A Dynamic Analysis of Human Welfare in a Warming Planet

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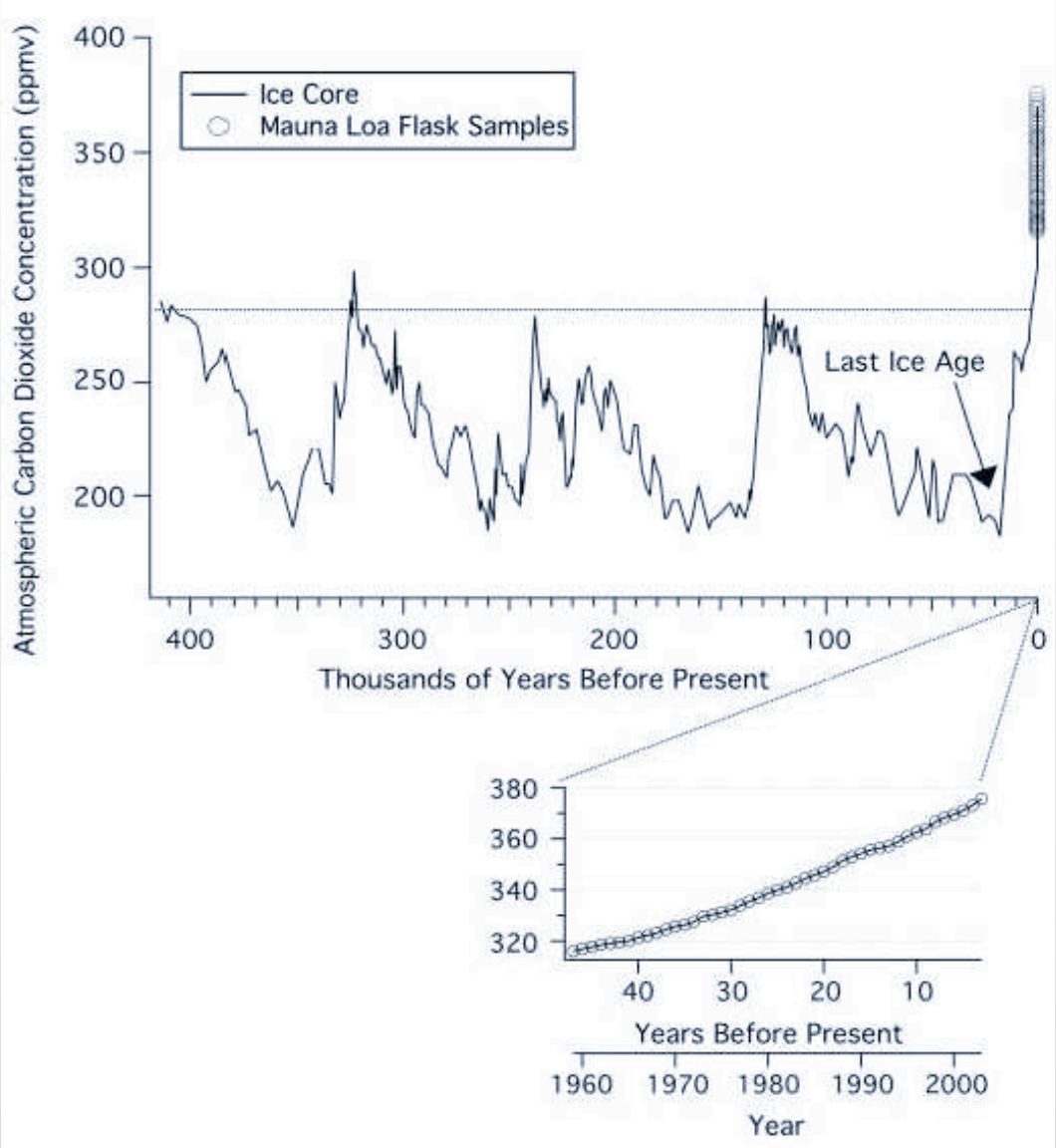
Introduction

Anthropogenic GHG emissions have caused atmospheric concentrations of CO_2 with no precedents in the last half million years

Introduction

Observed CO_2 concentrations in the last 400,000 years (Friedlingstein and Solomon, 2005)



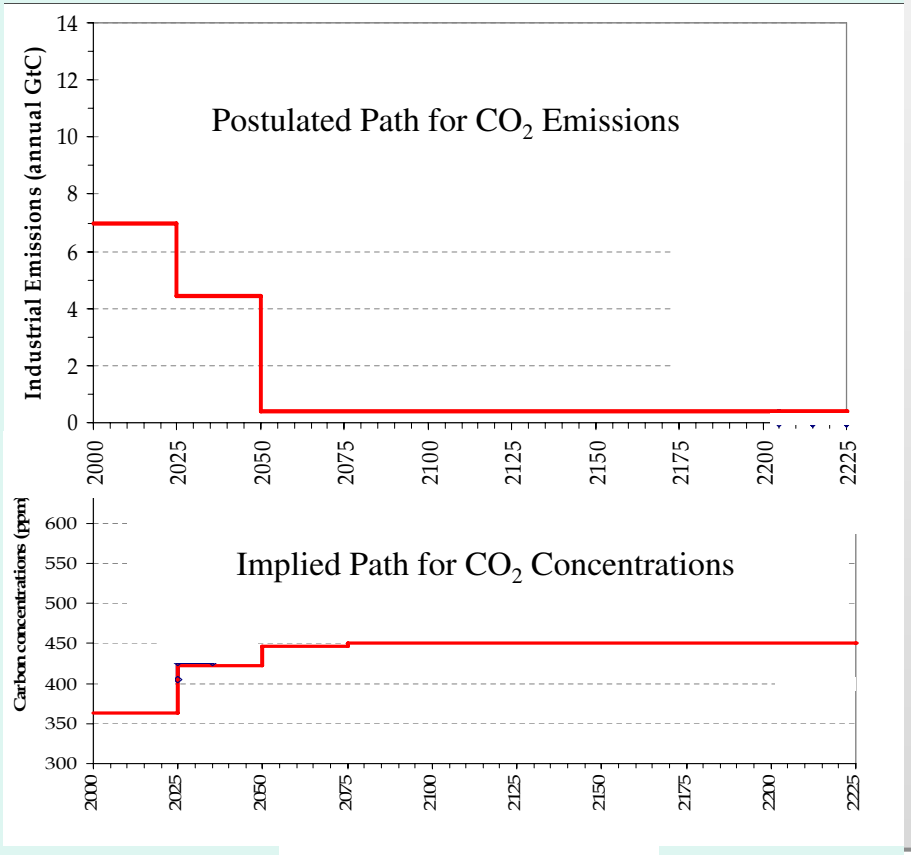
The urgency of the matter

- Global temperature is a function of atmospheric CO_2 concentration
- Present concentration is 380ppm.
- If stock stabilizes at 450ppm, the 90% confidence interval for increase in global temperature is $[1^oC, 3.8^oC]$
- At 550ppm, the 90% confidence interval is $[1.5^oC, 5.2^oC]$
- At a 5^oC increase, scientists estimate that perhaps one-half of Earth's species would disappear and most coastal areas would be submerged.
- Under "business as usual", we will reach 750ppm by the end of the 21st century.

The urgency of the matter

We need to "*stabilize*" GHG concentrations, understood not as a steady state, but as a slow change in temperature, so that the effects of climate change on human welfare can be ameliorated by adaptation.

Recent climate science supports the view that *stabilization* will require very low GHG emissions in the future.



Existing approaches

A. The present as an hegemon

(W. Nordhaus, M. Weitzman,...)

$$\max \sum_{1}^{\infty} \rho^{t-1} u(z_t)$$

where $\rho = \frac{1}{1+\delta}$ represents either the subjective rate of impatience of the first generation agent or the degree of altruism of parents or their children.

The intergenerational problem is ethically isomorphic to the utility maximization of the present generation.

Existing approaches

B. Discounted utilitarianism

(N. Stern.) Utilitarian ethical observer with uncertainty of existence of future generations. Suppose there is a prob. p that the human species disappears at each date t.

If the world lasts exactly T generations (which occurs with prob. $\pi(t)$), let

$$W^T(z) = \sum_1^T u(z_t)$$

Then, the utilitarian ethical observer maximizes

$$\sum_t^\infty \pi(t) W^t(z) = p \sum_1^\infty (1-p)^{t-1} u(z_t)$$

Now, $\rho = 1 - p$ is the probability that the human species does not disappears at each date t.

Stern = cost-benefit analysis.

Existing approaches

Indeed, Nordhaus takes $\delta = 0.015$ per annum
$\Rightarrow \rho^{100} = (1/1.015)^{100} = 0.22$.

Weitzman uses $\delta = 0.02$ per annum $\Rightarrow \rho^{100} = (1/1.02)^{100} = 0.138$.

Stern chooses $p = 0.001$ per annum
$\Rightarrow (1-p)^{100} = (0.999)^{100} = 0.9$.

Existing approaches

The debate between Stern (on the one hand) and Nordhaus and Weitzman in the past year (JEL,AER) has been over the size of the discount rate.
Nordhaus writes:

> How much and how fast should we react to the threat of global warming? The Stern Review argues that the damages from climate change are large, and that nations should undertake sharp and immediate reductions in greenhouse gas emissions. An examination of the Review's radical revision of the economics of climate change finds, however, that it depends decisively on the assumption of a near-zero time discount rate [i.e., $\delta = 0.001$] combined with a specific utility function. The Review's unambiguous conclusions about the need for extreme immediate action will not survive the substitution of assumptions that are consistent with today's marketplace real interest rates and savings rates.

Our Approach

1. Postulate a path of low GHG emissions, which according to current climate science (IPCC AR-4, 2008) is broadly consistent with the stabilization of GHG concentrations at 450ppm and
2. propose a *sustainabilitarian* approach:

   What is the highest sustainable level of human welfare we can attain?

   Is this low-emission path compatible with sustainable levels of human welfare?
3. We also ask:

   Is this low-emission path compatible with steady growth in human welfare?

Our *sustainabilitarian* Approach

1. Define human welfare measure $QuoL$ (*Quality of Life*).
2. Construct and calibrate an intergenerational model: set of feasible paths (**Z**).
3. Develop an algorithm to compute paths for the economic variables satisfying our sustainabilitarian criterion, i.e.

$$\begin{aligned} &\max \Lambda \\ &\text{s.t. } QuoL(z_t) \geq \Lambda, \quad t = 1, 2, \cdots \\ &z \in \mathbf{Z} \end{aligned}$$

Thus, Λ is the highest *sustainable* level of quality of life. This is equivalent to 'maximin' quality of life over all future generations.

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Sustainable growth.

Disclaimer

- We focus upon intergenerational equity, abstracting from the intragenerational conflict between North and South (future research).
- We ignore population issues (future research). Accordingly, we postulate one representative agent for whole world for each generation, to be thought of as the average person
  [One date $t = 1, 2, \cdots$ per generation $= 25$ years]
- We calibrate our technology parameters and reference values by North (First World) data.

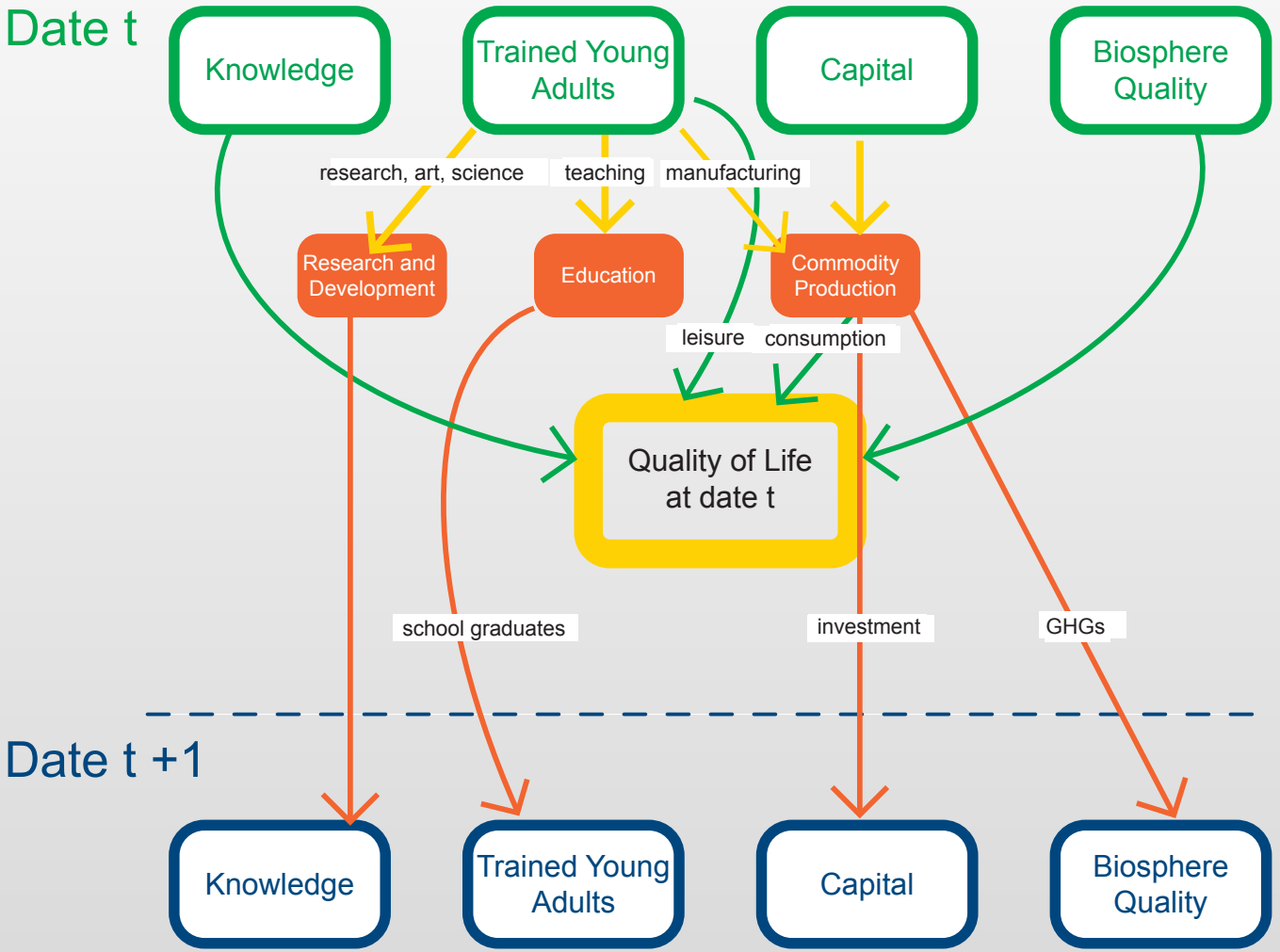
1. Quality of Life (QuoL)

- We define human welfare at each date (or generation) as the *Quality of Life* $(QuoL)$ that the representative agent of that generation enjoys.
- The $QuoL$ involves more than just commodity consumption:
  - commodity consumption: c_t.
  - leisure in efficiency units, more valuable the higher education level: x_t^l.
  - quality of biosphere (a public good): $(\hat{S}^m - S_t^m)$.
  - stock of knowledge: S_t^n.

$$QuoL_t = (c_t)^{\alpha_t}(x_t^l)^{\alpha_l}(\hat{S}^m - S_t^m)^{\alpha_m}(S_t^n)^{\alpha_n}$$

2. Intergenerational model

Stock-flow Dynamics (simplified)



2. Intergenerational model

- Aggregate production function

$$\begin{aligned} f(x_t^c, S_t^k, S_t^n, e_t, S_t^m) &\equiv k_1 (x_t^c)^{\theta_c} (S_t^k)^{\theta_k} (S_t^n)^{\theta_n} (e_t)^{\theta_e} (S_t^m)^{\theta_m} \\ &\geq c_t + i_t \qquad \theta_i > 0, i \neq m; \theta_m < 0. \end{aligned}$$

- Law of motion of physical capital

$$(1 - \delta^k) S_{t-1}^k + k_2 i_t \geq S_t^k, \quad t \geq 1$$

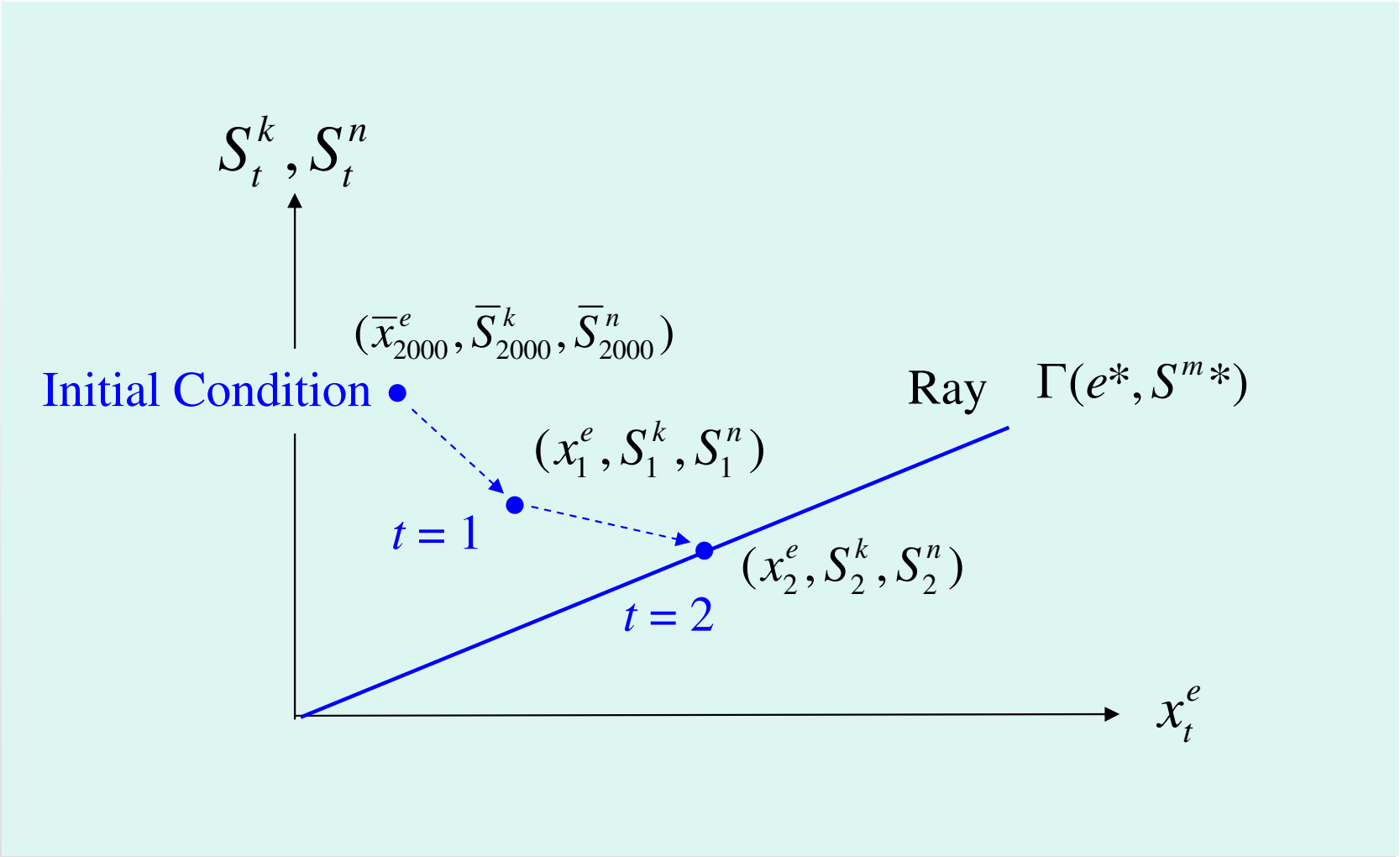
- Law of motion of knowledge

$$(1 - \delta^n) S_{t-1}^n + k_3 x_t^n \geq S_t^n, \quad t \geq 1$$

- Education production function

$$k_4 x_{t-1}^e \geq x_t, \quad t \geq 1.$$

Algorithm



Result 1: sustainabilitarian approach

Sustainable QuoL (Zero growth)

Gen	$\Lambda_t / \Lambda_{t_0}$	$\Lambda_t / \Lambda_{t-1}$	c_t	c_t / c_{t-1}	x_t^e	x_t^c	x_t^n	x_t^l	i_t	S_t^k	S_t^n
2000	1.	1.	23.88	-	0.04653	0.3955	0.0233	0.9307	7.59	73.65	15.64
1	1.3110	1.3110	40.399	1.6917	0.04660	0.4779	0.0608	1.0643	14.02	199.62	39.72
2	1.3110	1.	37.931	0.9390	0.05138	0.4444	0.0586	1.0977	8.14	149.26	43.48
3	1.3111	1.0000	31.759	0.8373	0.05138	0.5129	0.0572	1.2000	8.95	149.26	43.48
4	1.3111	1	31.759	1	0.05138	0.5129	0.0572	1.2000	8.95	149.26	43.48

Gen	x_t^e (%)	x_t^c (%)	x_t^n (%)	x_t^l (%)	x_t
2000	0.0333	0.2833	0.0167	0.6667	1.396
1	0.0282	0.2897	0.0369	0.6452	1.650
2	0.0311	0.2690	0.0355	0.6645	1.652
3	0.0282	0.2815	0.0314	0.6588	1.821
4	0.0282	0.2815	0.0314	0.6588	1.821

⋆ Human quality of life can be sustained at 31% higher than at year 2000 while following the recommended low emission path.

⋆ The proposed path requires doubling the resources devoted to the creation of knowledge.

Result 2: sustainable growth

1% annual growth
= 28% generational growth

Gen	$\Lambda_t / \Lambda_{t_0}$	$\Lambda_t / \Lambda_{t-1}$	c_t	c_t / c_{t-1}	x_t^e	x_t^c	x_t^n	x_t^l	i_t	S_t^k	S_t^n
2000	1.	1.	23.88	-	0.04653	0.3955	0.0233	0.9307	7.59	73.65	15.64
1	1.2999	1.2999	40.056	1.6774	0.06043	0.4737	0.0603	1.0552	13.89	197.88	39.38
2	1.6671	1.2824	48.281	1.2054	0.08548	0.5779	0.0796	1.3994	11.53	193.38	55.98
3	2.1380	1.2824	51.993	1.0769	0.10987	0.8544	0.1004	1.9656	15.81	248.56	71.95
4	2.7418	1.2824	66.829	1.2853	0.14122	1.0982	0.1290	2.5265	20.32	319.48	92.48

Gen	x_t^e (%)	x_t^c (%)	x_t^n (%)	x_t^l (%)	x_t
2000	0.0333	0.2833	0.01667	0.6667	1.396
1	0.0366	0.2872	0.03654	0.6397	1.649
2	0.0399	0.2697	0.03715	0.6532	2.142
3	0.0363	0.2819	0.03313	0.6486	3.030
4	0.0363	0.2819	0.03313	0.6486	3.895

$\star$ Sustaining positive growth rates $g > 0$ require a *sacrifice* by early generations. But the trade-off looks appealing: a growth rate of 1% per annum (or 28% per generation) reduces the $QuoL$ of the first generation by less than 1%.

Result 2: sustainable growth

2 % annual growth
= 64% generational growth

Gen	$\Lambda_t / \Lambda_{t_0}$	$\Lambda_t / \Lambda_{t-1}$	c_t	c_t / c_{t-1}	x_t^e	x_t^c	x_t^n	x_t^l	i_t	S_t^k	S_t^n
2000	1.	1.	23.88	-	0.0465	0.3955	0.0233	0.9307	7.59	73.65	15.64
1	1.2859	1.2859	39.618	1.6591	0.0780	0.4684	0.0595	1.0437	13.72	195.65	38.94
2	2.1097	1.6406	61.176	1.5441	0.1413	0.7441	0.1058	1.7750	15.76	248.44	71.56
3	3.4612	1.6406	84.505	1.3813	0.2328	1.4080	0.1717	3.1961	27.18	409.43	117.90
4	5.6784	1.6406	139.260	1.6480	0.3837	2.3204	0.2830	5.2671	44.79	674.74	194.40

Gen	x_t^e (%)	x_t^c (%)	x_t^n (%)	x_t^l (%)	x_t
2000	0.0333	0.2833	0.0166	0.6667	1.396
1	0.0473	0.2839	0.0361	0.6327	1.650
2	0.0511	0.2690	0.0382	0.6417	2.766
3	0.0465	0.2811	0.0343	0.6381	5.009
4	0.0465	0.2811	0.0343	0.6381	8.254

Conclusions

- Sustainability is arguably a very attractive ethic.
- Human quality of life can be sustained for ever at a level 31% higher than the year 2000 reference level while following a low emissions path that stabilizes atmospheric concentration at 450ppm.
- Our path recommends much higher investment in capital and knowledge than we currently have.
- “Sustainability of moderate growth” is appealing because the sacrifice by Generation 1 is small.
- Higher growth rates require substantial increases in the fraction of labor devoted to education, and moderate increases in the investment of capital and knowledge.

Caveat

This is stage 1 only. Justice requires considering intragenerational disparities and allow those *in the South* to converge in $QuoL$ to the $QuoL$ enjoyed in the rich North in two or three generations. Future research.