“Intergenerational and international equity in a warming planet”

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Revised January 2011

Outline of talk

- 1. The general framework
- 2. A generalization of the Solow growth model
- 3. A warming planet
- 4. International bargaining to control emissions

1. General Framework

- There is a set **P** $=\{u \mid u=(u^1,u^2,\ldots)\}$ of feasible utility paths
- An *event* is a pair (u,T) , meaning the chosen path is *u* and the world ends just after date *T.*
- There is an Ethical Observer (EO) who has vNM preferences over lotteries on the events.
- Its vNM utility function is $W^T(u)$.

Some examples

- Eg. 1. Utilitarianism $W^T(u) = \sum_{t=1}^{T} u_t$
- Eg. 2 Maximin or Sustainability: $W^T(u) = \min[u_1, \ldots, u_T]$
- Eg.3 Extended Maximin: $W^T(u) = (1 + (T-1)\theta)\min[u_1, \ldots, u_T]$,

some $\theta \in [0,1]$

Eg. 4 Sustainable growth: $W^T(u) = \min[u_1, \frac{u_2}{1+g}, \ldots, \frac{u_T}{(1+g)^{T-1}}]$

- Note that Extended Maximin puts value on the length of human existence, which regular maximin does not
- ‘ Sustainability’ is just ‘sustainable growth at *g*=0’

Uncertainty

- There is an exogenous probability *p* that the human species ends at each date, if it has survived to that date
- The probability that the world ends at date *T* is $\pi(T) = p(1-p)^{T-1}$
- Therefore the EO's problem is

$$\max \sum_{1}^{\infty} p(1-p)^{t-1} W^t(u) \quad \text{subj to } u \in \mathbf{P}$$

Discounted utilitarianism

- If the EO is a utilitarian, this reduces to

$$\max \sum \rho^{t-1} u_t, \quad \rho = 1 - p$$

- Hence, *discounted utilitarianism* (DU). This is, we claim, the best justification of DU. Note if *p*= .001 per annum (Stern Report), then
- $\rho = 0.999$. In generational terms (25 yrs = 1 gen),

$\rho = 0.975$

Discounted sustainabilitarianism

- If $W^T(u) = \min[u_1,...,u_T]$ then

$$EU = \max \sum \pi(t) \min[u_1,...,u_T], \text{ s.t. } u \in \mathbf{P}$$

- Suppose it can be shown that the solution of this program entails
- $(\forall t) u_{t+1} \leq u_t$
- Then the DS program reduces to

$$\max \sum \rho^{t-1} u_t$$

$$s.t.$$

$$u \in \mathbf{P}$$

$$u_t \geq u_{t+1}, \quad t = 1, 2, ...$$

- Call this the *constrained discounted utilitarian program (CDU)*

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2. A generalization of the Solow growth model

- The set $\mathfrak{I}$ of feasible paths with initial endowment (s_0^k, x_0^l)
-

$$u_t \equiv c_t^{\alpha}(x_t^l)^{1-\alpha}$$

$$s_t^k \le (1-\delta)s_{t-1}^k + i_t \quad \text{(capital's law of motion)}$$

$$(s_t^k)^{\theta}(x_t^c)^{1-\theta} \ge c_t + i_t \quad \text{(production)}$$

$$\xi x_{t-1}^e \ge x_t^e + x_t^c + x_t^l \quad \text{(skill formation, education)}$$

- Note that utility depends upon *educated leisure*. Non-Chicago approach.
- Think of ξ as the pupil-teacher ratio (~20)

Four Programs

- 1.DU $\max \sum \rho^{t-1} u_t \quad \text{s.t. } u_t \in \Im$
- 2. SUS $\max \Lambda \text{ s.t. } u_t \geq \Lambda, \quad t = 1, 2, \ldots \quad , u \in \Im$
- 3. DSUS $\max \sum \rho^{t-1} \min[u_1, \ldots, u_t] \quad \text{s.t. } u \in \Im$
- 4. Disc Ext Rawlsian

$$\max \sum \rho^{t-1} (1 + (t-1)\theta) \min[u_1, \ldots, u_t] \text{ s.t. } u \in \Im$$

Theorem A

- The DU program diverges if $\rho\xi > 1$

and converges if $\rho\xi < 1$. (Recall $\rho = 1 - p$.)

- Hence, if $\xi \approx 20$ and $\rho \approx 0.975$ then DU diverges.

Theorem B

- If DU diverges, then the solutions of the DSUS program and the Disc Ext Rawls program are identical, *and* are identical to the solution of the SUS program.
- In other words, in this case *the sustainabilitarian can ignore the discount rate*!

Intuition

- One can write the D-SUS program as the CDU program:

$$\begin{aligned} &\max \sum \rho^{t-1} u_t \\ &s.t. \quad u \in \Im \\ &\qquad u_t \geq u_{t+1} \quad t = 1, 2, \ldots \quad (+) \end{aligned}$$

Since DU diverges, there are paths in $\Im$ upon which u_t is unbounded. One might expect the optimal path of CDU to be one at which all constraints (+) bind. But then $CDU \cong SUS$

Sustainable growth

- Recall the (undiscounted) program is

$$\begin{aligned}&\max \Lambda\\ &s.t. \quad u \in \Im\\ &u_t \geq (1+g)^{t-1}\Lambda, \quad t = 1,2,\ldots\end{aligned}$$

- The program has a solution for $0 \leq g < \xi - 1$

Larger *g* implies smaller Λ. Trade-off between growth & utility of early generations.

Conjecture

- Conjecture that generalization of Thm B is true: if DU diverges then the solution to '*Un*discounted Sustainabilitarianism with growth' is identical to the solution of '*Dis*counted sustainabilitarianism with growth.'
- If so the growth-sustainabilitarian can continue to ignore the discount factor.

How to generalize DU?

- IF DU diverges, what should a utilitarian do? The solution that has been advocated is to impose a *partial ordering* on paths that generate an infinite value according to an *overtaking criterion.*
- We show that the overtaking criterion prefers paths that *eventually* grow at v. high rates, and hence *starve the early generations.*

Interpretation

- This is not a criticism of the overtaking criterion *per se. It is a critique of utilitarianism.*
- We advocate *sustaining growth* in contrast to utilitarianism. Does this not resonate more with popular views?

Alternative justifications of DU

- There is another popular justification of DU (see W. Nordhaus, P. Dasgupta, M. Weitzman).
- Suppose we model an infinite-generational society as an *infinitely lived agent* who discounts his future utility because of time impatience, so *his* lifetime utility is
   –

$$\sum \left(\frac{1}{1+\delta} \right)^{t-1} u[t]$$

- These authors advocate this approach *to climate change ethics* and they estimate δ from market analysis. They propose

$$\frac{1}{1+\delta} \approx 0.985 \text{ per annum}$$

- With this discount factor, the utility of those living 100 years from now is discounted by 80%; while with $\rho = 0.999$ it is discounted by 10%.

Nordhaus vs. Stern

- This is the argument between Nordhaus & Stern. *It appears to be simply over discount factors.* But the *basic underlying* argument is over the *justification* of discounted utilitarianism.

  We reject the infinitely-lived agent as a model for intergenerational welfare analysis. There is absolutely no reason to discount the welfare of future generations by the rate of time impatience of currently alive individuals.

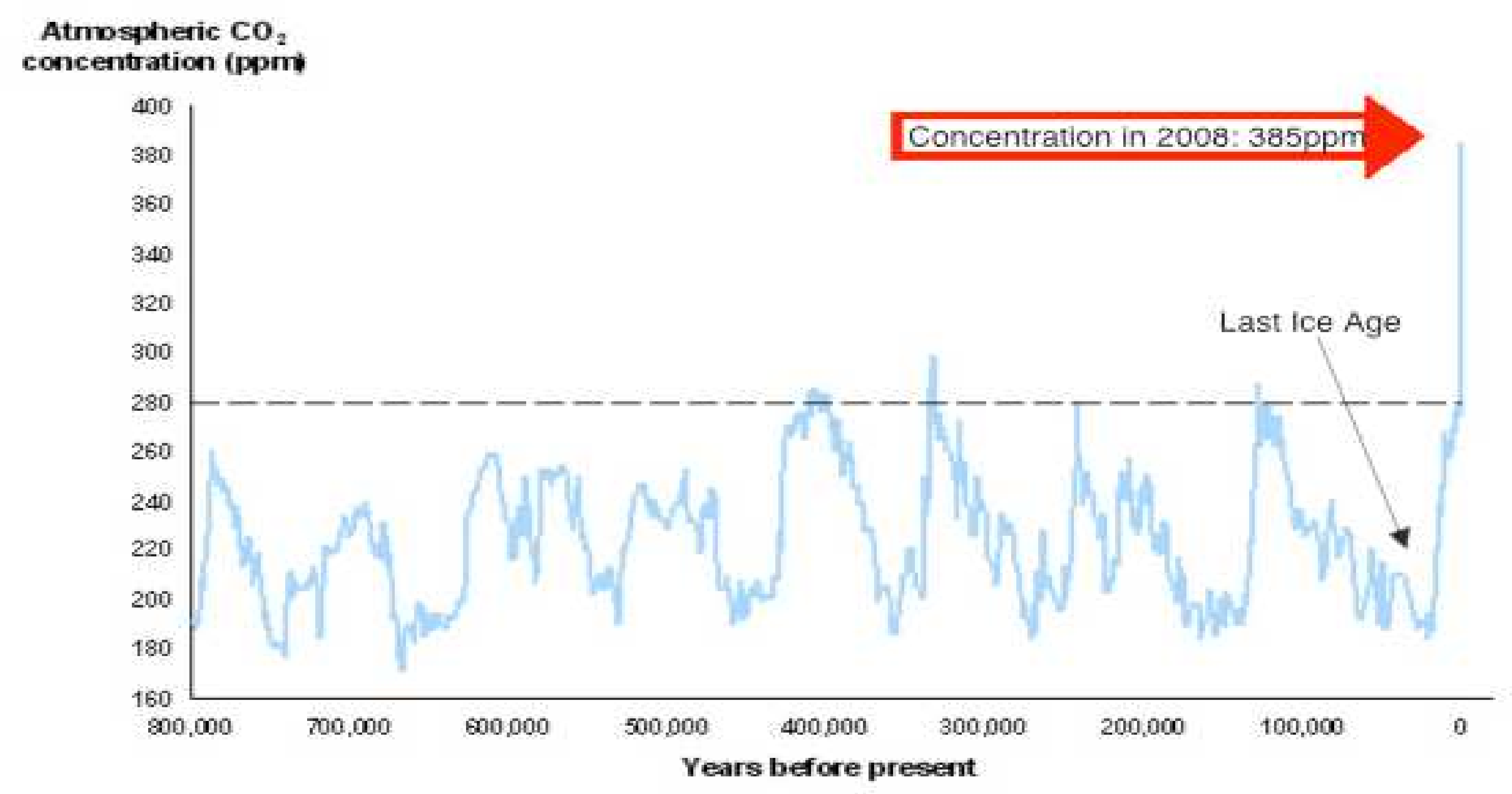
P. Dasgupta (2005)

- “An individual’s lifetime well-being is an aggregate of the flow of well-being she experiences, while intergenerational well-being is an aggregate of the lifetime well-beings of all who appear on the scene. *It is doubtful that the two aggregates have the same functional form.* (my italics- JR) On the other hand, I know of no evidence that suggests we would be way off the mark in assuming they do have the same form. As a matter of practical ethics, *it helps enormously* [my italics- JR] to approximate by not distinguishing the functional form of someone’s well-being through time from that of intergenerational well-being.”

Another fallacious justification

- Since future generations will have much better technologies than we, their future utility should be discounted.
- But *whether or not* they will have better technologies depends upon how much we decide to invest and educate! And these decision are guided by our choice of objective function. So the purported justification is *circular.*

3. A warming planet



A more complex model

- We construct a generalization of the model I developed earlier with two one additional sector: knowledge production (R&D).
- As well, *knowledge* and *carbon emissions* are additional inputs into commodity production
- As well, utility depends upon consumption, educated leisure, *knowledge and biospheric cleanliness* (low temperature)

Model E: Knowledge & Biosphere: Feasible paths

$$f^{e}(x_t^c, S_t^k, S_t^n, e_t, S_t^m) = k_{11}(x_t^c)^{\theta_c}(S_t^k)^{\theta_k}(S_t^n)^{\theta_n}(e_t)^{\theta_e}(S_t^m)^{\theta_m} \text{ (production)}$$

$$\theta^{\mathrm{c}}, \theta^{n}, \theta^{k}, \theta^{e} > 0, \theta^{m} < 0, \theta^{c} + \theta^{n} + \theta^{k} = 1$$

$$(1-\delta)S_{t-1}^k + k_5 i_t \geq S_t^k,\ t \geq 1 \text{(capital law of motion)}$$

$$(1-\delta^n)S_{t-1}^n + k_2 x_t^n \geq S_t^n,\ t \geq 1 \text{(knowledge law of m.)}$$

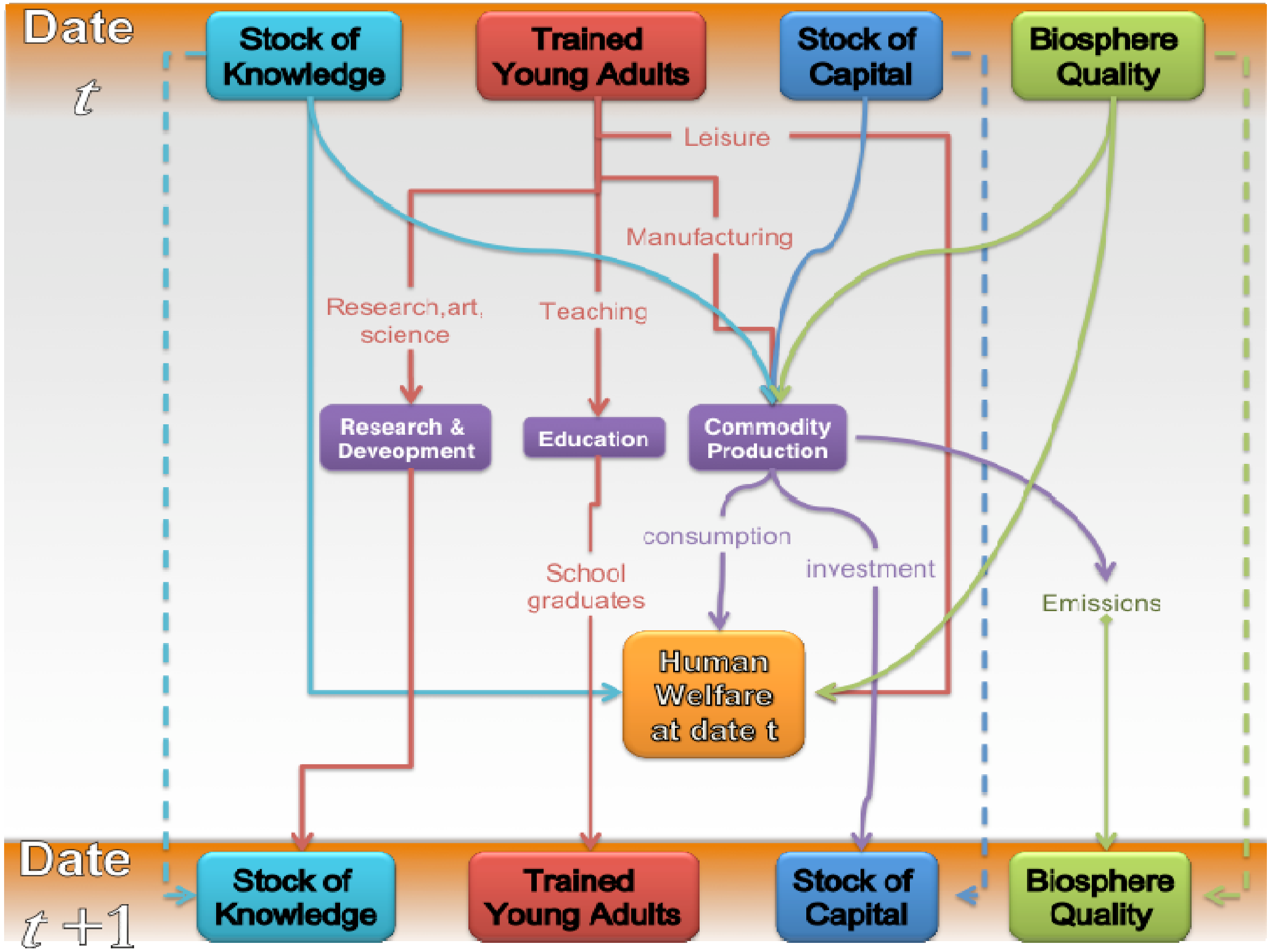
$$S_t^m \geq (1-\delta^m)S_{t-1}^m + k_3 e_t,\ t \geq 1 \text{(biosphere law of m.)}$$

$$x_t \equiv x_t^e + x_t^n + x_t^{\mathrm{l}} + x_t^c,\ t \geq 1 \text{(alloc'n of labor)}$$

$$\xi x_{t-1}^e \geq x_t \text{ (education product.fcn)}$$

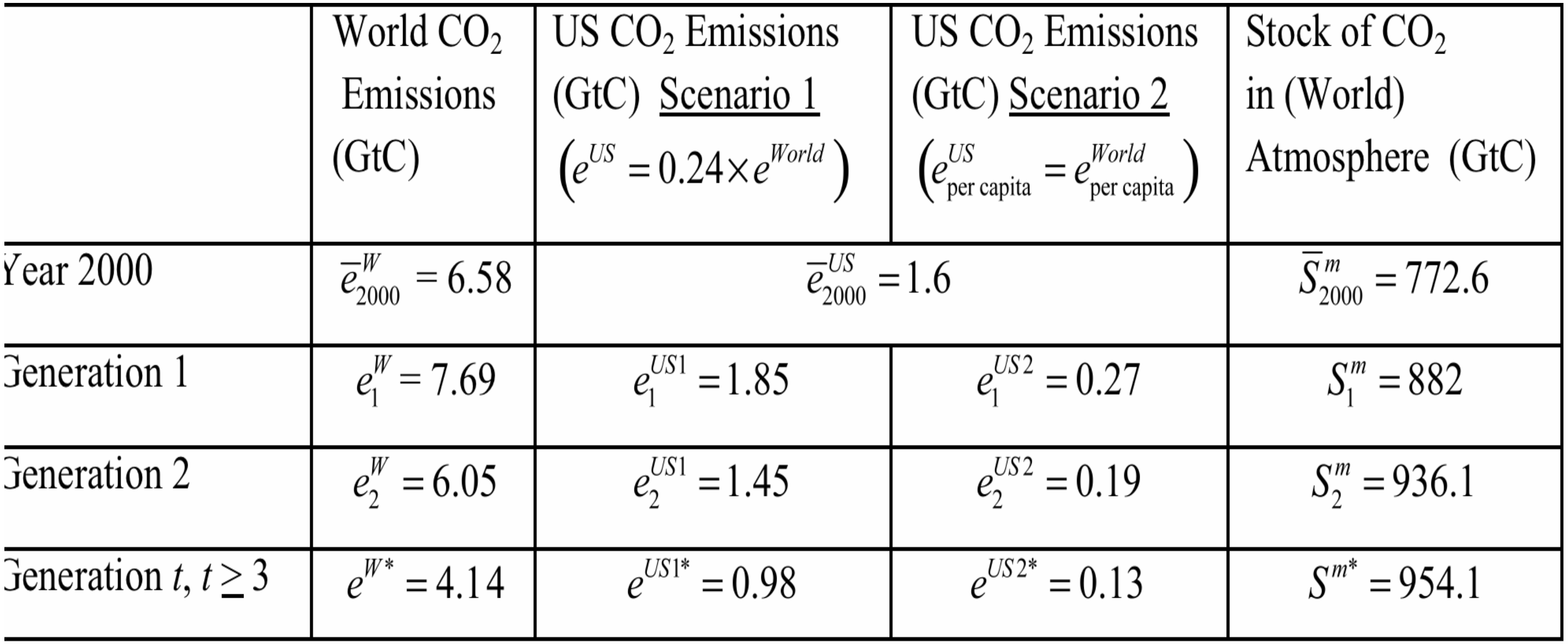
$$\text{Initial condition: } (x_0^e, S_0^k, S_0^n, S_0^m)$$

Flow chart of economy



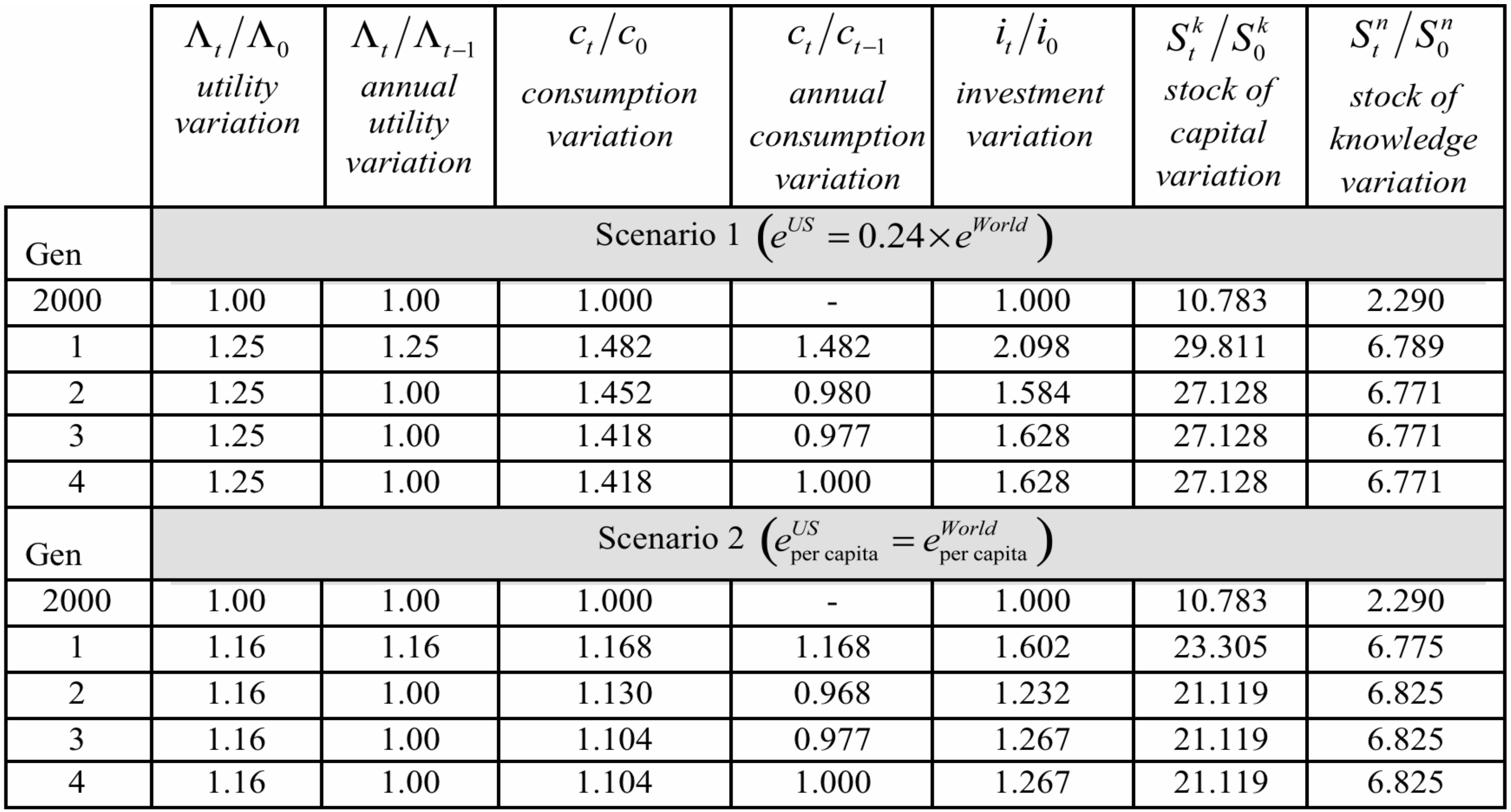
- We parameterize the model and compute *optimal sustainabilitarian paths for various values of* g.
- We constrain all paths to produce emissions sufficing to stabilize CO2 concentration at 450ppm
- Scenario one: US emits 24% of global; Scenario two: US emits per capita share

Tavoni emissions path: 450 ppm



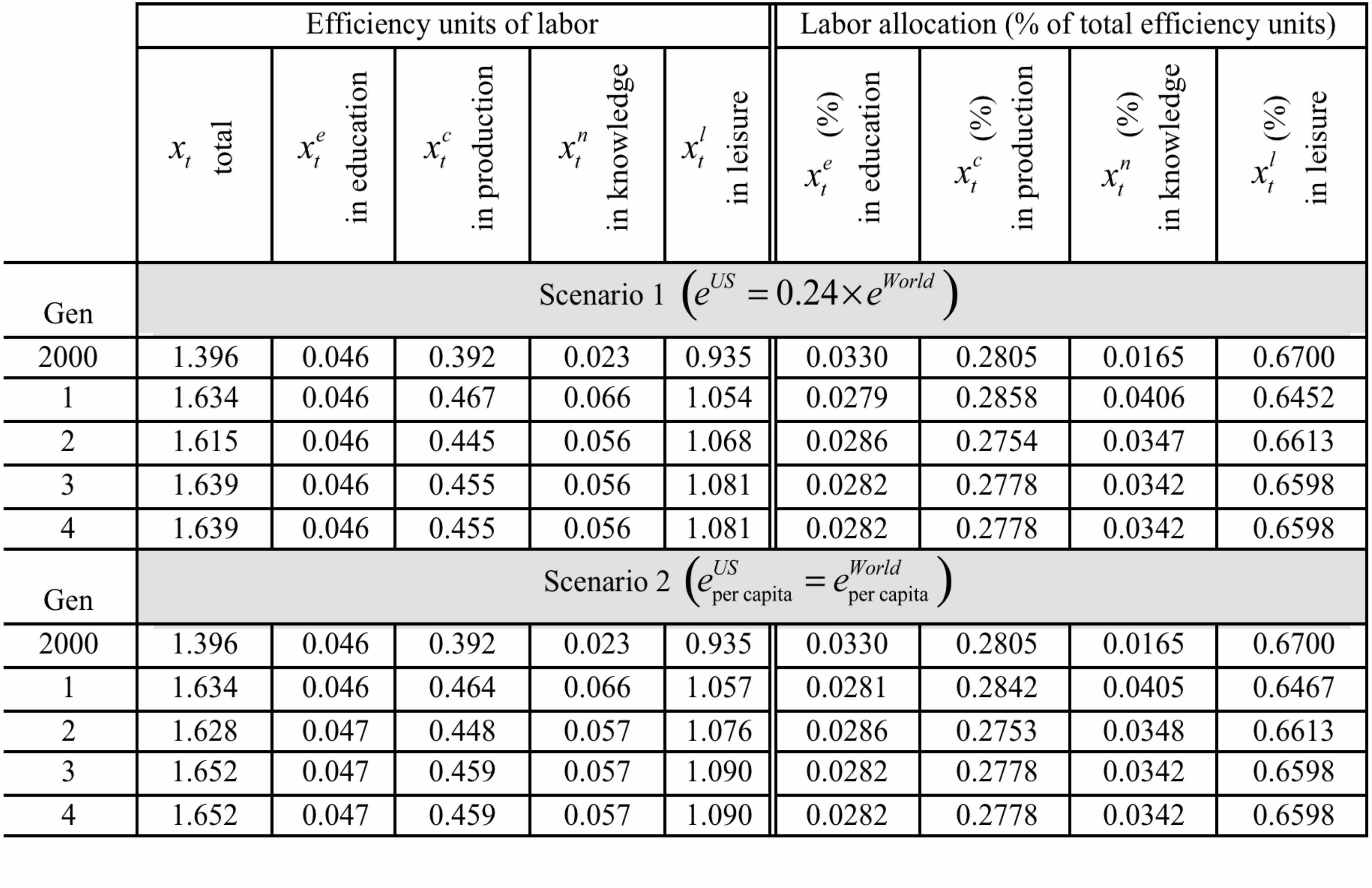
	World CO_2 Emissions (GtC)	US CO_2 Emissions (GtC) Scenario 1 $\left(e^{US} = 0.24 \times e^{World}\right)$	US CO_2 Emissions (GtC) Scenario 2 $\left(e^{US}_{\text{per capita}} = e^{World}_{\text{per capita}}\right)$	Stock of CO_2 in (World) Atmosphere (GtC)
Year 2000	$\bar{e}^{W}_{2000} = 6.58$	$\bar{e}^{US}_{2000} = 1.6$		$\bar{S}^{m}_{2000} = 772.6$
Generation 1	$e^{W}_{1} = 7.69$	$e^{US1}_{1} = 1.85$	$e^{US2}_{1} = 0.27$	$S^{m}_{1} = 882$
Generation 2	$e^{W}_{2} = 6.05$	$e^{US1}_{2} = 1.45$	$e^{US2}_{2} = 0.19$	$S^{m}_{2} = 936.1$
Generation t, $t \geq 3$	$e^{W*} = 4.14$	$e^{US1*} = 0.98$	$e^{US2*} = 0.13$	$S^{m*} = 954.1$

Pure sustainability



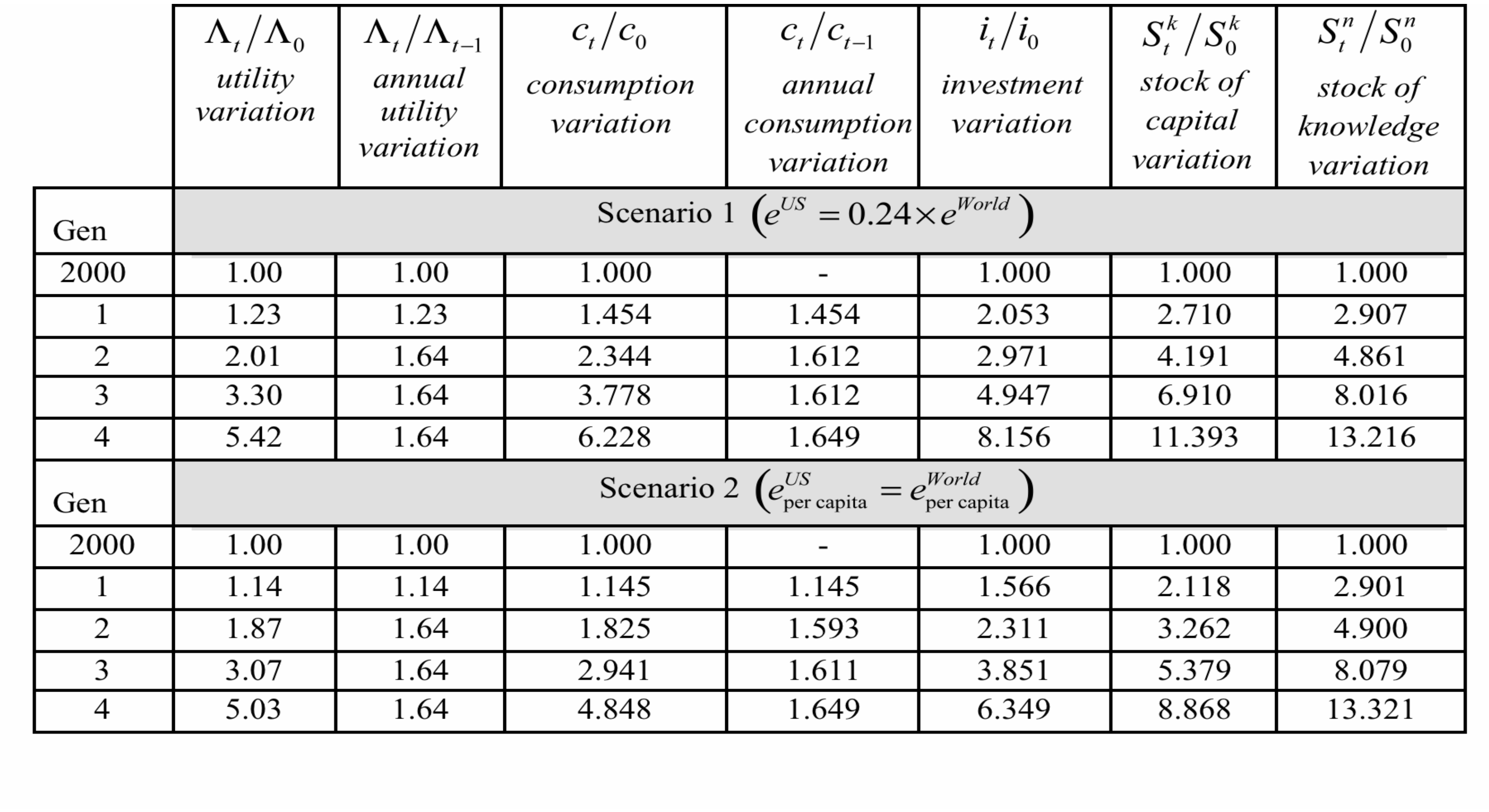
	Λ_t/Λ_0 *utility variation*	Λ_t/Λ_{t-1} *annual utility variation*	c_t/c_0 *consumption variation*	c_t/c_{t-1} *annual consumption variation*	i_t/i_0 *investment variation*	S_t^k/S_0^k *stock of capital variation*	S_t^n/S_0^n *stock of knowledge variation*
Gen	Scenario 1 $\left(e^{US} = 0.24 \times e^{World}\right)$						
2000	1.00	1.00	1.000	-	1.000	10.783	2.290
1	1.25	1.25	1.482	1.482	2.098	29.811	6.789
2	1.25	1.00	1.452	0.980	1.584	27.128	6.771
3	1.25	1.00	1.418	0.977	1.628	27.128	6.771
4	1.25	1.00	1.418	1.000	1.628	27.128	6.771
Gen	Scenario 2 $\left(e^{US}_{\text{per capita}} = e^{World}_{\text{per capita}}\right)$						
2000	1.00	1.00	1.000	-	1.000	10.783	2.290
1	1.16	1.16	1.168	1.168	1.602	23.305	6.775
2	1.16	1.00	1.130	0.968	1.232	21.119	6.825
3	1.16	1.00	1.104	0.977	1.267	21.119	6.825
4	1.16	1.00	1.104	1.000	1.267	21.119	6.825

Pure sustainability



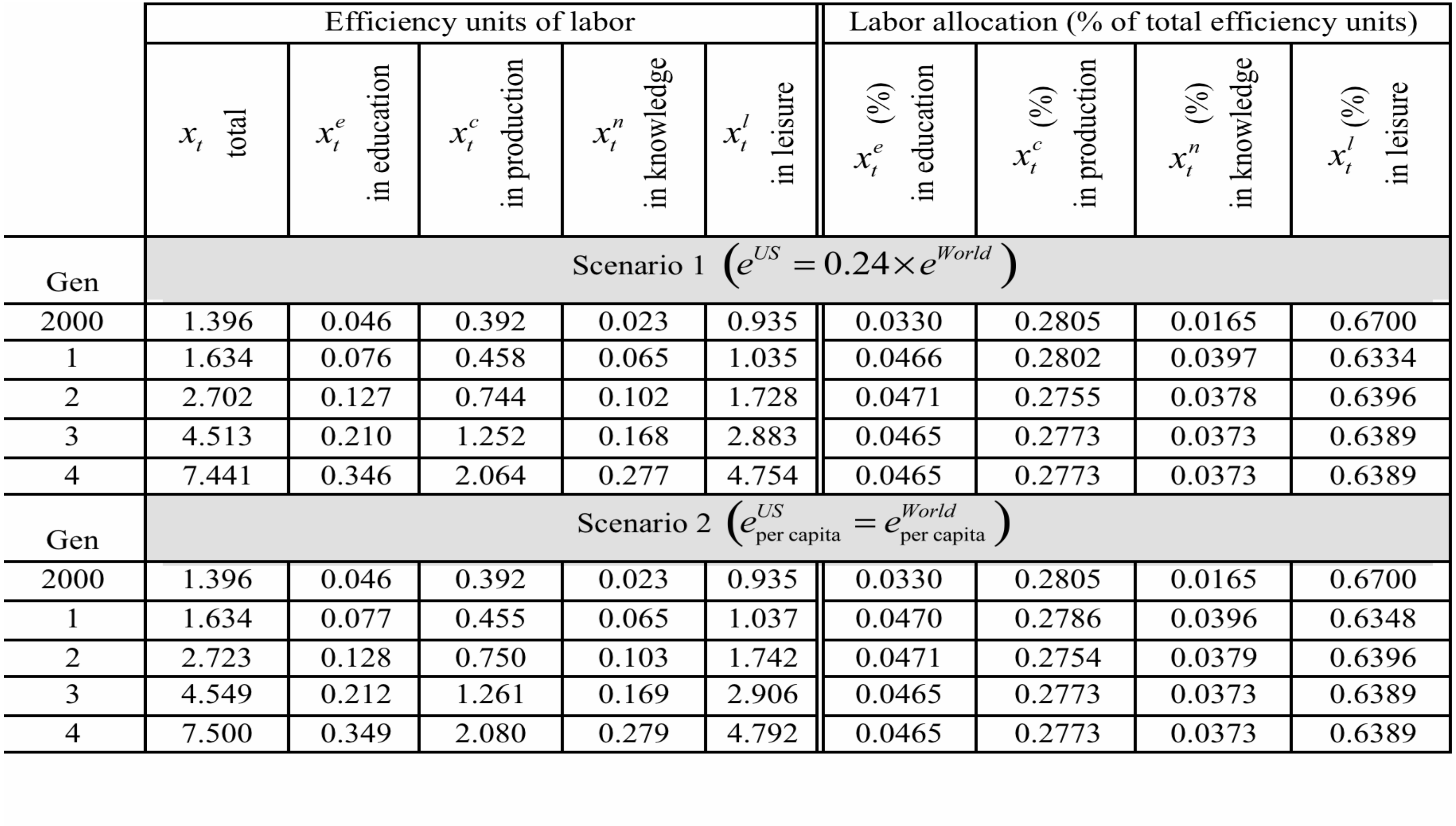
	Efficiency units of labor					Labor allocation (% of total efficiency units)			
	x_t total	x_t^e in education	x_t^c in production	x_t^n in knowledge	x_t^l in leisure	x_t^e (%) in education	x_t^c (%) in production	x_t^n (%) in knowledge	x_t^l (%) in leisure
Gen	Scenario 1 $\left(e^{US} = 0.24 \times e^{World}\right)$								
2000	1.396	0.046	0.392	0.023	0.935	0.0330	0.2805	0.0165	0.6700
1	1.634	0.046	0.467	0.066	1.054	0.0279	0.2858	0.0406	0.6452
2	1.615	0.046	0.445	0.056	1.068	0.0286	0.2754	0.0347	0.6613
3	1.639	0.046	0.455	0.056	1.081	0.0282	0.2778	0.0342	0.6598
4	1.639	0.046	0.455	0.056	1.081	0.0282	0.2778	0.0342	0.6598
Gen	Scenario 2 $\left(e^{US}_{\text{per capita}} = e^{World}_{\text{per capita}}\right)$								
2000	1.396	0.046	0.392	0.023	0.935	0.0330	0.2805	0.0165	0.6700
1	1.634	0.046	0.464	0.066	1.057	0.0281	0.2842	0.0405	0.6467
2	1.628	0.047	0.448	0.057	1.076	0.0286	0.2753	0.0348	0.6613
3	1.652	0.047	0.459	0.057	1.090	0.0282	0.2778	0.0342	0.6598
4	1.652	0.047	0.459	0.057	1.090	0.0282	0.2778	0.0342	0.6598

2% annual growth



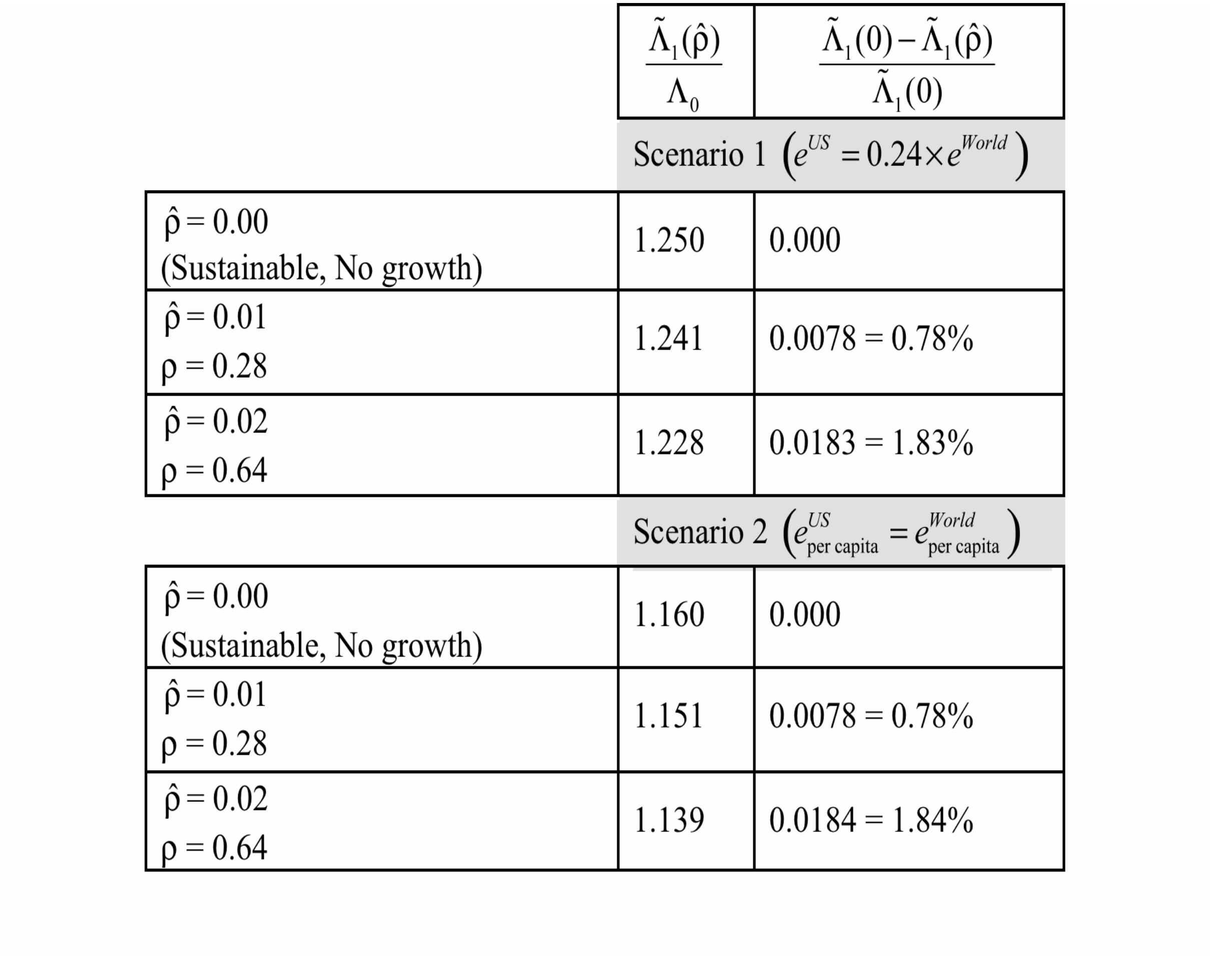
	Λ_t / Λ_0 *utility variation*	$\Lambda_t / \Lambda_{t-1}$ *annual utility variation*	c_t / c_0 *consumption variation*	c_t / c_{t-1} *annual consumption variation*	i_t / i_0 *investment variation*	S_t^k / S_0^k *stock of capital variation*	S_t^n / S_0^n *stock of knowledge variation*
Gen	Scenario 1 $\left(e^{US} = 0.24 \times e^{World}\right)$						
2000	1.00	1.00	1.000	-	1.000	1.000	1.000
1	1.23	1.23	1.454	1.454	2.053	2.710	2.907
2	2.01	1.64	2.344	1.612	2.971	4.191	4.861
3	3.30	1.64	3.778	1.612	4.947	6.910	8.016
4	5.42	1.64	6.228	1.649	8.156	11.393	13.216
Gen	Scenario 2 $\left(e^{US}_{\text{per capita}} = e^{World}_{\text{per capita}}\right)$						
2000	1.00	1.00	1.000	-	1.000	1.000	1.000
1	1.14	1.14	1.145	1.145	1.566	2.118	2.901
2	1.87	1.64	1.825	1.593	2.311	3.262	4.900
3	3.07	1.64	2.941	1.611	3.851	5.379	8.079
4	5.03	1.64	4.848	1.649	6.349	8.868	13.321

2% growth Labor alloc’n



	Efficiency units of labor					Labor allocation (% of total efficiency units)			
	x_t total	x_t^e in education	x_t^c in production	x_t^n in knowledge	x_t^l in leisure	x_t^e (%) in education	x_t^c (%) in production	x_t^n (%) in knowledge	x_t^l (%) in leisure
Gen	Scenario 1 $\left(e^{US} = 0.24 \times e^{World}\right)$								
2000	1.396	0.046	0.392	0.023	0.935	0.0330	0.2805	0.0165	0.6700
1	1.634	0.076	0.458	0.065	1.035	0.0466	0.2802	0.0397	0.6334
2	2.702	0.127	0.744	0.102	1.728	0.0471	0.2755	0.0378	0.6396
3	4.513	0.210	1.252	0.168	2.883	0.0465	0.2773	0.0373	0.6389
4	7.441	0.346	2.064	0.277	4.754	0.0465	0.2773	0.0373	0.6389
Gen	Scenario 2 $\left(e^{US}_{\text{per capita}} = e^{World}_{\text{per capita}}\right)$								
2000	1.396	0.046	0.392	0.023	0.935	0.0330	0.2805	0.0165	0.6700
1	1.634	0.077	0.455	0.065	1.037	0.0470	0.2786	0.0396	0.6348
2	2.723	0.128	0.750	0.103	1.742	0.0471	0.2754	0.0379	0.6396
3	4.549	0.212	1.261	0.169	2.906	0.0465	0.2773	0.0373	0.6389
4	7.500	0.349	2.080	0.279	4.792	0.0465	0.2773	0.0373	0.6389

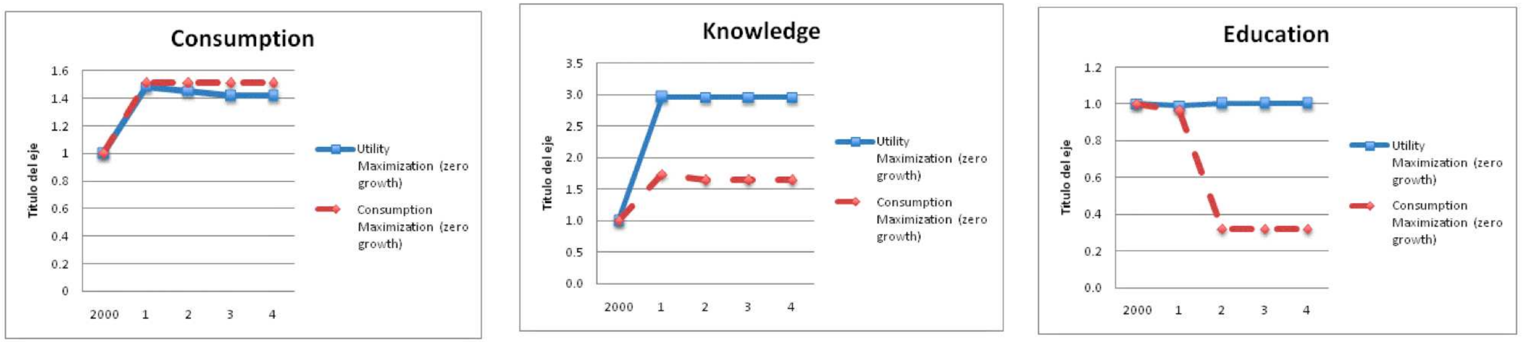
Trade-off between growth and welfare of Generation 1



	$\frac{\tilde{\Lambda}_1(\hat{\rho})}{\Lambda_0}$	$\frac{\tilde{\Lambda}_1(0)-\tilde{\Lambda}_1(\hat{\rho})}{\tilde{\Lambda}_1(0)}$
	Scenario 1 $\left(e^{US}=0.24\times e^{World}\right)$	
$\hat{\rho}=0.00$ (Sustainable, No growth)	1.250	0.000
$\hat{\rho}=0.01$ $\rho=0.28$	1.241	0.0078 = 0.78%
$\hat{\rho}=0.02$ $\rho=0.64$	1.228	0.0183 = 1.83%
	Scenario 2 $\left(e^{US}_{\text{per capita}}=e^{World}_{\text{per capita}}\right)$	
$\hat{\rho}=0.00$ (Sustainable, No growth)	1.160	0.000
$\hat{\rho}=0.01$ $\rho=0.28$	1.151	0.0078 = 0.78%
$\hat{\rho}=0.02$ $\rho=0.64$	1.139	0.0184 = 1.84%

Welfare vs. consumption

- **Figure 2**. Comparison of consumption, stock of knowledge and education paths for utility maximization and consumption maximization.



Discounting the sustainabilitarian path

- Our feasible set includes an emissions path stabilizing at 450 ppm concentration carbon. What are the probabilities of human extinction on this path?
- Suppose they take a simple form: an independent draw at each date with probability p of extinction

- If $p < 0.24\%$ per annum, then the discounted utilitarian program on our feasible set of paths diverges. Hence, by the Thm B, the solution of the *undiscounted* program that we have solved is the solution of the *properly discounted sustainabilitarian* program.
- This bound on *p* seems OK. (Stern Report assumes $p = 0.1\%$ per annum.)

4. Choosing the growth rate

- There are optimal solutions for our *g*-sustainable paths for an interval of values of *g.* How should *g* be chosen?
- My view: The ethical benchmark is *g* = 0. The date at which a person is born is a morallly arbitrary feature, and her welfare should therefore be independent of it. This implies *maximize the highest sustainable utility.*

Abdicating rights

- This establishes the *a priori right* of every individual. But people may wish *not to enforce this right* – because, e.g., they would like future generations to be better off than they. They may value growth of welfare as a public good. If so, then positive growth trumps the right to equal welfare.

The trade-off

- We can model this as follows:

$$\begin{aligned}&\max U(1+g, u_1)\\&\text{s.t. } u \in \mathbf{P}\\&u_t \geq (1+g)^{t-1} u_1\end{aligned}$$

where *U* expresses the preference order of the first-generation agent over her own utility and growth or ‘human development.’

The solution determines the value of *g* in the sustainabilitarian program

Empirically….

- Examining the solutions of our *g*-sustainabilitarian programs with empirical parameterizations suggests that a small positive rate of growth (1 or 2% per annum) is attractive.

5. International bargaining to control emissions

- A clean biosphere is a public good. How the should the rights to emit greenhouse gases (GHGs) be allocated to regions/countries of the world today?
- I now don the hat of a political scientist rather than a philosopher, and ask what might be an attractive political solution to this problem.

US and China

- US and China each emit approx one-quarter of global emissions. An agreement between them is necessary and (I think) *sufficient* to enable an international global agreement
- How should China and the US (think : the global South and North) share the emissions quotas of IPCC IV?

Proposal for a politically feasible principle

- Imagine the world consists of China and the US (for simplicity).
- Suppose we could agree that *absent the problem of global warming* Chinese GDP per capita would converge to US GDP in *n* years (say : *n* =75, i.e., three generations)
- Proposal: With the emissions constraint, they should still converge in *n* years

A ‘negotiating equilibrium’

- To see this, imagine, on the contrary, that an agreement was proposed in which China-US convergence occurs in less than 75 years. Then the US negotiators will say: “Why should you, China, benefit vis-à-vis US because of global warming?”
- Or imagine an agreement in which convergence occurs in more than 75 years. China will say: “Why should China lose vis-à-vis the US because of global warming?

Quick calculation

- gdpUS = \$47.4; gdpCH=\$ 5.97 (2008)

$$1+g^{US} \approx 1.02 \quad 1+g^{CH} \approx 1.05$$

Solve the equation: $\frac{(1+g^{CH})^t gnpCH}{(1+g^{US})^t gnpUS} = 1 \Rightarrow t = 71.5 \text{ years}$

- Convergence in approximately 3 generations.

Changing growth factors

- Suppose each country reduces its growth factor by the same fraction. Then the date of convergence remains unchanged

$$\frac{(\cancel{r}(1+g^{CH}))^t\, gnpCH}{(\cancel{r}(1+g^{US}))^t\, gnpUS} = 1 \Rightarrow t = 71.5\ \text{years}$$

- Suppose the US and China meet every 5 yrs. They must agree to reduce their growth factors by the same fraction . They agree that total emissions should be e^* during this period.
- Let $\alpha^J(b, I)$ be the *output-emissions ratio* that country *J* can achieve with investment in research *b* and mitigation investment *I*

- Then net GDP for the coming period, if investments (b^J, I^J) are incurred in *J* is

$$Y^J = \alpha^J(b^J, I^J)e^J - (b^J + I^J)$$

- Now the two countries have agreed to maintain the ratios of their constrainted incomes to some BAU level; that is

$$Y^C = \lambda Y^{US}$$

Where λ is the ratio of their growth factors.

Maximize joint output

- It follows that they should now choose investments and emission assignments to *maximize their joint incomes*; they then divide the income in the ratio $1:\lambda$
- In other words, *once the focal point of bargaining is to maintain GDP growth factor ratios, then the countries have their incentives aligned,* so maximizing joint GDP is the sol’n.

The program is

$$\max \alpha^{Ch}(b^{Ch}, I^{Ch})e^{Ch} - (b^{Ch} + I^{Ch}) +$$

$$\alpha^{US}(b^{US}, I^{US})e^{US} - (b^{US} + I^{US})$$

$$\text{subj. to } e^{*} \geq e^{US} + e^{Ch}$$

And then they adjust so that China receives fraction $\frac{\lambda}{1+\lambda}$ of the total , and the US receives fraction $\frac{1}{1+\lambda}$ of the total.

- In an example , it turns out that

$$\frac{e^{Ch}}{e^{US}} = \left(\frac{n^{Ch}}{n^{US}} \right)^{r/(r+s)}$$

where n^J is the pop. Of country *J*, and *r,s* are elasticities in the CD function specifying $\alpha(b, I)$

Note that emission ratios are *not equal* to pop’n ratios.

Key Points

- Emissions’ allowances are not set by *a priori* ethical considerations, but emerge *from the bargaining problem* once agreement is reached to preserve the relative growth factors of the parties.
- Under this rule, externalities from investment in new emissions-control technology are internalized

Summary

- The two countries need never compute the date of convergence
- At each negotiation, agree to maintain the ratio of relative growth factors
- Must agree on estimates of these factors, and on the functions $\alpha^J(b, I)$

The fly in the ointment…

- is US national politics.
- Ignorance of American citizens + linking by the Republicans of global-warming fears with the Left. Political leadership is required.
- The *technological and economic* problems are not critical. Our simulations show that.
- Optimistically, I predict that within 20 years, the skeptics will have disappeared

This talk is based on these papers available here:

- H. Llavador, J.Roemer, & J. Silvestre, “A dynamic analysis of human welfare in a warming planet”
- [same authors] “Intergenerational justice when the existence of future generations is uncertain,” *J. Math.Econ.* (in press)
- J. Roemer, “The ethics of intergenerational distribution in a warming planet,” *Environ.&Resource Econ.* (in press)
- J. Roemer, "How countries can negotiate to allocate greenhouse-gas emissions: A simple proposal” festschrift for J. Elster (in press)