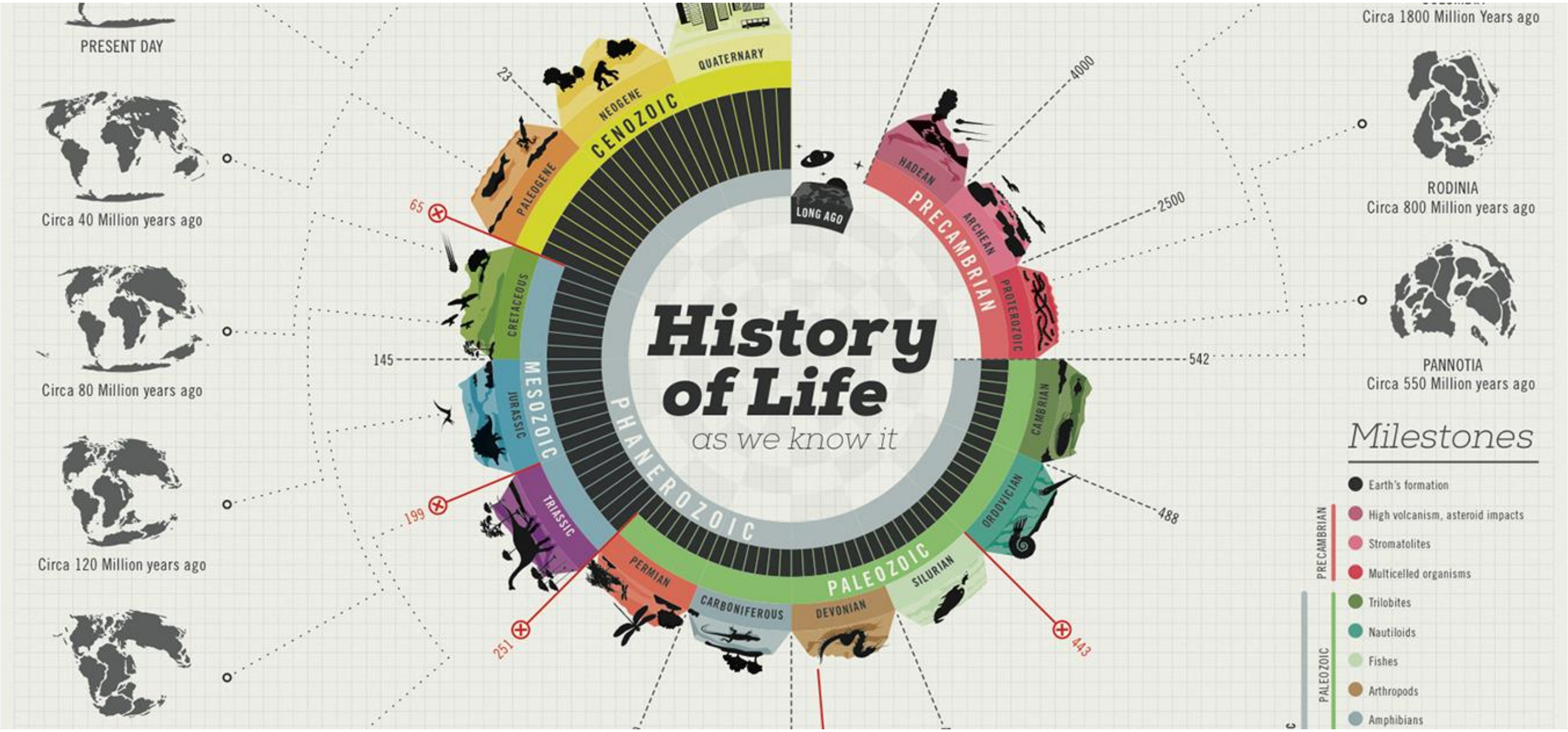
- **The current trend of a growing environmental and sustainability concern might be effective in achieving a more sustainable development path in the long run.**

Conclusions

- The degree of sustainability concern may be effectively affected through specific (education or advertising) policies, thus it represents an important tool to achieve a more sustainable and greener future.
- However, the reduction in the environmental burden associated with pollution control comes at the cost of a reduction in consumption possibilities, thus assessing the net impact on social costs of further increases in the susststainability concern is not straightforward.

References

- **Athanassoglou, S., Xepapadeas, A. (2012). Pollution control with uncertain stock dynamics: when, and how, to be precautious**, Journal of Environmental Economics and Management 63, 304-320
- **Baker, E. (2005). Uncertainty and learning in a strategic environment: global climate change**, Resource and Energy Economics 27, 19-40**2.**
- **Chichilnisky, G., Heal, G., Beltratti, A. (1995). The green golden rule**, Economics Letters 49, 174{179
- **Chichilnisky, G. (1997). What is sustainable development?**, Land Economics 73, 476{491
- **Saltari, E., Travaglini, G. (2011). Optimal abatement investment and environmental policies under pollution uncertainty**, in (de La Grandville, O., Ed.) \Frontiers of economic growth and development (Emerald)
- **Saltari, E., Travaglini, G. (2014). Pollution control under emission constraints: switching between regimes**, Energy Economics 01/2016, Volume 53



Thank you!!!

https://www.behance.net/gallery/10901127/History-of-Life