東京大学教養学部　　２００８年度冬学期

地球温暖化と経済学

第１７回　地球温暖化（その６　費用便益分析とStern Review）

山口　光恒

１、地球温暖化対策の究極目標

気候変動枠組み条約第２条

「……気候系　に対して危険な人為的干渉（Dangerous Anthropogenic Interference, DAI）を及ぼすこととならない水準において大気中の温室効果ガスの濃度を安定化させることを究極的な目的とする」

「そのような水準は、生態系が気候変動に 自然に適応し、食糧の生産が脅かされず、かつ、経済開発が持続可能な態様で進行することができるような期間内に達成されるべきである」

危険でない濃度に関する国際的合意なし

究極目標については山口光恒「合意のない気候変動政策の目標と長期戦略」国際問題2006年6月参照

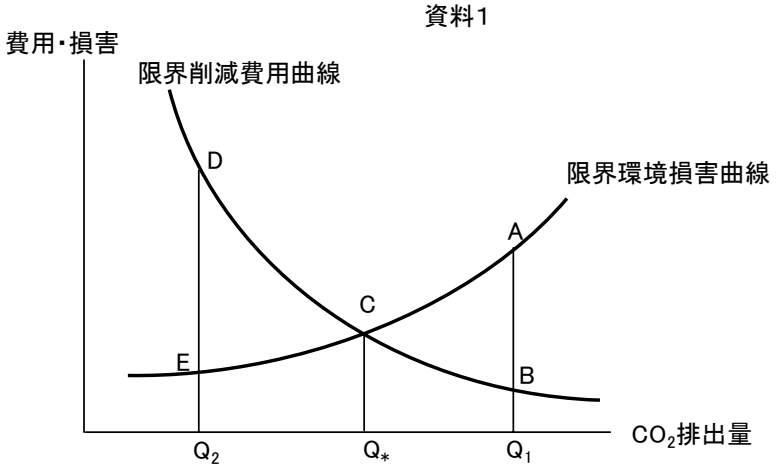
２、意志決定のツールとしての費用便益分析

http://premium.nikkeibp.co.jp/em/column/yamaguchi/21/index.shtml

http://premium.nikkeibp.co.jp/em/column/yamaguchi/22/index.shtml参照

費用便益分析と費用効果分析の相違

資料1



３、温暖化問題への応用１　W. D. Nordhaus 「地球温暖化の経済学」1994年

費用便益分析の代表的文献

DICE Model (Dynamic Integrated model of Climate and the Economy)

目的関数（人々の生活水準の向上）、経済関係式、地球物理関係式からなる

目的関数　C：一人あたり効用、L：人口、ρ：時間選好割引率

$$\max_{\{c(t)\}} \sum_t U[c(t),\ L(t)](1+\rho)^{-t}$$

基本的考え方：ラムゼー（最適成長）モデル

無限の時間軸の中で現在消費をするかあるいはその一部を投資（貯蓄）することで将来の消費に回すかという選択肢を設定した上で、現在から将来にわたる全ての時点の消費効用の現在価値を最大化するように全てが決まるモデル。Nordhausでは投資の代わりにGHG削減投資を用い、これによる将来の消費の悪化（環境損害）を防ぐ仕組み

DICEモデルの構成式

(2.1) $\max_{\{c(t)\}} \sum_t U[c(t),\ L(t)](1+\rho)^{-t}$　目的関数

(2.2) $U[c(t),\ L(t)] = L(t)\{[c(t)]^{1-\alpha} - 1\}/(1-\alpha)$

(2.3) $Q(t) = \Omega(t)A(t)K(t)^{\gamma}L(t)^{1-\gamma}$　生産量

(2.4) $Q(t) = C(t) + I(t)$

(2.5) $c(t) = C(t)/L(t)$

(2.6) $K(t) = (1-\delta_K)K(t-1) + I(t-1)$

(2.7) $E(t) = [1-\mu(t)]\sigma(t)Q(t)$　排出量

(2.8) $M(t) - 590 = \beta E(t-1) + (1-\delta_M)[M(t-1) - 590]$　濃度

(2.9) $F(t) = 4.1\{\log[M(t)/590]/\log(2)\} + O(t)$　放射強制力

(2.10) $T(t) = T(t-1) + (1/R_1)\{F(t) - \lambda T(t-1) - (R_2/\tau_{12})[T(t-1) - T^*(t-1)]\}$

$T^*(t) = T^*(t-1) + (1/R_2)\{(R_2/\tau_{12})[T(t-1) - T^*(t-1)]\}$　気温上昇

(2.11) $D(t) = Q(t)\theta_1 T(t)^{\theta_2}$　損害

(2.12) $TC(t) = Q(t)b_1\mu(t)^{b_2}$　削減コスト

(2.13) $\Omega(t) = (1 - b_1\mu(t)^{b_2})/[1 + \theta_1 T(t)^{\theta_2}]$

鍵となる式

・　気候感度

Schneider & Thompson modelなど３つの気候モデルから濃度倍増時の気温上昇（T2×CO2）は約３℃と推定(λ=1.41)

・　経済的損害

アメリカでの農業、エネルギー、沿岸活動、その他部門への損害予想を基に濃度倍増時の損害額はGDPの1.33%と想定、　$d(t) = (0.0133/9)\,T(t)^2 Q(t)$

・　GHG削減コスト

削減率の関数　50%削減費用はGDPの1%

・　BAU排出量の予想

エネルギー効率改善（1929年以来年率1%）

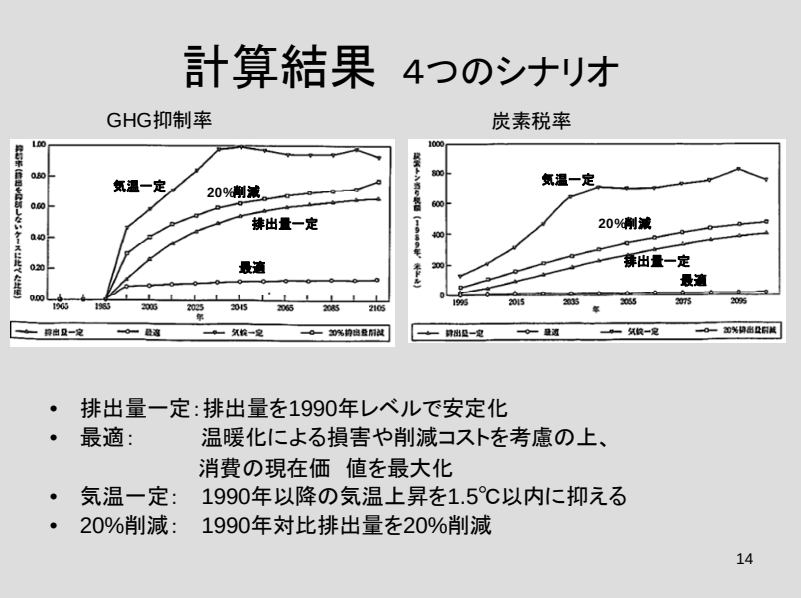
・ 割引率３％

温暖化問題での割引率の重要性

温暖化問題は超長期、従ってこの全期間につきどのように消費と排出削減投資を割り振っていけば、その時々の消費効用の現在価値の総計を最大化することが出来るかの観点から「最適」な削減水準を割り出す。

割引率（純時間選好割引率）という概念が必要、DICEは３％、但しClineのように０％を主張する学者もいる。

例、現在のCO2排出量を追加的に１単位削減する費用が１万円、これにより100年後に10万円の追加的損害を防ぐことが可能。割引率が３％なら100年後の10万円の便益の割引現在価値はたったの5,000円、１％なら約37,000円、0.1%なら約90,000円、従って割引率３％なら費用＞便益で対策見合わせとなるが、１％（及び0.1%）なら便益が大幅に費用を上回り対策実施。



モデルの制約

・　損害関数（特に途上国、生態系などはデータ不足）

・　不可逆且つ破壊的な気候変動の可能性

熱塩循環停止、グリーンランド・西部南極大陸氷床崩壊

$d=0.027(T/2.5)^{12}$　とすると、3.5℃上昇で60%GDPロス

５℃上昇だと111%　（大恐慌、戦争、共産主義の損害は？）

・　技術開発、冷却効果（エアロゾル）非考慮

・　割引率　３％の妥当性　現実への適合性と道徳

・　各種不確実性

４、温暖化問題への応用２　RICEモデル　Nordhaus/Boyer 2000

Regional Dynamic Integrated model of Climate and the Economy (RICE), Nordhaus/Boyer 2000

DICEモデルとの主たる相違点

Table 1-1. Reference Case Output Across Model Generations
for the Year 2100

	DICE-94	RICE-99
Industrial emissions (GtC/year)* エネルギー起源CO_2	24.9	13.6 成長率低下・脱炭素化
Output (trillions of 1990 U. S. $)	111.55	101.9
Population (billions)	9.8	10.4
Output per person (thousands of 1990 U. S. $)	11.4	9.5
Carbon intensity (tons carbon per $1000 of GDP, 1990 U.S. $)	0.22	0.11
Temperature (deg C above 1900)	3.39	2.53

気温上昇の低下は炭素集約度の低下（化石燃料枯渇）とエアロゾルの冷却効果を考慮したもの

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DICEとの相違（環境損害面）

- 地域ごとの計算（DICEはアメリカからの推測）
- 非市場損害及び大規模損害により重点
  - 農業以外では市場価値の損害は限られている
  - アンケート結果を参考に
- WTP（Willingness To Pay）により非市場価値損害を計算
  - 地域ごとの非市場損害額はこれ以外に得られそうにない
- 時間割引率
  - ３％、ただし低減（2100年に2.3%、2200年に1.8%）

地域別影響

地域別項目別影響度合い（GDP比）

Impact of 2.5 degree warming on different sectors
[Positive numbers are damages; negative numbers are benefits;
impacts measured as percent of market GDPs]

	TOTAL [2.5 degree]	Agriculture	Other vul-nerable market	Coastal	Health	Non-market time use	Settlements	Catastrophic impact [2.5 degree]	Catastrophic impact [6 degree]
United States	0.45%	0.06%	0.00%	0.11%	0.02%	-0.28%	0.10%	0.44%	2.97%
China	0.22%	-0.37%	0.13%	0.07%	0.09%	-0.26%	0.05%	0.52%	3.51%
Japan	0.50%	-0.46%	0.00%	0.56%	0.02%	-0.31%	0.25%	0.45%	3.04%
OECD Europe	2.83%	0.49%	0.00%	0.60%	0.02%	-0.43%	0.25%	1.91%	13.00%
Russia	-0.65%	-0.69%	-0.37%	0.09%	0.02%	-0.75%	0.05%	0.99%	6.74%
India	4.93%	1.08%	0.40%	0.09%	0.69%	0.30%	0.10%	2.27%	15.41%
Other High Income	-0.39%	-0.95%	-0.31%	0.16%	0.02%	-0.35%	0.10%	0.94%	6.39%
High Income OPEC	1.95%	0.00%	0.91%	0.06%	0.23%	0.24%	0.05%	0.46%	3.14%
Eastern Europe	0.71%	0.46%	0.00%	0.01%	0.02%	-0.36%	0.10%	0.47%	3.23%
Middle Income	2.44%	1.13%	0.41%	0.04%	0.32%	-0.04%	0.10%	0.47%	3.21%
Lower-middle Income	1.81%	0.04%	0.29%	0.09%	0.32%	-0.04%	0.10%	1.01%	6.86%
Africa	3.91%	0.05%	0.09%	0.02%	3.00%	0.25%	0.10%	0.39%	2.68%
Low Income	2.64%	0.04%	0.46%	0.09%	0.66%	0.20%	0.10%	1.09%	7.44%
Global [a]									
Output-weighted	1.50%	0.13%	0.05%	0.32%	0.10%	-0.29%	0.17%	1.02%	6.94%
Population-weighted	1.88%	0.17%	0.23%	0.12%	0.56%	-0.03%	0.10%	1.05%	7.12%

[a] Output-weighted global average is weighted by projected output in 2100 from RICE base case. Population-weighted global average is weighted by population in 1995.

大規模損害発生確率は1.2%（2.5℃）、6.8%（6℃）、インドはモンスーン・健康、欧州は寒冷化

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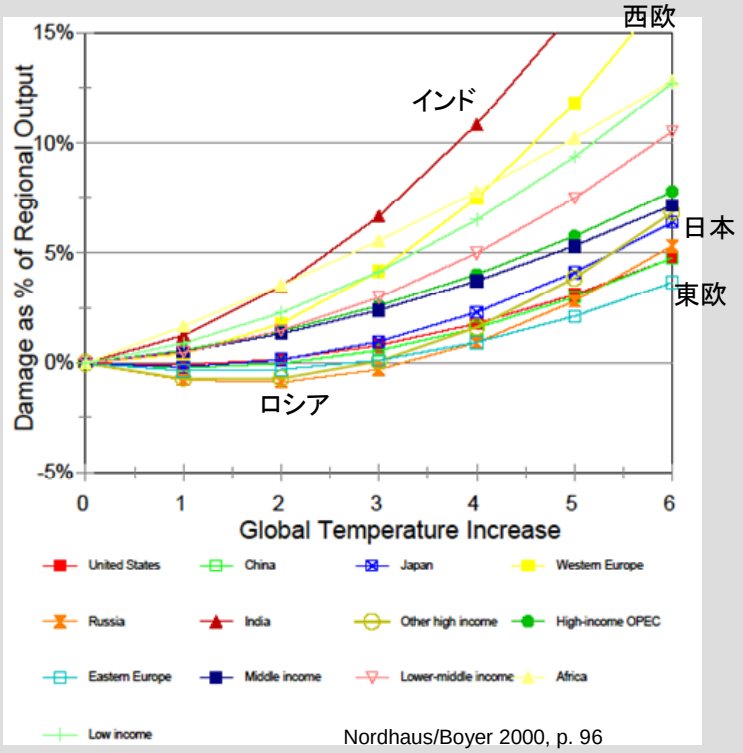
Nordhaus/Boyer 2000, p. 91

地域別気温別損害率

地域別・気温別損害率



Nordhaus/Boyer 2000, p. 96

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Climate change is not a global crisis – that is the problem

GIDEON RACHMAN

Here is another inconvenient truth. Global warming is good news for parts of the world. This is truly awkward. A "planetary emergency" that affected everyone equally would be much easier to tackle. However, climate change that hurts some places but helps others opens the way for dangerous political conflicts.

The latest report from the Intergovernmental Panel on Climate Change, issued this month, confirms that global warming puts large parts of the world at risk from the biblical woes of famine, flood and disease. The places most at risk are those that are already poor - sub-Saharan Africa and parts of Asia.

But in northern Europe, agriculture will become more productive and the climate will improve. From a parochial British point of view, the latest IPCC report sounds like good news. It has taken off the table the single most threatening scenario – the paradoxical threat that "global warming" was going to make Britain much colder by shutting down the Gulf Stream, the ocean current that gives the UK a much warmer climate than its latitude implies. The latest thinking from IPCC scientists is that this is very unlikely to happen during the next century.

Global warming offers a positive bonanza for Russia. The legendary Russian winter gets more tolerable. As the permafrost retreats in Siberia new mineral resources are revealed and huge new areas become available for settlement and cultivation.

In an irony that will infuriate environmentalists, oil companies are also likely to benefit from global warming. The US Geological Survey estimates that 25 per cent of the world's known oil and gas reserves are in the Arctic Circle. As the ice melts, they become easier to exploit.

As a new paper in Environment and Urbanization, an academic journal, makes clear, three-quarters of the 634m people deemed to be most at risk from rising sea levels connected to global warming live in Asia.

Coastal cities in the developed world, such as New York and Los Angeles, may be at risk. But wealthy countries are best placed to adapt to the problem. Certainly the Dutch, who have long experience of keeping the sea at bay, are not panicking. They are simply planning to spend billions more on flood defences.

Of course, even countries that may benefit directly from global warming could suffer indirectly – as other parts of the world descend into chaos. Britain is not an island (well, technically, Britain is an island - but you know what I mean). Dealing with refugees and desperate immigrants will only get harder as life becomes tougher in Africa and the Asian subcontinent.

In fact, it is now dawning on the world's politicians that global warming could transform international relations – introducing a range of new issues and conflicts.

The most obvious problems are struggles over refugees and resources. Some argue that the Darfur conflict is partially caused by global warming, as settled farmers and nomadic herders fight over failing land. This sort of conflict could proliferate in the future.

Last month, a conference arranged by the US Army War College heard that: "Within a century, extreme drought will affect 30 per cent of the world, up from 3 per cent today."

Water shortages are a particular threat. They have long been an underlying source of conflict in the Middle East. But in India and China run short of water, their neighbours are worried that struggles may arise over the diversion of rivers and the building of dams.

The idea that the Chinese are oblivious to the threat of global warming is untrue, as I discovered on a recent trip to Beijing. Officials were openly concerned that the Yangtze and Yellow rivers were at their lowest levels for years. Much of the problem is to do with irrigation and industrial use. But the Chinese believe that global warming is also contributing to water shortages because of its effect on rainfall and the glaciers that feed into Chinese rivers.

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The FT's international affairs columnist writes regularly throughout the week on the political, economic and social trends shaping Europe; US foreign policy; and the flow of money, people, jobs, and ideas around the world. Read his authoritative and lively commentary at: www.ft.com/rachmanblog

The government in Beijing faces a dilemma. Terrified of social unrest, it is reluctant to do anything that might slow economic growth – such as stopping the building of coal-fired power stations. Yet, water shortages are already causing social unrest in the countryside and the water table is falling fast in Beijing. One western analyst based in China speculates that the next political upheaval there could come "when people in Beijing turn on their taps in 2009 and find there is no water coming out".

Global warming will not just provoke conflicts over scarcity. It may also cause struggles over the emergence of new resources – in particular, the oil and gas that lies underneath the Arctic. Outstanding territorial disputes between Canada and the US, between Russia and Norway, and between Denmark and Russia have taken on a new urgency in recent years, as these countries develop a new interest in hitherto unpromising stretches of ice.

Struggles over territory and borders are, at least, familiar ground for politicians and diplomats. But the new diplomatic world will increasingly be dominated by debates over the environment and international regimes for combating climate change.

The argument over global warming could quickly turn into the latest and bitterest struggle between the traditional industrialised countries and the developing world.

Any successor to the Bush administration is likely to be much more concerned about global action on climate change. And in 2009, just as a new administration settles down in Washington, China is likely to surpass the US as the world's leading source of carbon dioxide emissions.

Although rich northern countries are best placed to cope with global warming, domestic public opinion means they are also likely to be the countries pushing hardest for new international regulations to tackle carbon dioxide emissions. In the US and Europe, climate change is becoming a new issue to berate China about – merging with protectionist concerns about exports from Chinese companies that practise "environmental dumping".

But the Chinese will not lack allies in any struggle over who bears the costs of global warming. The Russians – with an economy based on fossil fuels, and a society that benefits from a warmer climate – may well stand with them. So could India and much of the developing world. Global warming presents a formidable environmental and scientific challenge. The political consequences may prove just as vexing.

gideon.rachman@ft.com

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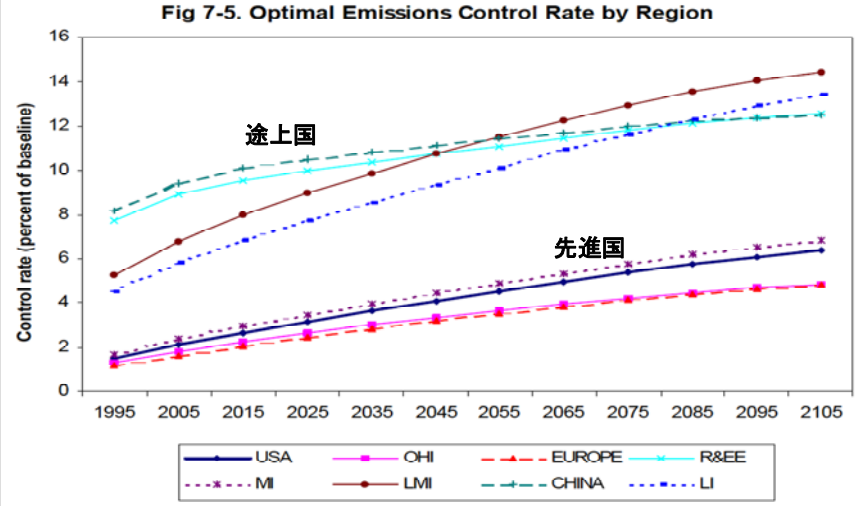
Financial Times, April 17, 2007

最適政策の下での地域別削減率と共通だが差異のある責任

最適政策での地域別削減割合



Nordhaus/Boyer 2000

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政策別費用便益分析

政策別費用便益比率

Abatement Costs and Environmental Benefits of Different Policies
[Billions of 1990 U.S. $]

	Abatement Cost	*Environ-mental Benefit*	*Net Economic Impact*	*Benefit/cost Ratio*
Base	0	0	0	na
Optimal				
Policy in 1995	-98	296	198	3.02
Policy in 2005	-92	283	192	3.08
Limit Emissions				
Global stabilization	-4,533	1,512	-3,021	0.33
Kyoto Protocol	-217	96	-120	0.44
Limit concentrations				
Double CO2	-1,365	681	-684	0.50
Limit temperature				
2.5 degree increase	-3,553	1,139	-2,414	0.32
1.5 degree increase	-28,939	2,383	-26,556	0.08
Geoengineering	0	3,901	3,901	na

最適政策の下での気温上昇 2.34℃(2100年)、3.65℃(2200年)

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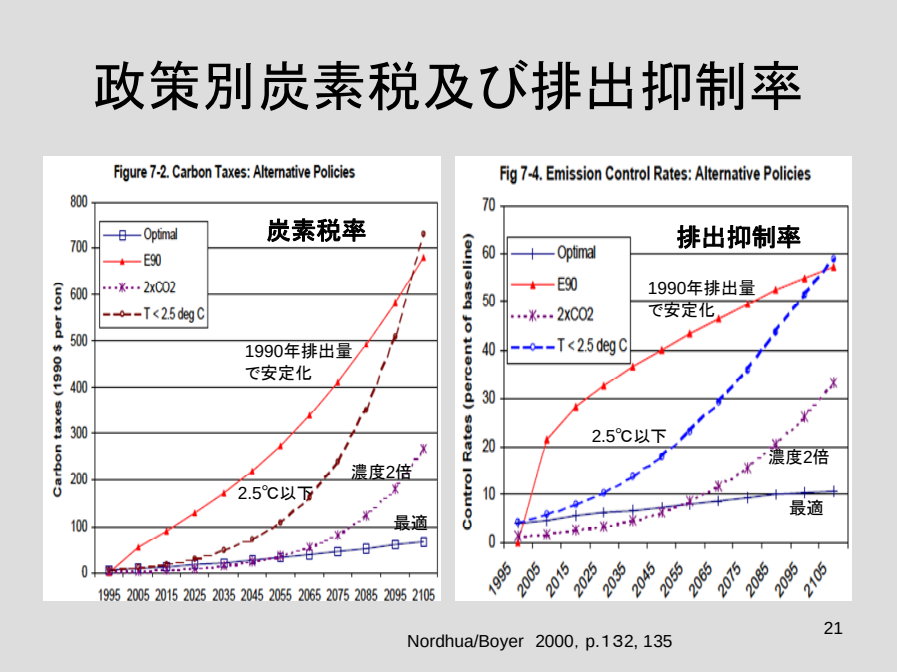
Bordhaus/Boyer 2000, p. 130

政策による相違



５、温暖化への応用３　**DICE2007モデル**　http://nordhaus.econ.yale.edu/dice_mss_072407_all.pdf

後述のStern Review批判

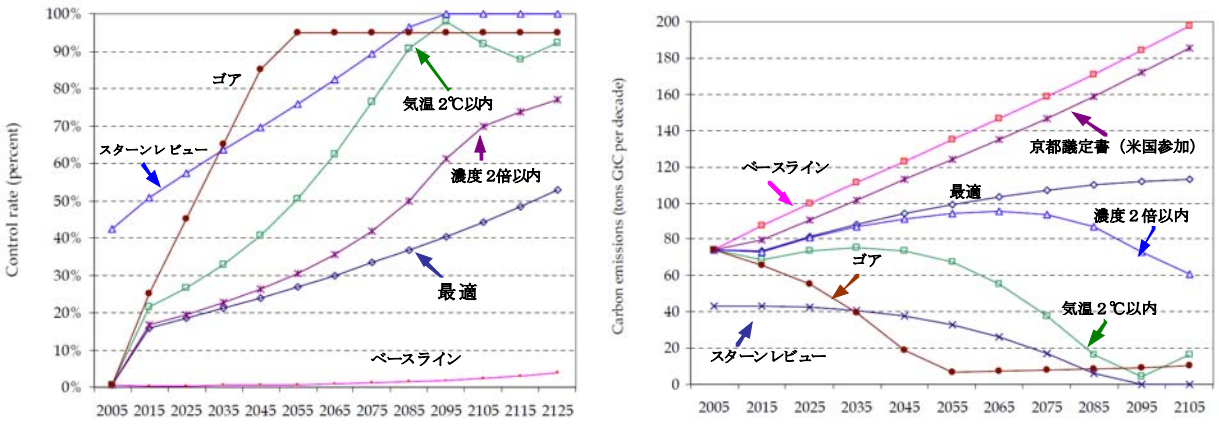
割引率を1.5%に、大規模損害の見直しによる損害の上方修正など

DICE 2007 モデルによる政策評価（費用便益分析）単位１兆ドル

政策	削減費用	環境便益	便益／費用(%)
BAU	0	0	
最適政策	−2.16	5.23	2.4
工業化以前対比濃度２倍での安定化	−3.90	6.57	1.7
1990 年対比気温上昇幅 2℃以内	−11.25	9.45	0.8
スターンレビュー	−27.70	13.53	0.5

DICE2007 p.218 の表Ⅴ-3 から抜粋

政策別結果比較



６、**Stern Review**　2006年10月刊行

内容

Stern Review（1）Oct. 2006

- Act now!　対策の便益＞対策のコスト
- 450-550ppmCO2e以内での濃度安定化を目指す
  現状は430ppmCO2e、BAUはA2シナリオ（次葉）
  目標を先に決めているので最適点を目指してはいない
- 550ppmCO2e安定化の場合
  2050年に現在に比べ25%削減、GDP原単位は1/4（経済は3-4倍）
- 損害額（BAUの場合）　2200年以降も含む

  市場損害5.0%（大規模災害考慮）、非市場損害(人命等)考慮で14.4%、南北間のWelfare weight考慮で約20%、（世代間）割引率0.1%を使用
- 削減コスト

  500-550ppmCO2e安定化の場合2050年までは GDPの１%、
  450ppmCO2eは非現実的

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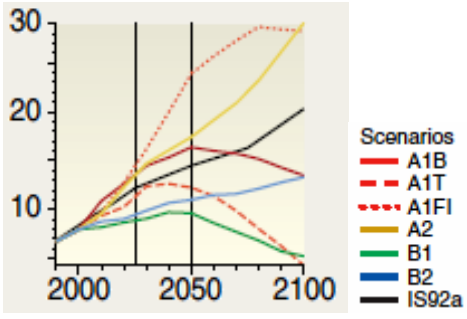
批判

１）疑似費用便益分析

２）損害と削減コストは別のシナリオ



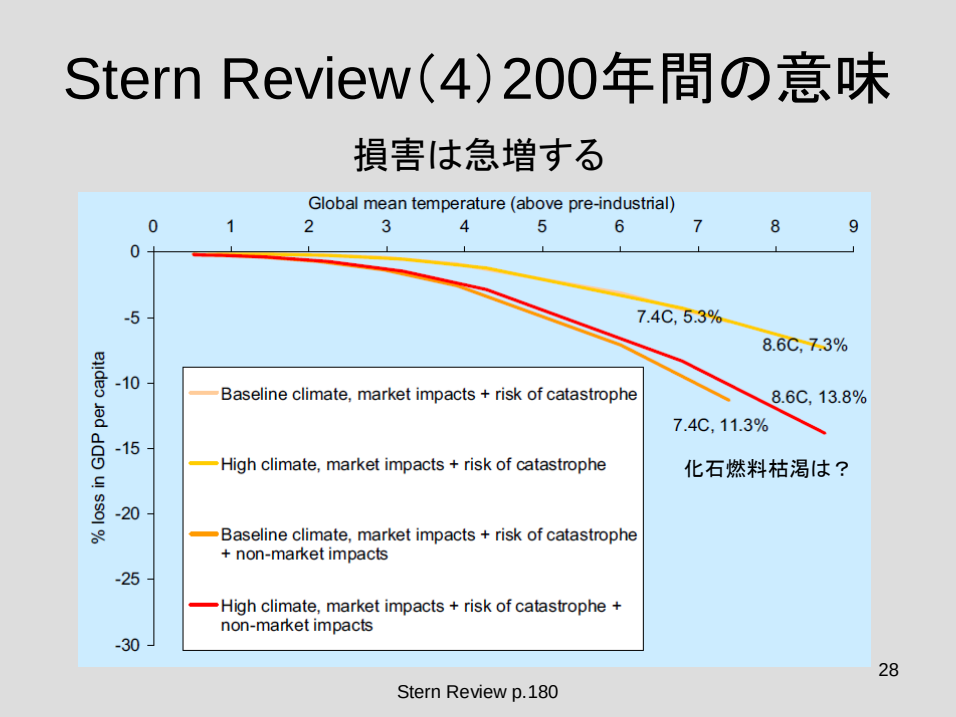
３）過大な損害見積もり

	2060	2100	2200	2200(割引後)[1]	2200(割引後)[2]
市場損害のみ （一般損害） （大規模損害）	0.2%	0.9%	5.3% （ 2.2% ） （ 3.1% ）	5.0% （ 2.1% ） （ 2.9% ）	1.4%
非市場損害込み （High Climateシナリオ）		2.9%	13.8%	14.4%	4.2%
途上国の重み付け考慮				20% （上記の約25%UP）	
気温上昇			7.4～8.6℃		

Stern Reviewの内訳　1）時間選好割引率　0.1%　2）同　1.5%

４）割引率　0.1%　（1.5%にしただけで損害は３割になる）

５）損害を超長期でとる



７、費用便益分析の限界　C. Azar

環境損害の金銭評価が極めて困難

不連続且つ大規模な損害のモデルへの組み込みが難しい

衡平性　カルドア・ヒックスの仮説補償原理

割引率についての合意がない

８、費用便益分析は不要か

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