Preference constraint for sustainable development

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Today's talk

- Economic optimality of sustainable development
  – Based on Akao and Managi (2007) "Feasibility and optimality of sustainable growth under materials balance," *Journal of Economic Dynamics and Control* 31, 3778-3790.

and

- Its preference constraint
  – Based on Akao (2014) "Preference constraint for sustainable development," *Environmental Economics and Policy Studies* 16, 343-357.

Economic optimality of sustainable development

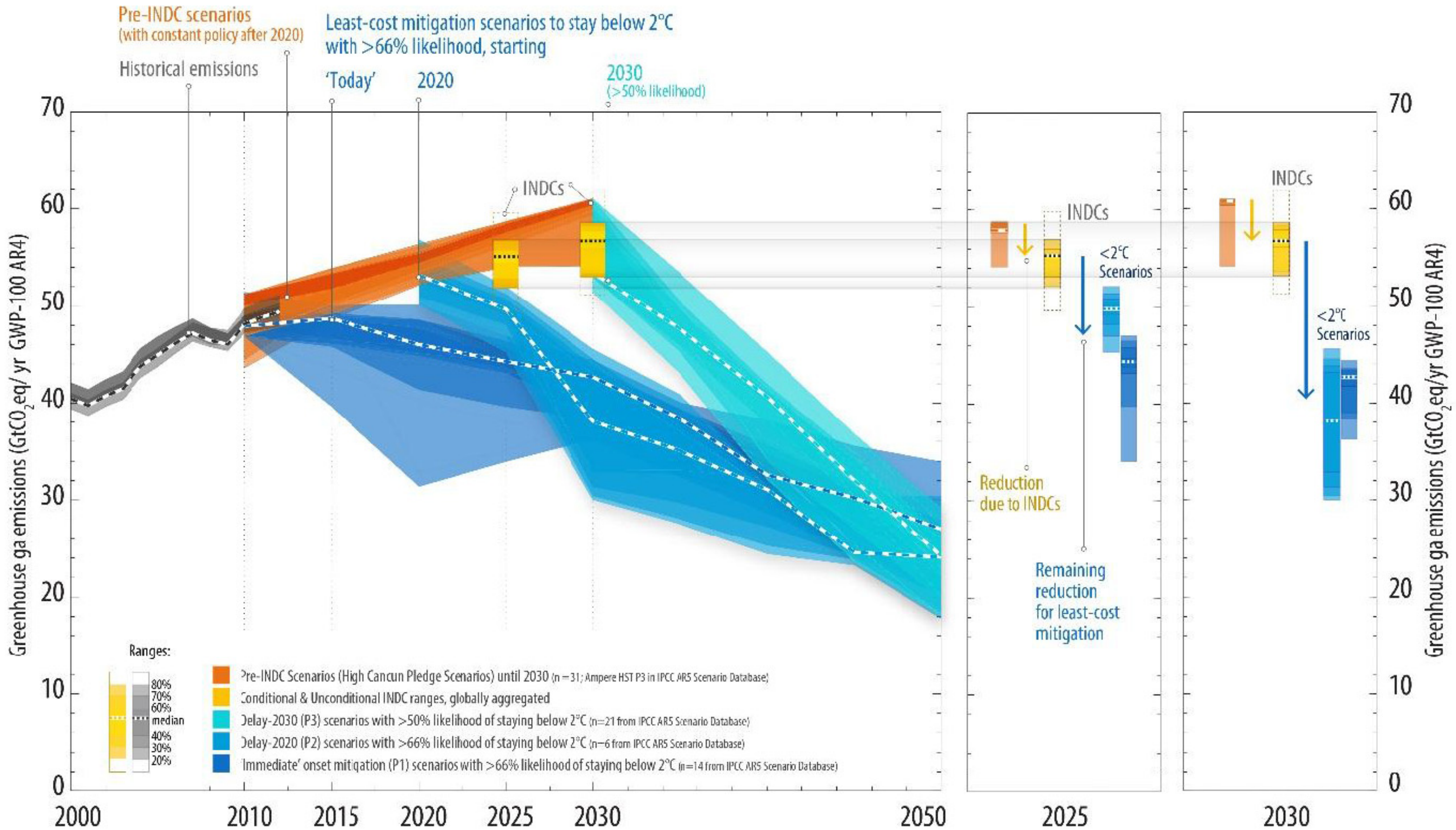
- Economic optimality
    - in the standard model (utilitarian)
  - Maximizing the time aggregate social welfare.

- Sustainable development
    - in the context of endogenous growth theory
  - Economic growth with environmental conservation

- When these two different concepts accord?
  - Under what conditions is an economically optimal path environmentally sustainable?

2 ^{o}C ceiling on global warming: Illustration of the problem

- Paris Agreement (adapted at COP21 of UNFCCC, 2015)
  - reaches the international consensus:
  - *holding the increase in the global average temperature to well below, 2 ^{o}C above pre-industrial* (Article 2 (a)),
  - which is accepted as the global mitigation target to prevent "*dangerous anthropogenic interference with the climatic system* (UNFCCC, Article 2). "
- But it is also broadly recognized that the current climate pledges of individual countries (Intended Nationally Determined Contributions: INDCs) are far from reaching the target, even if they are fully implemented.



Emissions gap between the full implementation of INDCs and the least-cost emission level: 8.7 GtCO2 in 2025, and 15.1 GtCO2 in 2030.

Source: UNFCCC (2015) Synthesis report on the aggregate effect of the intended nationally determined contributions. (FCCC/CP/2015/7) (http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf)

- IEA estimates that if climate ambition is not raised progressively, the path set by the INDCs would be consistent with an average global temperature increase of around 2.7 °C by 2100. (IEA, 2015, Energy and Climate Change: World Energy Outlook Special Briefing for COP21.)

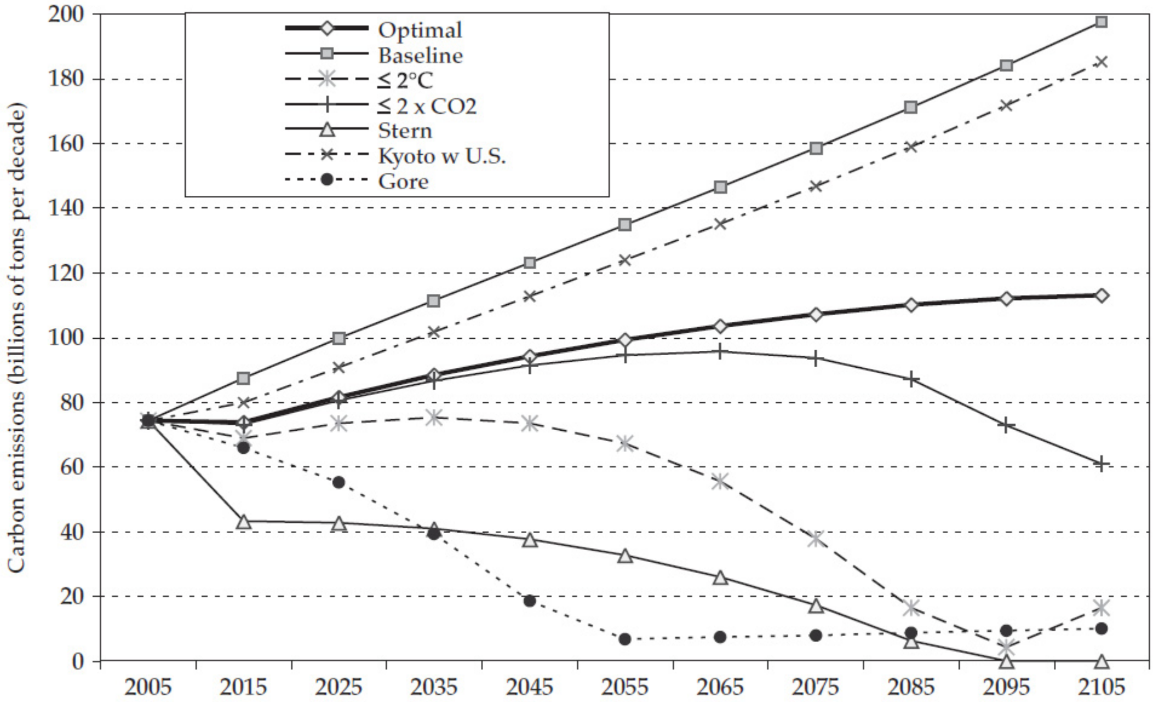


Figure 5-6. Global emissions of industrial CO_2 per decade under different policies. The global emissions of industrial CO_2 under different policies over the next century. The figure for 2005 is the actual value.

Results by DICE (Dynamic Integrated model of Climate and the Economy) -2007 model.
With the optimal policy, the global temperature is expected to be 2.67 ^{o}C above at 2100.

Source: Nordhaus, William (2008) A Question of Balance: Weighing the Options on Global Warming Policies. Yale University Press.

- Nordhaus' optimal path is based on our preferences whose parameters are chosen to fit with the past macroeconomic performances and has some empirical rationale. In contrast, Stern chooses them by popular ethical beliefs on intergenerational equity.

2 ^{o}C ceiling on global warming: Illustration of the problem

- The Nordhaus' optimal path may exceed the 2 ^{o}C ceiling and touch the level of "*dangerous interference*."
- We see a discordance between sustainable development and an economically optimal path.
- The present generation might willingly take an unsustainable path by the very rationality, although recognizing that it will be hardly acceptable for future generations.

Then a question in economic theory is:

- *what are the conditions under which sustainable development becomes an economically optimal path?*

"Growth and the environment" model

- Aghion and Howitt (1998, Ch. 5)

$$\max \int_0^\infty \left(\frac{c^{1-\sigma}-1}{1-\sigma} - \frac{(-E)^{1+\omega}}{1+\omega} \right) e^{-\rho t} dt$$

subject to

$$\dot{K} = K^{\alpha(1-1/\beta)}(nH)^{(1-\alpha)(1-1/\beta)} x^{1/\beta} - C,$$

$$\dot{H} = \eta(1-n)H, \ \dot{E} = -x - \theta E.$$

$H =$ human capital.

$E =$ environmental stock. $(E^{\min} \leq E \leq 0)$

$E^{\min} =$ threshold to catastrophe

$n =$ share of labor into the final sector.

$x =$ pollution flow.

- An optimal balanced growth path (steady state) is a sustainable development path (positive economic growth and environmental improvement) only if a growth engine sector does not pollute the environment.

- An optimal balanced growth path (BGP) is a sustainable development path (SDP) if and only if these inequalities are satisfied.

$$(1)\ \sigma \geq 1,\ (2)\ \eta > \rho,$$

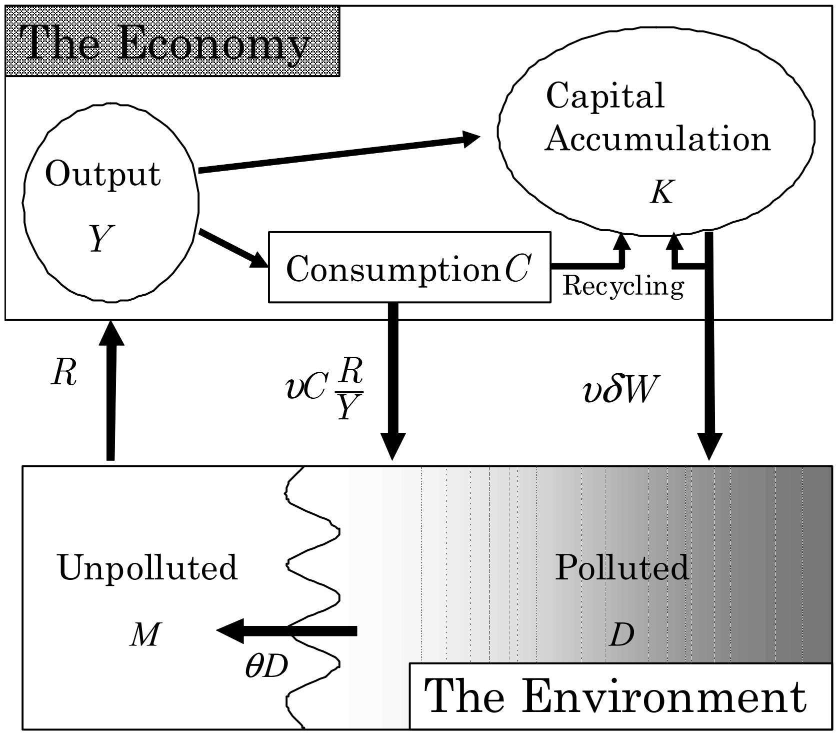
$$(3)\ \theta > -\frac{1-\sigma}{1+\varpi} g_K$$

(g_K = the optimal balanced growth rate)

- Question: Is this result valid in the other models?

Feasibility and optimality of sustainable growth under materials balance

- Akao & Managi (2007) take into account:
  1. The negative effects of both production and <u>*consumption*</u>.
  2. <u>*Recycling*</u> and its technological progress.
- Capture the interaction between the economic system and the environment
- By a materials balance approach (the low of conservation of mass).



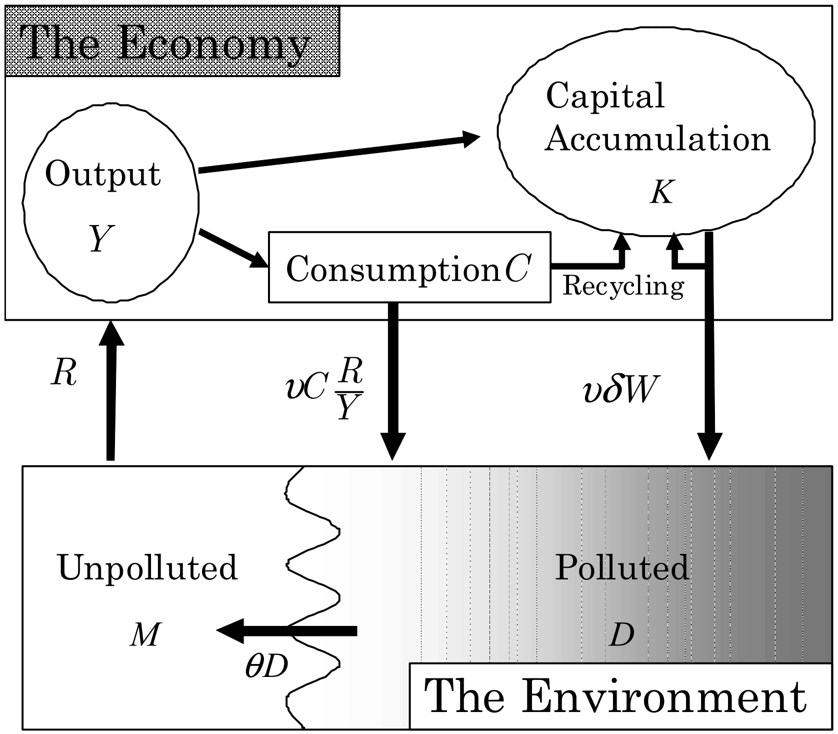
Materials balance approach

- The low of mass conservation: $M(t)+D(t)+W(t)=\text{constant}$
  - The unit weights of output, consumption and invstment goods: $R(t)/Y(t)$
- Two way unit system:
  - Economic and physical (weight) units.
  - E.g. Capital stock

$$K(t)=\int_{-\infty}^{t} I(t,\tau)d\tau,$$

$$W(t)=\int_{-\infty}^{t} \frac{R(\tau)}{Y(\tau)} I(t,\tau)d\tau.$$

where $I(t,\tau)$ is the amount of capital stock of vintage τ at time t.



- Other notation
  - Recycling rate $1-\upsilon$,
  - Depreciation rate δ,
  - Assimilation factor θ.

Feasibility of SDP

– Without preference, without specific structure of Technology.

$$\dot{K} = Y - \upsilon(C + \delta K) \ (1),\ \dot{W} = -\upsilon\left(C\frac{R}{Y} + \delta W\right) + R \ (10),\ \dot{D} = \upsilon\left(C\frac{R}{Y} + \delta W\right) - \theta D \ (8)$$

- Assumption: existence of the critical level $D_{\max}(< \infty)$

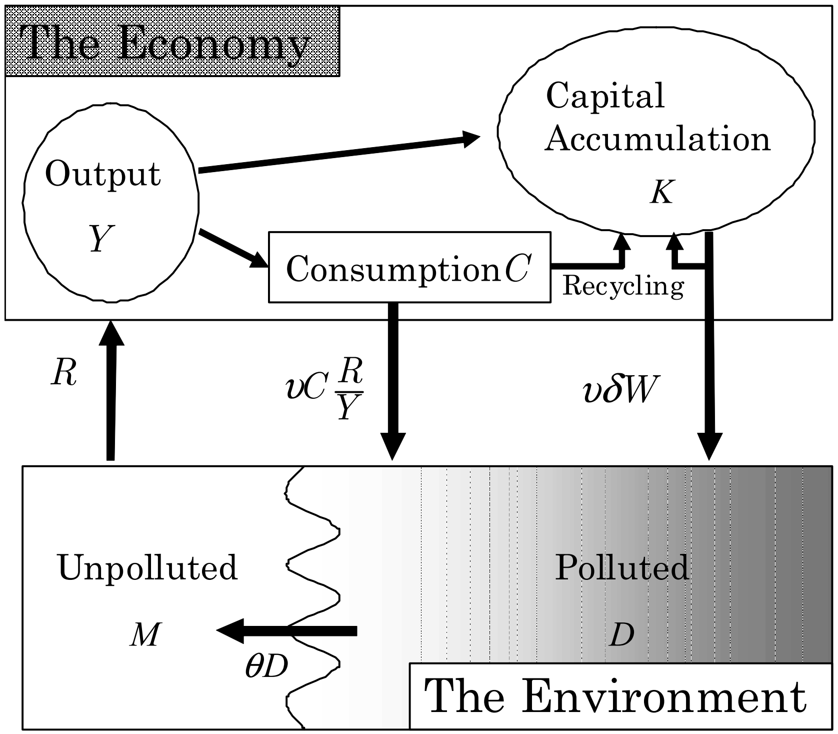
  Once the environment has degraded at the level, the economy inevitably suffers fatal damage.

- Results:

For the realization of sustainable development,

1. neither the flow of natural resources nor pollution from industries must exceed the assimilation capability: $\theta D \geq \max\{R, \upsilon\delta W\}$.
2. The time path of natural resource flows must be nonincreasing $g_R \leq 0$.
3. $$\frac{R/Y}{W/K} = \frac{\text{Unit weight of flow}}{\text{Unit weight of stock}} < 1$$

   implying "dematerialization" of the products.



Optimal SDP

$$\max \int_0^\infty \left[\frac{C^{1-\sigma}}{1-\sigma} - \gamma \frac{D^{1+\omega}}{1+\omega} \right] e^{-\rho t} dt \;\; (\gamma, \rho, \sigma, \omega > 0)$$

subject to $Y = AK^{\alpha}(BL_f)^{\beta} R^{1-\alpha-\beta} \;\; (A, \alpha, \beta, 1-\alpha-\beta > 0)$

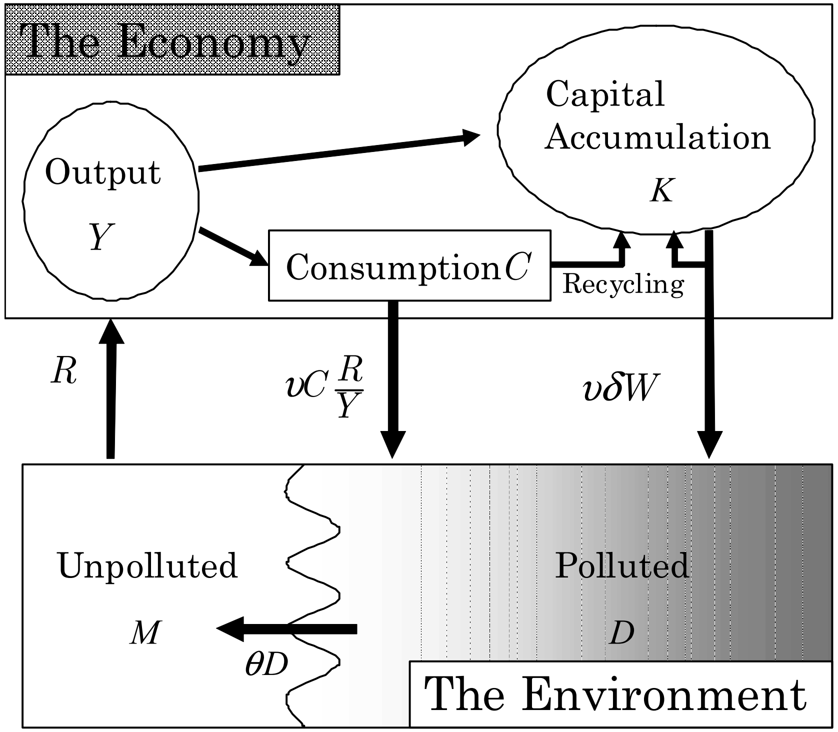
$$\dot{K} = Y - \upsilon(C + \delta K), \;\; \dot{B} = \eta_B L_B B, \;\; \dot{Q} = \eta_Q \left[1 - L_f - L_B - q(\upsilon)(C + \delta K)/Q \right],$$

$$\dot{W} = -\upsilon(CR/Y + \delta W) + R,$$

$$\dot{D} = \upsilon(CR/Y + \delta W) - \theta D, D \in (0, D_{\max}),$$

the nonnegativity condition, and

the initial values K_0, B_0, Q_0, D_0 given.



- Necessary conditions for the existence of an optimal SDP are:

(1) $\sigma \geq 1$,

(2a) $1 > (\eta_B^{-1} + \eta_Q^{-1})\rho$ or (2b) $1 > \eta_B^{-1}\rho$,

(3) $\theta > -\frac{1-\sigma}{1+\varpi} g_K$,

where g_K is the optimal balanced growth rate. (2a) implies recycling is active ($\upsilon < 1$) whereas (2b) implies it is inactive ($\upsilon = 1$) along the optimal SD.

Interpretation of the conditions for an optimal path to be a SDP

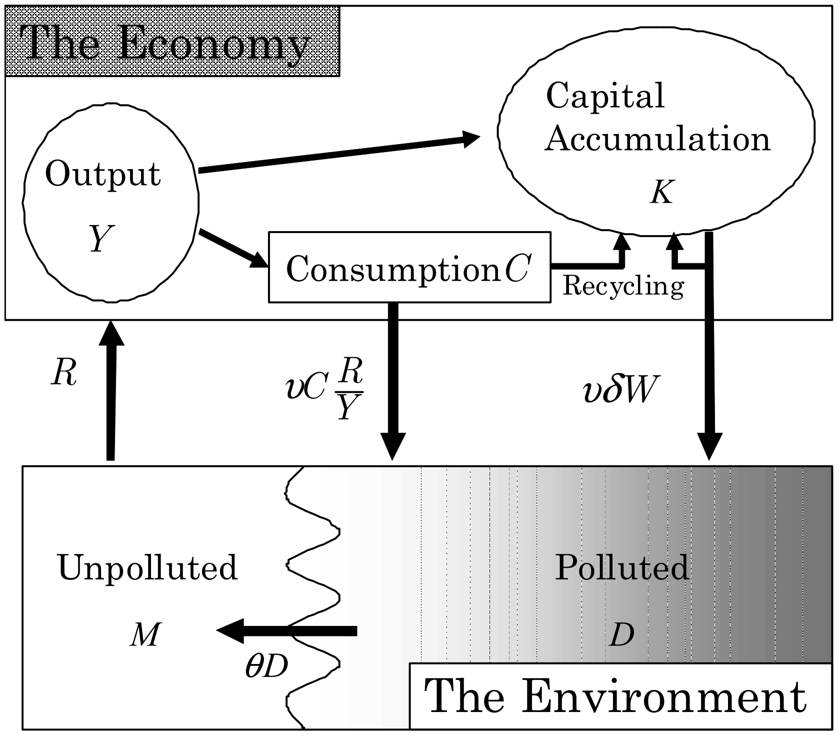
An optimal SDP exists only if (1) $\sigma \geq 1$, (2b) $\eta_B > \rho$, (3) $\theta > -\frac{1-\sigma}{1+\varpi} g_K$.

- Interpretation

(1) The population has an egalitarian propensity such that the elasticity of the marginal utility of consumption is greater than or equal to one.

(2) There is an industrial sector that is environmentally friendly and free from decreasing returns to scale with the productivity greater than the discount rate.

(3) The assimilation capacity of the environment is high enough to endure the increasing environmental load along an optimal balanced growth path.



Interpretation of the conditions for an optimal path to be a SDP

- On the assimilation factor θ.

(3) $\theta > -\frac{1-\sigma}{1+\varpi} g_K.$

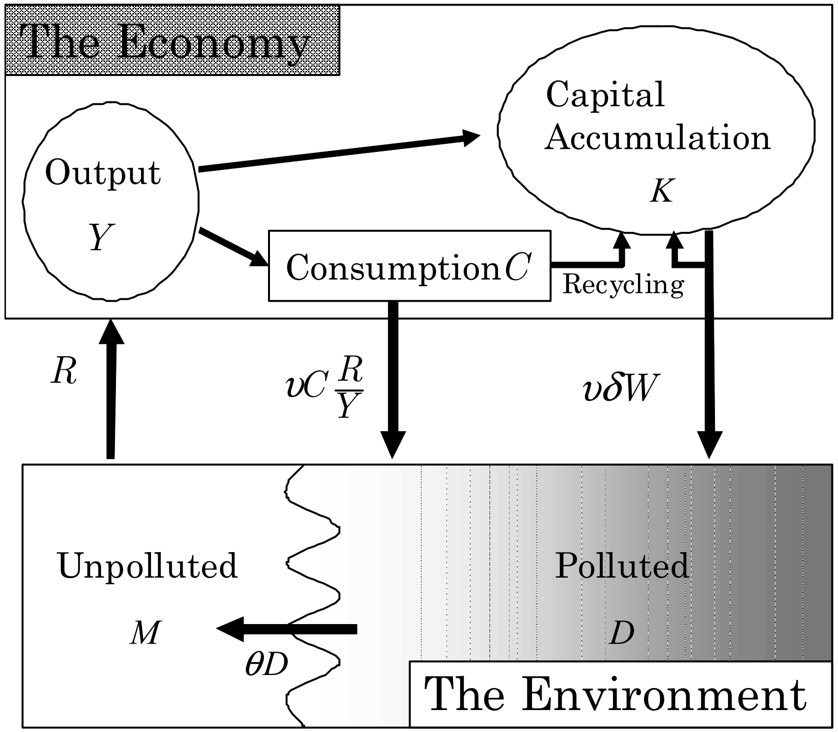
The assimilation capacity of the environment is high enough to endure the increasing environmental load along an optimal balanced growth path.

In the aggregative model, no distinction between renewable and non-renewable resources or among several types of pollutants. But, as a possible interpretation,

- a very low θ implies that:

1. The economy heavily depends on nonrenewable resources.
2. The major pollution emissions are difficult to naturally decompose.

(e.g. carbon dioxide, radioactive wastes, ozone depleting substances, etc.)



Lifetime, half-life of pollutants and the assimilation coefficient Ɵ

		Atomospheric Lifetime	Half-life time	θ
Ozone depleting substances and their substitutes				
	CFC-12	100		0.010000
	HCFC-22	12		0.083333
	HFC-134a	14		0.071429
Long-lasting greenhouse gasses*				
	Carbon Dioxide	various		0.008629
	Methane	12		0.083333
	Nitrous oxide	114		0.008772
High-level radioactive waste**				
Long-lived Nuclear fission product	Pu-239		24110	0.000029
	Am-241		432.6	0.001602
	I-129		15700000	0.000000
Nuclear fission productMedium-lived	Sr-90		28.9	0.023984
	Cs-137		30.08	0.023043

Source:

* Intergovernmental Panel on Climate Change (2007) *Fourth Assessment Report, Working Group I: Technical Summary* (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html Access 7/18/2018)

** International Atomic Energy Association (2009) *Determination and Use of Scaling Factors for Waste Characterization in Nuclear Power Plants.* (http://www-pub.iaea.org/MTCD/publications/PDF/Pub1363_web.pdf Access 7/18/2016)

Condition (3) $\omega > (\sigma - 1) g_C / \theta - 1$ Cf. Period utility $u(C,D) = \frac{C^{1-\sigma}}{1-\sigma} - \gamma \frac{D^{1+\omega}}{1+\omega}$

- If we assume that the intertemporal elasticity of consumption is $\sigma = 2$ as Nordhaus's DICE-2007 and the steady state growth rate is $g_C = 0.01$, then the elasticity of marginal disutility of pollution stock ω must be larger than …

		θ	$\omega>$
Ozone Depleting Substances			
	CFC-12	0.01	0.00
	HCFC-22	0.08333333	-0.88
Long-lived greenhouse gasses			
	Carbon dioxide	0.00862905	0.16
	Methan	0.08333333	-0.88
	nitrous oxide	0.00877193	0.14
High-level radioactive wastes			
Long-lived actinides and fission products	Pu-239	2.8749E-05	346.83
	Am-241	0.00160228	5.24
	I-129	4.415E-08	226,502.12
Short-lived fission products	Sr-90	0.02398433	-0.58
	Cs-137	0.02304346	-0.57

On the preference constraint for a sustainable development to be optimal

- Sustainable development is optimal only if: (1) $\sigma \geq 1$,

  (g_K = the optimal balanced growth rate) (2) $\eta > \rho$,

  (3) $\theta > -\dfrac{1-\sigma}{1+\varpi} g_K$

- The difference between (1) and (2), (3):
- The latter two contain the parameters about technology. They can be satisfied, if we have a good technology,
  - including breakaway from the dependence on nonrenewable resources and persistent wastes such as carbon dioxide and radioactive wastes.
- The first one is purely preference condition. It is not obtained by our efforts
  - except for relying on education which could alters our preference.
- Can the preference constraint $\sigma \geq 1$ be relaxed?

Plan of the study and the results

- *Exogenous* growth model with flow pollution

$$\max_{c,x,n} \int_0^\infty \frac{\left(cx^\phi\right)^{1-\sigma}}{1-\sigma} e^{-\rho t} dt, \quad 0<\phi\le\frac{\sigma}{1-\sigma}$$

$$\text{subject to } \dot{K} = (nHL)^{1-\alpha}\left(AK^\alpha - Bx^\beta\right) - c,$$

$$\dot{H} = \eta\left(1-n\right)H$$

with the initial condition and the nonnegativity condition, $L=1,\ A,B>0,\ n,\alpha\in(0,1),\ \beta>1.$

↓

- Two extensions:

  Stock pollution

and recursive model

↓

- Endogenous growth model.

$$\sigma > 1 - \frac{\rho/\eta}{1+(\alpha/\beta)\phi}$$

Exogenous growth model

$$\max_{c(t)\geq 0, x(t)\geq 0} \int_0^\infty u(c(t),x(t))e^{-\rho t}dt$$

subject to $\dot{K}(t) = e^{gt}f(K(t),x(t)) - c(t),\ K(t) \geq 0\ K(0) = K > 0$ given.

- Assumption 1: Standard assumptions of monotonicity, concavity and differentiability.

F.O.C. $u_c - \lambda = 0;$

$$u_x + \lambda e^{gt} f_x = 0;$$

$$\dot{\lambda} = \rho\lambda - \lambda e^{gt} f_K.$$

$\Rightarrow$

$$g_\lambda = -\sigma^u_{cc} g_c + \sigma^u_{cx} g_x;$$

$$g_\lambda = \sigma^u_{xc} g_c - \sigma^u_{xx} g_x - \sigma^f_{xK} g_K + \sigma^f_{xx} g_x - g;$$

$$g - \sigma^f_{KK} g_K + \sigma^f_{Kx} g_x = 0,$$

where $\sigma^u_{cc} = \frac{-cu_{cc}}{u_c}; \sigma^u_{cx} = \frac{xu_{cx}}{u_c}; \sigma^u_{xc} = \frac{cu_{xc}}{u_x}; \sigma^u_{xx} = \frac{-xu_{xx}}{u_x};$

$$\sigma^f_{KK} = \frac{-Kf_{KK}}{f_K}; \sigma^f_{Kx} = \frac{xf_{Kx}}{f_K}; \sigma^f_{xK} = \frac{Kf_{xK}}{f_x}; \sigma^f_{xx} = \frac{-xf_{xx}}{f_x}.$$

- Assumption 2: All these elasticities are constant.
- F.O.C. implies: $\left(\sigma^u_{xx} + \sigma^u_{cx} - \sigma^f_{xx} - \sigma^f_{Kx}\right)g_x = \left(\sigma^u_{cc} + \sigma^u_{xc} - \sigma^f_{xK} - \sigma^f_{KK}\right)g_c.$

Results

$$\left(\sigma^u_{xx} + \sigma^u_{cx} - \sigma^f_{xx} - \sigma^f_{Kx}\right)g_x = \left(\sigma^u_{cc} + \sigma^u_{xc} - \sigma^f_{xK} - \sigma^f_{KK}\right)g_c.$$

Lemma 2.2 *Under Assumptions 1 and 2, (i) either of the following holds: (a)* $\sigma^i_{xj} = \sigma^i_{jx} = 0$ *or (b)* $\sigma^i_{jj} + \sigma^i_{xj} = \sigma^i_{xx} + \sigma^i_{jx} = 1$, *where* $i = u, f$ *and* $j = c$ (K) *if* $i = u$ (f). *(ii) Corresponding to each case, the utility and the production functions take the forms:*

$$u(c,x) = \ (a)\ \frac{c^{1-\sigma^u_{cc}} - 1}{1-\sigma^u_{cc}} + \gamma\frac{x^{1-\sigma^u_{xx}} - 1}{1-\sigma^u_{xx}}\ \text{or}\ (b)\ \frac{\left(cx^{\phi}\right)^{1-\sigma^u_{cc}}}{1-\sigma^u_{cc}}, \tag{2.14}$$

$$f(K,x) = \ (a)\ AK^{1-\sigma^f_{KK}} - Bx^{1-\sigma^f_{xx}}\ \text{or}\ (b)\ AK^{1-\sigma^f_{KK}}x^{1-\sigma^f_{xx}}, \tag{2.15}$$

respectively, where $\phi = (1-\sigma^u_{xx})/(1-\sigma^u_{cc})$. *(iii) The production function (2.15 b) is available only in the case of* $f_x > 0$. *If* $\sigma^u_{cc} \in (0,1)$, *then the utility function (2.14 b) is available only in the case of* $u_x > 0$.

Proposition 2.1 *Under Assumptions 1 and 2, if* $\sigma^u_{cc} < 1$ *and if an optimal sustainable development path exists, then the production function should take the form of (2.15 a) in Lemma 2.2.*

Two extensions

- Stock pollution model

$$\max_{c(t),p(t)} \int_0^\infty u(c(t),P(t))e^{-\rho t}dt$$

$$\text{subject to } \dot{K}(t) = e^{gt}f(K(t),x(t)) - c(t),$$

$$\dot{P}(t) = -\xi P(t) + \zeta x(t), \quad P(t) \geq 0$$

$$(\xi > 0, \zeta > (<)0 \text{ if } f_x > (<)0.)$$

$$\Rightarrow \boxed{(\sigma^u_{PP} + \sigma^u_{cP} - \sigma^f_{xx} - \sigma^f_{Kx})g_P = (\sigma^u_{cc} + \sigma^u_{Pc} - \sigma^f_{xK} - \sigma^f_{KK})g_c.}$$

- Recursive utility model

$$J(K^*_{t-1}) = W(u(c^*_t,x^*_t),J(K^*_t)) = \max_{c,x,K\geq 0} W(u(c,x),J(K))$$

$$\text{subject to } K = e^{gt}f(K^*_{t-1},x) - c \geq 0$$

$$\text{where } u(c,x) = \left(\frac{c^{\sigma^u_{cc}}-1}{1-\sigma^u_{cc}}\right) - \tilde{\gamma}\frac{x^\omega}{1+\omega} \; (\tilde{\gamma},\omega > 0), \; f(K,x) = \tilde{g}^t K^\alpha x^\beta,$$

$$\tilde{g} = e^g > 1, \; \alpha,\beta > 0, \; \alpha+\beta \leq 1.$$

$$\Rightarrow \boxed{x^*_t = \delta\theta^{\frac{1-\sigma^u_{cc}}{1+\omega}(t-1)} c_1^{*\frac{1-\sigma^u_{cc}}{1+\omega}}, \text{ wehre } \theta = \frac{K^*_t}{K^*_{t-1}}.}$$

→ The previous results do not change.

Endogenous growth model

$$\max_{c(t),x(t),n(t)} \int_0^\infty u(c(t),x(t))e^{-\rho t}dt \qquad (4.5)$$

subject to $\dot{K}(t) = F(K(t),H(t),x(t),n(t)) - c(t)$

$$\dot{H}(t) = \eta(1-n(t))H(t), \quad H(t) \geq 0,\ n(t) \in [0,1],$$

where $u(c,x) = \dfrac{(cx^\phi)^{1-\sigma_{cc}^u}}{1-\sigma_{cc}^u}, \quad 0 < \phi \leq \dfrac{\sigma_{cc}^u}{1-\sigma_{cc}^u}$, and

$$F(K,H,x,n) = (nH)^{1-\alpha}(AK^\alpha - Bx^\beta), \quad A,B > 0, \alpha \in (0,1), \beta > 1.$$

Proposition 4.1 *For the endogenous growth model (4.5), there exists an optimal sustainable development path if the elasticity of the marginal utility of consumption satisfies:*

$$\sigma_{cc}^u > 1 - \frac{\rho/\eta}{1+(\alpha/\beta)\phi}. \qquad (4.31)$$

- On an optimal sustainable development path, the following hold:

$$g_K = g_c = g_H = (\beta/\alpha)g_x \text{ and } g_n = 0. \qquad g_c = \frac{\eta - \rho}{\sigma_{cc}^u - (\alpha/\beta)\phi(1-\sigma_{cc}^u)}.$$

→ The higher the growth potential in the production technology (e.g. η) is, the stricter the preference constraint shown in (4.31) is.

Conclusion

- The direction of technological progress in order for sustainable development to be economically optimal (or in order to avoid a conflict between two value concepts of environmental sustainability and economic optimality) contains the following:

1. The growth engine should be clean.
2. We should avoid relying on nonrenewable resources.
3. Wastes that we emit and effluent should be easily decomposable in the natural process.
4. There is a preference constraint: $\sigma > 1 - \frac{\rho / \eta}{1 + (\alpha / \beta)\phi}$

   – If the elasticity of marginal utility of consumption is less than one, then the marginal productivity of the growth engine sector should be not too high and the elasticity of transformation to the production factor and the environmental service (or the pollution abatement service), after an appropriate monotone transformation, should be greater than one.

References

1. Aghion, Philippe and Peter Howitt (1998) *Endogenous Growth Theory*. MIT Press.
2. Akao, Ken-Ichi (2017) “When society moves away from sustainable development,” *Waseda Review of Socio-Science* 22 (in press) (Japanese with English summary)
3. Akao, Ken-Ichi (2014) “Preference cons、traint for sustainable development,” *Environmental Economics and Policy Studies* 16: 343–357.
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