

FOIA MARKER

This is not a textual record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

Collection/Record Group: Clinton Presidential Records
Subgroup/Office of Origin: Council of Economic Advisers
Series/Staff Member: Joseph Stiglitz
Subseries:

OA/ID Number: 9569
FolderID:

Folder Title:
[Intergovernmental Panel on Climate Change Lead Authors Meeting] [1] [loose]

Stack:	Row:	Section:	Shelf:	Position:
S	20	5	9	3

**INTERGOVERNMENTAL
PANEL ON
CLIMATE CHANGE**

IPCC Lead Authors Meeting,
Geneva, Switzerland

Sept. 8-11, 1994

Joe Stiglitz
CEA Member

IPCC LEAD AUTHORS MEETING
Geneva, Switzerland
September 8-10, 1994

More Minor Comments

1. Chapter 2 on "Benefit Cost Analysis" is well balanced and a technically strong discussion. Is it necessary to devote so much attention to multicriteria analysis, almost 10% of text in the chapter? The summary is well crafted and emphasizes the importance of tradeoffs between equity and economic efficiency; no mention of MCA is made in the summary.
2. Chapter 3 has a thorough treatment of damage estimates, but estimates provided may be misleading because the degree of uncertainty associated with climate change damages is not conveyed. An evaluation of categories of damages that are most uncertain is needed. The techniques used to generate these estimates should be discussed more fully. Perceptions of damages from climate change drive the international debate and as such should be buttressed with as much information as possible about different factors influencing range of estimates. (Tables 3.4, 3.5, 3.6, and 3.8 should show confidence bounds).
3. The caution that should be observed in transplanting OECD instruments to LDCs should be more fully assessed in the chapter on policy instruments.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

OUTLINE

COMMENTS ON "SCOPE"

COMMENTS ON OTHER CHAPTERS, EXCLUDING "SCOPE"

CHAPTERS

CHAPTER 1: SCOPE

CHAPTER 2: BENEFIT-COST

CHAPTER 3: SOCIAL COSTS

CHAPTER 4: MITIGATION COST

CHAPTER 5: EQUITY AND

CHAPTER 6: DECISION-MAKING

CHAPTER 7: RESPONSE OPTIONS

CHAPTER 8: POLICY INSTR.

CHAPTER 9: EMISSION

Schemes

① Work unity - social welfare fr.

② Borge's model -
dividing surplus

→ Separating of utility fr.
Rawlsian / Cooperative

[Turn down vs bottom up
Other Center]

INTERGOVERNMENTAL PANEL ON
CLIMATE CHANGE

1) Who is the beneficiary for
✓ International Public Goods

✓ External → explanation
page may clear to show
OUTLINE/CONTENT TAB 1

COMMENTS

TAB 2

CHAPTERS

TAB 3 - 10

↓
Hard use — Roads
Gap Railroads

→ Endogenous preferences
Equity
Intended shadow prices

Property rights issues
Market failures

History →

Reserve gap

|| Economic Perspectives
Framework

Timing Trade Focus Lead and the || craft letter
| review

tab
tab
outlines
comments on
scope

tab
comments on
all chapters
excluding
"SCOPE"
chapter 1 - scope

tab
chapter -



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

145 King Street West, Suite 1002, Toronto, Ontario M5H 3X6 CANADA

Tel: (416) 369-0900 Fax: (416) 369-0922

MEMORANDUM

TO: Working Group III Lead Authors and Bureau Members

FROM: Erik Haites *Erik Haites*

RE: Draft Report

DATE: August 5, 1994

*JOE: Letter
sent with
zero-order
chapters!*

Enclosed is a draft of the Working Group III Second Assessment Report that contains the most up to date chapter available as of August 15 for review and discussion at the Lead Authors Meeting in Geneva, September 8 to 10.

The report does not include a draft of the chapter on Evaluation of the IPCC IS 92 Emissions Scenarios. As you know, that chapter will be published as part of the IPCC's 1994 Special Report. That chapter has undergone peer review and is in the process of being revised. A revised copy will be distributed at the Lead Authors Meeting. That chapter will also be included in the Second Assessment Report.

A draft Summary for Policy Makers is being prepared based on these draft chapters. The draft Summary for Policy Makers will be distributed in Geneva.

Please read the report before the Lead Authors Meeting and be prepared to discuss:

- the overall report structure
- areas of overlap and how they should be addressed
- inconsistencies and gaps and how they should be resolved

This is your opportunity to discuss and provide input to the overall report.

Clinton Presidential Records Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a tabbed divider. Given our digitization capabilities, we are sometimes unable to adequately scan such dividers. The title from the original document is indicated below.

Outlines

Divider Title: _____



OUTLINE AS of 10/9/93



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

145 King Street West, Suite 1002, Toronto, Ontario M5H 3X6 CANADA
Tel: (416) 369-0900 Fax: (416) 369-0922

*Chris
Werner
Suzanne
Kane*

MEMORANDUM

TO: WG III Lead Authors
FROM: Erik Haites *Erik Haites*
RE: Proposed Reorganization of the Second Assessment Report
DATE: September 20, 1993

Attached is a revised proposal for the organization of the WG III Second Assessment Report.

The main objective of the reorganization is to move away from the benefit-cost structure implicit in the current structure. A benefit-cost analysis is designed for a "go/no go" decision on a well-defined project. Since policies can be adjusted frequently over the next few decades, a more useful framework is one that asks what measures to adopt and how aggressively to pursue them. These decisions can be adjusted over time as better data become available.

The new structure is designed to focus more on the policy questions of:

- how much to spend on climate change
- what adaptation and mitigation measures are most cost-effective in generic terms
- what policy measures are most effective under different conditions

Thus the new structure provides a more useful assessment of the policy implications of our knowledge of the economic and social aspects of climate change.

Please let me have your comments on the proposed structure by September 30.

P938005\memo.72

Post-It™ brand fax transmittal memo 7671		# of pages
To: <i>Joseph Stiglitz</i>	From: <i>Erik Haites</i>	
Co.:	Co.:	
Dept.:	Phone #	
Fax #		

**PROPOSED WRITING ASSIGNMENTS FOR
THE WORKING GROUP III
SECOND ASSESSMENT REPORT
(Draft September 9, 1993)**

PREFACE Working Group III Bureau

EXECUTIVE SUMMARY Working Group III Bureau for review by all lead authors

SUMMARY FOR POLICY MAKERS Working Group III Bureau for review by all lead authors

PART I: SCOPE OF THE ASSESSMENT = motivation, why structure of assessment

Writing Team 1: SCOPE OF THE ASSESSMENT

C

Jose Goldemberg, Brazil

Joe Stiglitz, U.S.A.

Akihiro Amano, Japan - energy

Xie Shaoxiong, China - developing country author (p. 3)

Ruby Saha, Mauritius - sustain dev. with exp. d. - 2001

* Udo Simonis, Germany

10 pages

**PART II: THE SOCIO-ECONOMICS OF IMPACTS, ADAPTATION, AND
MITIGATION OF CLIMATE CHANGE**

**Writing Team 3: APPLICABILITY OF BENEFIT-COST ANALYSIS TO
CLIMATE CHANGE**

C

Mohan Munasinghe, World Bank

Michael Hoel, Norway

Sung-Woong Hong, Korea

Carlos Hurtado, Mexico

* Carl-Christian von Weizsacker, Germany

Writing Team 5: SOCIAL COSTS OF CLIMATE CHANGE

C

David Pearce, U.K.

William Cline, U.S.A.

R.K. Pachauri, India

Pier Vellinga, Netherlands

WG II

WG II

* = Participation still to be confirmed
C = Proposed Convening Lead Author

JEAN-CHARLES HOURCADE, FRANCE
RICHARD RICHEL, U.S.A.
DALE JORGENSEN, U.S.A.
DOMENICO SINISCALCO, ITALY
SERGEY PEGOV, RUSSIA
JIN-GYU OH, KOREA
JOHN ROBINSON, CANADA
THOMAS JOHANSSON, SWEDEN
PILO NASTARI, BRAZIL
PETER STURM, OECD
OGUNLADÉ DAVIDSON, SIERRA LEONE
WILLIAM NORDHAUS, U.S.A.

Writing Team 4: EQUITY AND SOCIAL CONSIDERATIONS
C Harold Jacobson, U.S.A.

Harold Jacobson, U.S.A.
Karl Goran-Maler, Sweden
Michael Grubb, U.K.
Tariq Banuri, Pakistan

Writing Team 2: DECISION-MAKING FRAMEWORK TO ADDRESS CLIMATE CHANGE

Jyoti Parikh, India **WG II**
Kenneth Arrow, U.S.A.
Gonzague Pillet, Switzerland
Carlos Suarez, Argentina

Writing Team 9: **GENERIC ASSESSMENT OF RESPONSE OPTIONS**
 1. Introduction
 2. Objectives
 3. Methodology
 4. Results
 5. Conclusions
 6. References
 7. Appendix A
 8. Appendix B
 9. Appendix C
 10. Appendix D
 11. Appendix E
 12. Appendix F
 13. Appendix G
 14. Appendix H
 15. Appendix I
 16. Appendix J
 17. Appendix K
 18. Appendix L
 19. Appendix M
 20. Appendix N
 21. Appendix O
 22. Appendix P
 23. Appendix Q
 24. Appendix R
 25. Appendix S
 26. Appendix T
 27. Appendix U
 28. Appendix V
 29. Appendix W
 30. Appendix X
 31. Appendix Y
 32. Appendix Z
 33. Appendix AA
 34. Appendix AB
 35. Appendix AC
 36. Appendix AD
 37. Appendix AE
 38. Appendix AF
 39. Appendix AG
 40. Appendix AH
 41. Appendix AI
 42. Appendix AJ
 43. Appendix AK
 44. Appendix AL
 45. Appendix AM
 46. Appendix AN
 47. Appendix AO
 48. Appendix AP
 49. Appendix AQ
 50. Appendix AR
 51. Appendix AS
 52. Appendix AT
 53. Appendix AU
 54. Appendix AV
 55. Appendix AW
 56. Appendix AX
 57. Appendix AY
 58. Appendix AZ
 59. Appendix BA
 60. Appendix BB
 61. Appendix BC
 62. Appendix BD
 63. Appendix BE
 64. Appendix BF
 65. Appendix BG
 66. Appendix BH
 67. Appendix BI
 68. Appendix BJ
 69. Appendix BK
 70. Appendix BL
 71. Appendix BM
 72. Appendix BN
 73. Appendix BO
 74. Appendix BP
 75. Appendix BQ
 76. Appendix BR
 77. Appendix BS
 78. Appendix BT
 79. Appendix BU
 80. Appendix BV
 81. Appendix BW
 82. Appendix BX
 83. Appendix BY
 84. Appendix BZ
 85. Appendix CA
 86. Appendix CB
 87. Appendix CC
 88. Appendix CD
 89. Appendix CE
 90. Appendix CF
 91. Appendix CG
 92. Appendix CH
 93. Appendix CI
 94. Appendix CJ
 95. Appendix CK
 96. Appendix CL
 97. Appendix CM
 98. Appendix CN
 99. Appendix CO
 100. Appendix CP
 101. Appendix CQ
 102. Appendix CR
 103. Appendix CS
 104. Appendix CT
 105. Appendix CU
 106. Appendix CV
 107. Appendix CW
 108. Appendix CX
 109. Appendix CY
 110. Appendix CZ
 111. Appendix DA
 112. Appendix DB
 113. Appendix DC
 114. Appendix DD
 115. Appendix DE
 116. Appendix DF
 117. Appendix DG
 118. Appendix DH
 119. Appendix DI
 120. Appendix DJ
 121. Appendix DK
 122. Appendix DL
 123. Appendix DM
 124. Appendix DN
 125. Appendix DO
 126. Appendix DP
 127. Appendix DQ
 128. Appendix DR
 129. Appendix DS
 130. Appendix DT
 131. Appendix DU
 132. Appendix DV
 133. Appendix DW
 134. Appendix DX
 135. Appendix DY
 136. Appendix DZ
 137. Appendix EA
 138. Appendix EB
 139. Appendix EC
 140. Appendix ED
 141. Appendix EE
 142. Appendix EF
 143. Appendix EG
 144. Appendix EH
 145. Appendix EI
 146. Appendix EJ
 147. Appendix EK
 148. Appendix EL
 149. Appendix EM
 150. Appendix EN
 151. Appendix EO
 152. Appendix EP
 153. Appendix EQ
 154. Appendix ER
 155. Appendix ES
 156. Appendix ET
 157. Appendix EU
 158. Appendix EV
 159. Appendix EW
 160. Appendix EX
 161. Appendix EY
 162. Appendix EZ
 163. Appendix FA
 164. Appendix FB
 165. Appendix FC
 166. Appendix FD
 167. Appendix FE
 168. Appendix FF
 169. Appendix FG
 170. Appendix FH
 171. Appendix FI
 172. Appendix FJ
 173. Appendix FK
 174. Appendix FL
 175. Appendix FM
 176. Appendix FN
 177. Appendix FO
 178. Appendix FP
 179. Appendix FQ
 180. Appendix FR
 181. Appendix FS
 182. Appendix FT
 183. Appendix FU
 184. Appendix FV
 185. Appendix FW
 186. Appendix FX
 187. Appendix FY
 188. Appendix FZ
 189. Appendix GA
 190. Appendix GB
 191. Appendix GC
 192. Appendix GD
 193. Appendix GE
 194. Appendix GF
 195. Appendix GG
 196. Appendix GH
 197. Appendix GI
 198. Appendix GJ
 199. Appendix GK
 200. Appendix GL
 201. Appendix GM
 202. Appendix GN
 203. Appendix GO
 204. Appendix GP
 205. Appendix GQ
 206. Appendix GR
 207. Appendix GS
 208. Appendix GT
 209. Appendix GU
 210. Appendix GV
 211. Appendix GW
 212. Appendix GX
 213. Appendix GY
 214. Appendix GZ
 215. Appendix HA
 216. Appendix HB
 217. Appendix HC
 218. Appendix HD
 219. Appendix HE
 220. Appendix HF
 221. Appendix HG
 222. Appendix HH
 223. Appendix HI
 224. Appendix HJ
 225. Appendix HK
 226. Appendix HL
 227. Appendix HM
 228. Appendix HN
 229. Appendix HO
 230. Appendix HP
 231. Appendix HQ
 232. Appendix HR
 233. Appendix HS
 234. Appendix HT
 235. Appendix HU
 236. Appendix HV
 237. Appendix HW
 238. Appendix HX
 239. Appendix HY
 240. Appendix HZ
 241. Appendix IA
 242. Appendix IB
 243. Appendix IC
 244. Appendix ID
 245. Appendix IE
 246. Appendix IF
 247. Appendix IG
 248. Appendix IH
 249. Appendix II
 250. Appendix IJ
 251. Appendix IK
 252. Appendix IL
 253. Appendix IM
 254. Appendix IN
 255. Appendix IO
 256. Appendix IP
 257. Appendix IQ
 258. Appendix IR
 259. Appendix IS
 260. Appendix IT
 261. Appendix IU
 262. Appendix IV
 263. Appendix IW
 264. Appendix IX
 265. Appendix IY
 266. Appendix IZ
 267. Appendix JA
 268. Appendix JB
 269. Appendix JC
 270. Appendix JD
 271. Appendix JE
 272. Appendix JF
 273. Appendix JG
 274. Appendix JH
 275. Appendix JI
 276. Appendix JJ
 277. Appendix JK
 278. Appendix JL
 279. Appendix JM
 280. Appendix JN
 281. Appendix JO
 282. Appendix JP
 283. Appendix JQ
 284. Appendix JR
 285. Appendix JS
 286. Appendix JT
 287. Appendix JU
 288. Appendix JV
 289. Appendix JW
 290. Appendix JX
 291. Appendix JY
 292. Appendix JZ
 293. Appendix KA
 294. Appendix KB
 295. Appendix KC
 296. Appendix KD
 297. Appendix KE
 298. Appendix KF
 299. Appendix KG
 300. Appendix KH
 301. Appendix KI
 302. Appendix KJ
 303. Appendix KK
 304. Appendix KL
 305. Appendix KM
 306. Appendix KN
 307. Appendix KO
 308. Appendix KP
 309. Appendix KQ
 310. Appendix KR
 311. Appendix KS
 312. Appendix KT
 313. Appendix KU
 314. Appendix KV
 315. Appendix KW
 316. Appendix KX
 317. Appendix KY
 318. Appendix KZ
 319. Appendix LA
 320. Appendix LB
 321. Appendix LC
 322. Appendix LD
 323. Appendix LE
 324. Appendix LF
 325. Appendix LG
 326. Appendix LH
 327. Appendix LI
 328. Appendix LJ
 329. Appendix LK
 330. Appendix LL
 331. Appendix LM
 332. Appendix LN
 333. Appendix LO
 334. Appendix LP
 335. Appendix LQ
 336. Appendix LR
 337. Appendix LS
 338. Appendix LT
 339. Appendix LU
 340. Appendix LV
 341. Appendix LW
 342. Appendix LX
 343. Appendix LY
 344. Appendix LZ
 345. Appendix MA
 346. Appendix MB
 347. Appendix MC
 348. Appendix MD
 349. Appendix ME
 350. Appendix MF
 351. Appendix MG
 352. Appendix MH
 353. Appendix MI
 354. Appendix MJ
 355. Appendix MK
 356. Appendix ML
 357. Appendix MM
 358. Appendix MN
 359. Appendix MO
 360. Appendix MP
 361. Appendix MQ
 362. Appendix MR
 363. Appendix MS
 364. Appendix MT
 365. Appendix MU
 366. Appendix MV
 367. Appendix MW
 368. Appendix MX
 369. Appendix MY
 370. Appendix MZ
 371. Appendix NA
 372. Appendix NB
 373. Appendix NC
 374. Appendix ND
 375. Appendix NE
 376. Appendix NF
 377. Appendix NG

GENERIC ADDRESSES

Catrinus Jepma, Netherlands
Shakespeare Maya, Zimbabwe
Irving Mintzer, Stockholm Environment Institute
Majid Al-Muneef, Saudia Arabia
Mohammed Asaduzzaman, Bangladesh

• = Participation still to be confirmed
C = Proposed Convening Lead Author

Writing Team 8:

C

POLICY INSTRUMENTS

Brian Fisher, Australia
Scott Barrett, U.K.
Peter Bohm, Sweden
Anwar Shah, World Bank
John Mubazi, Uganda
Masahiro Kuroda, Japan
Robert Stavins, U.S.A.

PART III: EMISSIONS SCENARIOS

Writing Team 10:

C

EMISSIONS SCENARIOS

Joseph Alcamo, the Netherlands
Tsuneyuki Morita, Japan
James (Jae) Edmonds, U.S.A.
Zhou Dadi, China
Aca Sugandhy, Indonesia
Amulya Reddy, India

WG II

P938005\writing3.sum

* = Participation still to be confirmed
C = Proposed Convening Lead Author

Contents

3.1 Conceptual Framework

- 3.1.1 Purpose of the Chapter
- 3.1.2 The Nature of Damage Assessment
- 3.1.3 The Valuation of Market and Non-Market Impacts
- 3.1.4 Transient and Equilibrium Warming
- 3.1.5 Time Horizon and Discounting
- 3.1.6 Technological Change
- 3.1.7 Adaptation
- 3.1.8 Recent Scientific Evidence

3.2 Damage Estimates for Benchmark Warming (2xCO₂)

- 3.2.1 Agriculture
- 3.2.2 Sea Level Rise
- 3.2.3 Forests
- 3.2.4 Water Supply
- 3.2.5 Space Cooling and Heating
- 3.2.6 Insurance
- 3.2.7 Other Market Sectors
- 3.2.8 Health
- 3.2.9 Air Pollution
- 3.2.10 Water Pollution
- 3.2.11 Migration
- 3.2.12 Human Amenity
- 3.2.13 Ecosystem and Biodiversity Loss
- 3.2.14 Extreme Weather Events
- 3.2.15 Damage Estimates: Summary

3.3 Damage Estimates for Longer Term Warming

3.4 Catastrophic Risks

3.5 Regional Implications of Global Warming Damage

- 3.5.1 Regional Damage Estimates
- 3.5.2 Japan
- 3.5.3 Africa
- 3.5.4 Bangladesh
- 3.5.5 India
- 3.5.6 Indonesia
- 3.5.7 Malaysia

- 3.5.8 Thailand
- 3.5.9 Latin America
- 3.5.10 Small Island States
- 3.5.11 Conclusions on Regional Impacts

3.6 From Greenhouse Damages to Abatement Benefits

3.7 The Secondary Benefits of Abatement Strategies

3.8 Comparing Benefits and Costs of Response Strategies

- 3.8.1 Social Efficiency of Abatement
- 3.8.2 Possible Implications

Boxes

- Box 3.1 Estimating the Value of a Statistical Life
- Box 3.2 Damage Aggregation Across Countries and Individuals
- Box 3.3 Relative Damage in Developing and Industrialised Countries

Figures

- Fig 3.1 Global Warming, Cost-Benefit Analysis and Sustainable Development
- Fig 3.2 2xCO₂ Damage vs. Abatement Benefits

Tables

- Tab 3.1 Overview on Climate Change Impacts
- Tab 3.2 The Economic Value of Endangered Species and Prized Habitats
- Tab 3.3 Reported Fatalities due to Weather Events 1989-1992
- Tab 3.4 Economic Damages from Global Warming: US Economy at Present Scale
- Tab 3.5 Quantitative 2xCO₂ Damages in Different World Regions
- Tab 3.6 Monetary 2xCO₂ Damage in Different World Regions
- Tab 3.7 Expert Opinion on Climate Change Damage
- Tab 3.8 Illustrative Damages from Long Term Warming: US Economy at Present Scale
- Tab 3.9 Losses of Rice Output in Coastal Zones of Bangladesh
- Tab 3.10 Vulnerability Index for Different Categories of Countries
- Tab 3.11 The Social Costs of CO₂ Emissions in Different Decades
- Tab 3.12 Reduced Air Emissions due to CO₂ Abatement
- Tab 3.13 The Social Costs of Air Pollution

Table of Contents

0. Introduction	1
1. The Measurement of Costs	3
1.1 Gross Costs, Net Costs and the Overall Cost-Benefit Balance of Mitigation Strategies	3
1.2 Taxonomy of Emission Reduction Cost Concepts	4
1.3 Costs as a Function of Baselines and Policy Strategies	5
2. Patterns of Development and Technological Change	9
2.1 Links Between Development Patterns, Technical Change and Emission Reduction Costs	9
2.1.1 The Importance of the Socio-Economic Assumptions Underlying Scenarios	9
2.1.2 Current and Future Socio-Economic Development Patterns	12
2.2 Modeling Development Paths and Mitigation Costs	16
2.2.1 Prediction and Simulation: The Need for Multiple Baselines	16
2.2.2 Economic Modeling and Development Trends: Some Limits	19
2.3 Multiple Baselines, Uncertainty and Long-Term Mitigation Costs	20
2.3.1 Multiple Baselines and the Non-Comparability of Cost Assessments	20
2.3.2 Development Patterns in Developing Countries and Economies in Transition	22
2.3.3 Mitigation and Prevention: An Uncertain Baseline	22
3. Technology Dynamics in Economic Models	24
3.1 Critical dimensions of a typology of existing models	25
3.1.1 Diversity of models, diversity of purposes	25
3.1.2 Two different representations of technology: the meaning of the "aggregation gap"	26
3.1.3 Representing economic behavior: how do market mechanisms really operate with regard to innovation and technology adoption?	29
3.1.4 Technology and behaviors over the short term or the long term, two different questions addressed	31
3.1.5 Typology of models in the energy field	32
3.2 Overall Lessons from the Efficiency Gap Controversy in the Energy Field	32
3.2.1 Bottom-Up Approaches to Analysing the "Efficiency Gap"	33
3.2.2 How to Explain and Assess Market Imperfections	34
3.2.3 Top-Down Approaches to Capturing Actual Behaviours	39
3.3 Beyond Energy: Technology and Non-Energy GHG Emissions	43
4. Review of Existing Costing Studies	44
4.1. Studies of the Costs of Reducing CO ₂ Emissions in the U.S.	44
4.1.1 A Review of Top-down Studies	44
4.1.2 A Review of Bottom-up Studies	49
4.2. Studies of the Costs of Reducing CO ₂ emissions in Other OECD Countries	53
4.2.1 A Review of Top-down Studies	53
4.2.2 A Review of Bottom-up Studies	57
4.3 Studies of the Costs of Reducing CO ₂ Emissions in Transitional Economies	61
4.3.1 A Review of Top-down Studies	61
4.3.2 A Review of Bottom-up Studies	62
4.4 Studies of the Costs of Reducing CO ₂ Emissions in Developing Countries	69

4.4.2 A Review of Bottom-up Studies	70
4.5 Global Studies of the Costs of Reducing CO ₂ Emissions	78
4.5.1 A Review of Top-down Studies	79

5. Scenarios, Models and the Costs of GHG Emission Reduction	85
---	-----------

List of Figures and Tables

All Figures and Tables are at the end of the text

Box 1.1 Gross and Net Costs

Figure 1.1	Sample technology cost curves
Figure 1.2	Relationship Between Economic Activity and Emission Reduction
Figure 1.3	Alternative Views on Costs of Emission Reduction
Figure 4.1.1	US Studies: Cost of CO ₂ Abatement Relative to Baseline Projection
Figure 4.1.2	US Carbon Emissions
Figure 4.1.3	EMF Reference and Emission Reduction Scenarios
Figure 4.1.4	US Carbon Taxes - Average of All Models
Figure 4.1.5	US GDP Loss Projections - Average of All Models
Figure 4.1.6	Decoupling Between Carbon Emissions and GDP Annual Growth Rates (1990-2010)
Figure 4.1.7	Two Alternative Paths Leading to Identical Cumulative Emissions
Figure 4.2.1	Non-US OECD Studies: Cost of CO ₂ Abatement Relative to Baseline Projection
Figure 4.2.2	GDP Losses in the Stabilization Scenario
Figure 4.2.3	Carbon Taxes in the Stabilization scenario
Figure 4.2.4	marginal cost in ECU/t of CO ₂
Figure 4.2.5	Cost as a percentage of 1988 GDP
Figure 4.3.1	Comparison of Carbon Taxes in the Stabilization Scenario
Figure 4.3.2	Cost Studies: Emissions Reduction in the Former Soviet Union
Figure 4.3.3	Cost Studies: Emissions Reduction in Central Europe
Figure 4.3.4	Efficiency Potential in Poland
Figure 4.4.1	UNEP Studies: marginal abatement costs of 2005/10
Figure 4.4.2	UNEP Studies: marginal abatement costs of 2020/30
Figure 4.5.1	Global Studies of CO ₂ Abatement Costs Relative to Baseline Projection
Figure 4.5.2	Estimated CO ₂ Abatement Cost in 2020
Figure 4.5.3	The Costs of Stabilizing Global Carbon Emissions
Figure 4.5.4	World CO ₂ Emissions and GDP Losses
Figure 4.5.5	Regional Carbon Tax Required for Equi-Proportional CO ₂ Emission Reductions from Baseline
Figure 4.5.6	Grandfathered Emissions Rights Principle
Figure 4.5.7	Equal per Capita emissions Rights Principle
Figure 4.5.8	No Net Cost to Developing Nations Emissions Rights Principle
Table 4.1.1	US CO ₂ Abatement Cost Modelling Studies
Table 4.1.2	Models used in Energy Modeling Forum (EMF) Study
Table 4.1.3	Description of EMF Scenarios
Table 4.1.4	Comparison of Carbon Taxes and GDP Losses in 2010
Table 4.1.5	GNP Loss, 1990-2010
Table 4.1.6	Bottom-up Studies of US Emissions Mitigation Costs Major Assumptions (annual growth rates, %)
Table 4.1.7	Results, US Emissions Mitigation Studies
Table 4.2.1	Non-US OECD CO ₂ Abatement Cost Modelling Studies
Table 4.2.2	Comparison of the Emissions Reduction Between Energy Tax and Carbon Tax
Table 4.2.3	Differences of the Macro-Effects of the Energy Tax Between EC Countries: in 2001 or 2005 (difference in % with the baseline)
Table 4.2.4	Effects of Different Types of Tax Revenue Recycling at the Community Level

Table 4.2.5	Bottom up exercises on European countries
Table 4.2.6	Characterization of sectorial optimization and technico-econometric energy models
Table 4.2.7	Comparison of marginal costs of reduction in the EC countries in the CEC bottom up exercise with EFOM-ENV.
Table 4.2.8	Comparison of marginal cost of CO ₂ limits in the COHERENCE exercise
Table 4.2.9	Main categories of CO ₂ reduction options and related marginal abatement cost (MAC) in Denmark
Table 4.2.10	Main categories of CO ₂ reduction options in the Netherlands
Table 4.3.1	Cost of Carbon Dioxide Emissions Reduction
Table 4.4.1	Comparative Results from Five Models for Carbon Emission and GDP Losses for China and the World
Table 4.4.2	Growth rates of population, GDP, primary energy consumption and CO ₂ emissions in reference and abatement scenarios for 1990 to 2020/30
Table 4.4.3	Key elasticities in reference and abatement scenarios for 1990 to 2020/30.
Table 4.4.4	Marginal (MAC), Average (AAC) and Total Abatement Costs (TAC) for maximum reductions, comparison with GDP
Table 4.4.5	
Table 4.4.6	
Table 4.5.1	Global CO ₂ Abatement Cost Modelling Studies
Table 4.5.2	Cost Differences for Emission Trading

CONTENTS

8.1 Introduction

- 8.1.1 Guidelines from the FCCC
- 8.1.2 The Greenhouse Policy Problem
- 8.1.3 A Guide to the Chapter

8.2 Greenhouse Policy Instruments and Criteria for Policy Assessment

- 8.2.1 Domestic Policy Instruments
 - 8.2.1.1 Conventional regulatory instruments
 - 8.2.1.2 Market-based instruments
 - 8.2.1.2.1 Taxes and subsidies
 - 8.2.1.2.2 Tradable permits
 - 8.2.1.2.3 Other complementary policies
- 8.2.2 International Policy Options
 - 8.2.2.1 Regulatory instruments
 - 8.2.2.2 International taxes and harmonised domestic taxes
 - 8.2.2.3 Tradable quotas
 - 8.2.2.4 Other complementary policies
- 8.2.3 Criteria for Policy Assessment
- 8.2.4 Coverage of Greenhouse Gases
 - 8.2.4.1 The need for comprehensive targets
 - 8.2.4.2 Initial coverage of CO₂ sources and sinks

8.3 The Domestic Policy Context

- 8.3.1 Pre-existing Market Distortions
 - 8.3.1.1 Energy Subsidies
 - 8.3.1.2 The 'Local' Environmental Benefits of Climate Change Policy
 - 8.3.1.3 Information and Energy Conservation
 - 8.3.1.4 Transport
 - 8.3.1.5 Agriculture and Forestry
- 8.3.2 Tax or Permit Sales Revenue Recycling
- 8.3.3 The Broader Context for Climate Change Policies

8.4 Regulations, Voluntary Agreements and other Non-Market-Based Instruments

- 8.4.1 Uniform Technology and Performance Standards
- 8.4.2 Government Investment
- 8.4.3 Voluntary Agreements
- 8.4.4 Demand Side Management

8.4.5 Distributional Impacts

8.5 Market-Based Policy Instruments

8.5.1 Introduction

8.5.2 Carbon Taxes

8.5.2.1 Related instruments – deposit refund systems for carbon removal

8.5.3 Tradable Quotas and Permits

8.5.4 Joint Implementation

8.5.5 Distributional Impacts of Market-based Measures

8.6 Policy Implementation Issues

8.6.1 The 'Currency' of Regulation

8.6.2 Market Power

8.6.3 Transaction Costs

8.6.4 Participants in the System

8.6.5 Free-Riding and Emissions Leakage Problems

8.6.5.1 Policies to reduce free-riding

8.6.5.2 The severity of emissions leakage

8.6.5.3 Policies to reduce leakage

8.6.6 Information Issues, the Role of Brokers and Risk Management

8.6.7 Possibilities of Technology Transfers to Developing Countries

8.6.8 The Adaptability of Policy Instruments to Evolving Scientific Understanding

8.7 Comparative Assessment of Greenhouse Policy Instruments

8.7.1 Introduction

8.7.2 Comparing Command-and-Control Systems and Market-Based Instruments

8.7.3 Comparing International Tradable Quotas and Tax Systems

8.7.4 Comparing Domestic Tradable Permits and Domestic Tax Systems

8.8 Concluding Comments

8.9 References

Figures

8.1 Fuelwood stumpage fees as a percentage of replacement costs, late 1980s

8.2 Electricity output, by type of fossil fuel used: Toronto-type target in MENSA

8.3 Electricity output, by type of fossil fuel used: 1990 OECD-type stabilisation target in MENSA

Tables

8.1 A Taxonomy of costs of environmental regulation

8.2 A Summary of empirical evidence on the redistributive impacts of economic instruments

8.3 Carbon tax incidence in developing countries

DRAFT 1.1

**Intergovernmental Panel on Climate Change
Working Group III**

Equity and Social Considerations

**Lead Authors:
Tariq Banuri, Karl Goran-Maler,
Michael Grubb, and Harold K. Jacobson**

Table of Contents

I	Introduction	1
II	Intergenerational Equity	6
III	Equity Among Regions and Countries	25
IV	Equity Within Countries	40
V	Conclusion	40
	References	41
	Notes	43

Contents

Preface

Foreword

Policymakers Summary

Introduction

1	Decision Criteria	i
2	Factors that Affect Decision Making	19
3	Candidate Policy Options to Address Global Climate Change Issues	37
4	Risk Analysis of Climate Change	57
	References	77

Section 6.1*Contents***6.1 Decision Criteria**

6.1.1	Criteria of choice	2
6.1.1.1	What is choice?	3
6.1.1.2	Maximising something	4
6.1.1.3	Bounded rationality	6
6.1.1.4	Procedural kind of rationality	7
6.1.1.5	Accommodating the added uncertainty attached to climate change	8
6.1.2	Decision Problems under Uncertainty and Risk	10
6.1.2.1	Standard responses to uncertainty and risks	10
6.1.2.2	Standard uncertainty and risk decision rules	10
6.1.3	Uncertainty and Risk Revisited in the Context of Climate Change	11
6.1.3.1	Certainty	12
6.1.3.2	Risk	12
6.1.3.3	Uncertainty	13
6.1.3.4	Catastrophic risk	13
6.1.3.5	How to address uncertainty and risk associated to climate change?	14

CONTENTS

Executive Summary	-
1. Introduction	1
2. A Conceptual Framework	1
2.1 Mitigation Options	2
2.2 Adaptation Options	3
2.3 Indirect Policy Options	3
3. Criteria for Assessment	4
4. Mitigation Options	6
4.1 Energy Conservation and Efficiency Improvement	6
4.2 Fuel Switch between Fossils	10
4.3 Renewable Energy Technologies	11
4.4 Nuclear Energy	13
4.5 Capture and Disposal	13
4.6 Enhancing Sinks: Forestry Options	14
4.6.1 Costs	16
4.7 Methane	19
5. Adaptation Options	19
5.1 Adaptation to what?	19
5.2 How to adapt	20
5.3 Modeling Adaptation	21
6. An Integrated Approach	22
7. International Policy Cooperation	24
8. Conclusions	25
References	30

Clinton Presidential Records Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a tabbed divider. Given our digitization capabilities, we are sometimes unable to adequately scan such dividers. The title from the original document is indicated below.

Comments on "Scope"

Divider Title: _____

Tom- Ambass

Ray

~~Atta~~

Urban

Transpot

Cumby - Index

W/OX ITC

Refiner - Oil / Friday

/lines

~~Major~~, ~~David Keim~~

here

Tickets

Hotels

Friday

Kupnik

Selly-

I like this chapter a lot. It is reasonably well-written and provides a balanced view of a difficult evaluation of cost-benefit analysis. I made some notes on the text as I read through it - I hope they prove useful.

Mark

APPLICABILITY OF COST-BENEFIT ANALYSIS
TO CLIMATE CHANGE

PS - Thanks for letting me read this. I feel like I learned quite a bit.

Prepared for WORKING GROUP III
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Draft, July 1994

Prepared by:

Mohan Munasinghe, Michael Hoel, Sung Woong Hong,
Peter Meier, and Asbjorn Aaheim.

editorial comments:

use "straight forward" too often

Some material is repeated a couple times -- the chapter probably could be shortened a bit

I'm not sure "multiple criteria" is as much an "issue" as a fundamental broadening of CBA.

1. Introduction

In public policy-making, a comparison between the perceived costs and the perceived benefits of an action is routinely made by decision-makers. However, this choice is frequently made on intuitive and qualitative grounds. Cost benefit analysis (CBA) provides an analytical framework that seeks to compare the consequences of alternative policy actions on a quantitative rather than qualitative basis. Indeed, the approach forces quantitative thinking, for its very essence is that costs and benefits must be expressed in a common monetary unit that provides the basis for the tradeoffs. The basic principles are well understood and straight forward. For an action to be justified, the costs of the action should be less than the benefits derived therefrom¹. If there are several alternatives, then one ought to pick that option whose benefits most exceed the costs.²

The objective of this Chapter is to examine how and under what circumstances can CBA make a contribution to the resolution of the central questions now facing decision-makers about global climate change: (1) by *how much* should emissions of greenhouse gases (GHGs) be reduced? (2) *when* should emissions be reduced? (3) *how* should emissions be reduced? and (4) *who* should reduce emissions? CBA can at least theoretically and conceptually answer the first three questions. The fourth question is one of equity, and not amenable to resolution by CBA even in simple, traditional applications not complicated by the complexities of the climate change problem³.

Section 2 defines more carefully what is meant by CBA. In fact the term has come to encompass a wide variety of specific techniques. We also review the basic concepts. In section 3 we examine the unique features of global warming and climate change as they pertain to decision-making. Section 4 presents a discussion of the application of CBA to the climate change problem in light of these unique features. In section 5 we discuss the key issues: risk uncertainty, irreversibility, valuation, discounting, equity, and multiple criteria.

¹ Indeed, that cost-benefit analysis is appropriate to the analysis of policy options to address global climate change is not universally accepted. A major report recently issued by the US Office of Technology Assessment (OTA, 1993) contains an extensive discussion of how adaptation strategies should be chosen, yet manages to avoid all mention of cost-benefit analysis *per se*. It talks about how one might minimize vulnerability to climate change and about insurance strategies, but avoids the central question of how one might determine the amount of insurance one wishes to buy. Similarly, priorities may be set on non-economic grounds, and CBA could be used in a secondary role (see e.g. Turner, 1991).

² ~~Although this needs a little bit of modification~~ *characterization must be modified* in the presence of capital constraints, which may limit selection of the "best" single project.

³ However, as we shall see later, extensions of CBA can help in identifying the *trade-offs* between economic efficiency and equity.

2. Cost-benefit analysis

Cost-benefit analysis (CBA) is a generic term that subsumes a wide body of specific techniques. Developed originally as a means to evaluate projects, the original techniques have been extended to cover applications of increasing complexity.

Traditional project level CBA

CBA evolved as a technique to evaluate and compare project alternatives. In the early years of its application, there was little concern with externalities, and the analysis took into account just the direct costs of projects, and the direct benefits. Developed in the west, market prices provided appropriate guidance on how to evaluate benefits. But even as the World Bank began to apply the technique to non-market economies, or where prices were subject to significant distortions, shadow pricing techniques provided simple corrections.⁴

One of the central concepts in CBA is that of discounting, which addresses the fact that costs and benefits may not occur at the same point in time. Thus, while costly actions to avoid future global warming must be taken now, the benefits of such actions may arise very far in the future. Discounting enables one to take into account the time value of money. In the case of evaluating simple investment alternatives over shorter time horizons (e.g., < 15 years), the use of the opportunity cost of capital as the discount rate to be applied to both costs and benefits, is well established and uncontroversial. However, in the case of complex public policy applications, particularly those whose time horizons are very great, and involving environmental impacts or the depletion of natural resources — essential characteristics of the global climate change issue — there is sharp disagreement as to what discount rate is appropriate. This issue is dealt with in Section 5.

Cost-effectiveness analysis

As CBA began to be applied to much broader contexts, and particularly to the comparison of alternative *portfolios* of projects and to broad policy choices, the increasing complexity made it desirable to keep the level of benefits constant, and to analyze the problem simply in terms of finding the most effective, or "least-cost" option to meet the desired level of benefits. This has the additional advantage that benefits in some cases do not need to be explicitly valued. For example, in power sector planning, models are applied to identify the capacity expansion plan whose present value of system costs are minimized, given some exogenously specified time path of electricity demand, and some exogenously specified level of reliability. As we shall see below, this is the variant of CBA that has seen the most widespread application to the climate change problem, in which one seeks to identify the least-cost option to achieve given levels of GHG emission reductions, without any explicit attempt to specify what the *benefits* of that level of emission reduction may be.

The Framework Convention on Climate Change emphasizes that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost." Being a global matter, most of the actions that will be taken to mitigate climate change will be equally efficient independent of where in the world the action takes place. Strictly speaking, therefore, cost effective measures are those that minimize total world cost, given a target for the world as a whole.

⁴ For example, if an oil-importing country kept the domestic price of oil at artificially low levels, CBA requires the use of the border price, not the domestic price, as a basis for costing oil inputs.

The importance of CBA in relation to cost effective mitigation of climate change depends partly on the kind of measure that is considered. Analysis of general measures (such as carbon taxes) is straight forward, assuming that market behavior leads to cost minimization based on the prices of the taxed goods and services. Cost effectiveness is then a question of a proper tax. A global marketable permit system would result in permit prices equivalent to the proper tax — if countries could agree on the target level and how to share the initial distribution of permits. Responses based on the efficient functioning of markets would similarly lead to cost minimization. For a closer examination, see Hoel (1992).

For the evaluation of investments in GHG emissions abatement, CBA will play a more central role. Cost effective measures should be evaluated on the basis of global models in which economic interdependencies between world regions are taken care of. However, such models have to be quite aggregate, and will generally not allow the evaluation of measures for which a rather detailed description of national economies is required. Measures that aim at sectoral substitution within energy intensive industries may be such an example. To evaluate such measures, national macro-economic models might be applied. These will have to take certain conditions on the world market as given — conditions that might change if many countries initiated climate measures.

Many of the potential climate change mitigation measures require a rather detailed technical description to be evaluated. In these cases CBA would normally assume all the prices to be fixed at observed market prices. If introduced on a large scale, however, these kinds of measures might affect market prices at the world level. Thus, a fully consistent evaluation of cost effective measures may require analysis at several levels of aggregation.

In order to evaluate cost effectiveness it is crucial to clarify in what terms the target is set, because there are several options in the global climate change context. Most of the recent analyses of the cost of mitigation have focused on targets of future emission levels⁵, such as stabilization of the emission of certain greenhouse gases by a given year. However, it might be more relevant to express the targets in terms of concentrations of atmospheric greenhouse gases.

To change the target for climate policy from emissions to atmospheric concentrations indicates a radically different cost effectiveness strategy. A stabilization of CO₂ emissions at present levels is not sufficient to stabilize the atmospheric concentrations. Richels and Edmonds (1993) have compared the costs of reaching the same concentration level by year 2100 from alternative strategies. They show that the same concentration level can be met at a considerably lower cost than the cost of stabilizing emissions immediately. The reason being that the economic shock following a sudden stabilization of emissions is avoided, future advanced technologies could be utilized to a larger extent, and sizable abatement costs are postponed.

A third possible target, also affecting the cost effectiveness of alternative measures, could refer to the physical consequences of climate change. Apart from the fact that predictions of these consequences are far more difficult to make than predictions of emissions and atmospheric concentrations of greenhouse gases, the effects of regional differences would have to be included if targets were set on the consequences. For instance, whether global warming contributes to sea level rise or to an increase in the frequency of rain storms will be of quite different importance to people in Nepal and Netherlands. In this context, an additional problem

⁵ The degree of emission abatement is reported in such studies in two rather different ways. The first is as reductions from some baseline, defined as the trajectory of GHG emissions for some postulated business-as-usual scenario. The second is in terms of reductions from some reference year (e.g. "reduce greenhouse emissions to 80% of their 1990 levels by 2100").

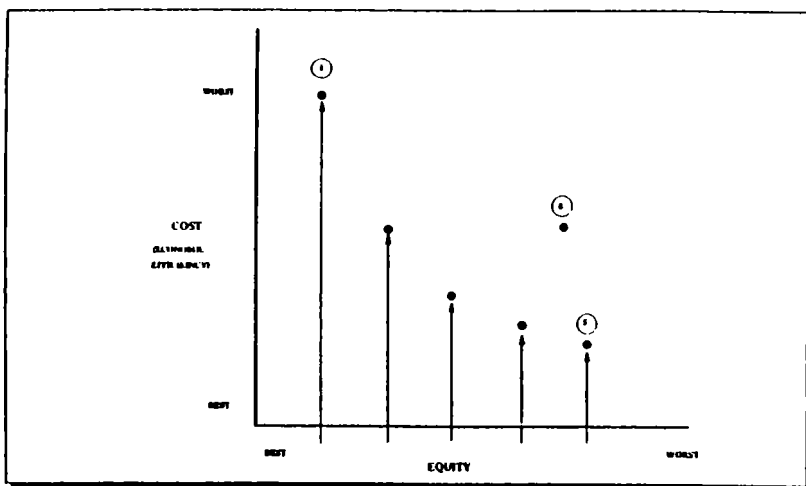


Figure 2.1: Multi-criteria analysis

arises as to how to assess benefits from abatement of different consequences for different countries.

Multi-criteria analysis

The most basic requirement for the application of CBA is that both costs and benefits can be given economic value. This is typically a two step process: first the costs and benefits must be quantified in terms of the physical measures that apply; and then those physical impacts must be valued in economic terms.

Some applications of valuation techniques are likely to be controversial. Putting a value on human health and illness has been a major problem in the practical application of cost-benefit analysis in the past, even in those situations where one can agree upon the levels of increased morbidity and mortality that might be caused by some policy or project. Efforts to place economic value on the loss of biodiversity have been equally difficult. Recognizing this problem has led to the development of so-called multicriteria analysis (MCA) techniques, which are expressly designed to deal with multiple objectives -- of which economic efficiency is indeed only one of several that may be employed.

Even if one can place economic value on certain impacts -- such as human life -- not everyone agrees that it is *appropriate*. Indeed, cost-benefit analysis presupposes that costs and benefits are those perceived by humans -- an endangered species might view the trade-off between threatened habitat and GHG emissions in an entirely different way, and use a different numeraire than money⁴. Such views give further support for MCA-based approaches to

⁴ A recent survey of economists and scientists knowledgeable about the climate change problem elicited typical views at the extreme of this spectrum. One respondent argued "the existence value of species is irrelevant-- I don't care about ants except for drugs", while another cautioned that "loss of genetic potential might lower the income of the tropical regions substantially". In Section 5 we address the different types of value -- use, option, existence -- in more detail. (W. Nordhaus, Expert Opinion on Climatic Change, *American Scientist*, 82, 45-51, 1994).

decision-making. Similarly, there are concerns that monetized values themselves may be inaccurately estimated, and in any case such values might not reflect welfare.

As noted earlier, conventional CBA cannot provide answers about the optimum level of equity in the same way that it provides answers about the optimum level of economic efficiency. But MCA can identify the *trade-offs* between equity objectives and economic efficiency, as suggested by Figure 2.1. Thus, the best equity result (indicated by option 1, say an equal per capita sharing of the burden of GHG emission reduction) may have the highest cost, while the worst equity result (indicated by option 5, say based on the present distribution of GHG emissions), may have the lowest economic cost⁵. Nevertheless, even MCA requires a quantification or at least an ordinal ranking of the non economic efficiency criteria, as suggested in the figure. However, even such a non-cardinal ranking may prove problematic when a global issue like climate change requires comparisons across countries and cultures.⁶

Decision analysis

While MCA addresses certain shortcomings of conventional CBA (like valuation problems), it does not necessarily deal more effectively with uncertainty. Thus has developed a further extension of CBA that goes under the general term decision analysis. Here the focus is expressly on how one makes decisions under conditions of uncertainty. These techniques find application in a wide variety of situations, from decision-making in the high risk field of wildcat oil drilling to analysis of financial options. As we shall see below, these techniques provide a rational approach to deal with irreversibility, one of the more important characteristics of the climate change problem.

Basic concepts

An economically efficient policy for emissions reduction is one that maximizes the net benefits, i.e. maximizes the benefits of reduced global warming less the associated costs of emission reductions⁷. Economic theory provides that emission reduction efforts should be pursued up to the level where the marginal environmental benefits of an additional unit of reduced warming is equal to the marginal cost of emissions reduction. Figure 2.2 illustrates the concepts of total and marginal costs in simplified form -- the marginal costs at any level of emission reduction is equal to the slope of the total cost curve at the same level.

The shape of the total cost and benefit curves reflects the idea of diminishing returns. Each additional unit of emissions reduction will have a higher unit cost: the first 10% reduction can be done cheaply, but the next 10% will cost considerably more, and so on.⁸ Thus the

⁷ But see below for a discussion of the difficulties of making cross-country comparisons of costs.

⁸ There may also be some outcomes that are inefficient, i.e. those that lie inside the frontier of efficient points shown on Figure 2.1. Such an inefficient point is represented by option 6. This is discussed further in the presentation of multi-criteria analysis, below.

⁹ It should be noted that the algebra of cost-benefit analysis can be expressed in many different ways: the cost-benefit ratio, net present value, or the internal rate of return are all different ways of doing the arithmetic. However, particularly in situations involving portfolios of potential actions, and where shortages of capital may constrain the choice, great care must be paid to rigorous application of principles, else different methods can yield different decisions. Maximizing net present value subject to applicable resource constraints is the most useful approach for climate change analysis.

¹⁰ Perhaps the simplest and most intuitive example as to why the marginal cost of emissions reduction increases with increasing levels of reduction is the removal of pollutants from wastewater. The first 60% can be easily removed by a settling basin, that require just a structure. Large particles

In discussion above there is no sense of efficiency being relevant in Figure 2.1

A good point (and one that is often overlooked)

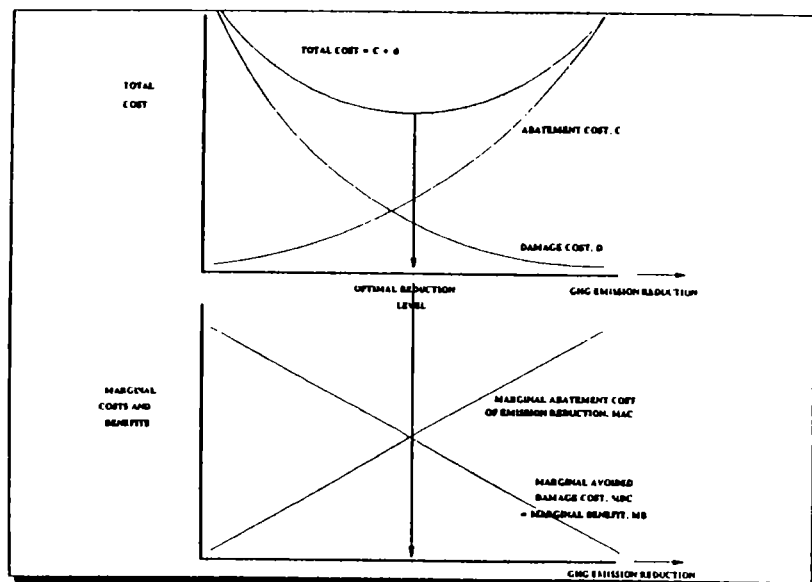


Figure 2.2: Total and marginal costs and emissions reductions.

abatement cost curve is upward sloping (with increasing slope) as shown on Figure 2.2A. Similarly, the marginal benefit (or avoided cost of GHG damages) falls as emission levels are reduced. The consequences of the foregoing is that the total cost (TC) has a minimum at the point where the slope of the abatement cost curve equals the negative slope of the damage cost curve (or avoided costs).

The foregoing analysis ignores many complications. For example, the emission of a unit of CO_2 may give rise to a varying stream of environmental costs which must be discounted to yield a present value aggregate. The environmental damage function may be discontinuous and non-convex. Abatement costs may change over time, depending on when the technologies are applied -- because of technological progress. Similarly, abatement costs may exhibit economies of scale (e.g. mass production of solar photovoltaic cells), resulting in a marginal cost curve that actually declines beyond a certain point. Finally, the abatement costs are net costs, to the extent that certain technologies (e.g. renewables) may produce other (non-climate related) benefits and costs -- the so-called joint products complication.

simply settle by gravity. The next 5%, to reach, say 90% removal, requires biological treatment: this requires not just a physical structure, but pumps to aerate the water to promote aerobic bacteria. The next 5-6% requires chemical treatment, with high operating costs of chemical agents. 100% removal, theoretically possible, would require complete desulfation, which is extremely expensive.

3. Unique features of global warming

There are several important characteristics that define the conventional context in which CBA is applied. First is that costs and benefits arise within a time span typically no more than 15-25 years, corresponding roughly to the physical life of most projects over which benefits are derived. Second is that the elements of uncertainty are relatively tractable, and can often be characterized by probability distributions.

Most of these characteristics are very different in the context of global warming. The relevant time spans extend to a century or more. The uncertainties are extremely large, and few elements of uncertainty are amenable to characterization as probability distributions.

Figure 3.1 shows the chain of causality. It begins with emissions of greenhouse gases. While the most important of these is CO_2 , it should be noted that there are many other gases that contribute to the global warming phenomenon, including methane, and CFCs. While estimates of CO_2 emissions from fossil fuel combustion are fairly straight forward, emissions from other sources are subject to much higher uncertainty.

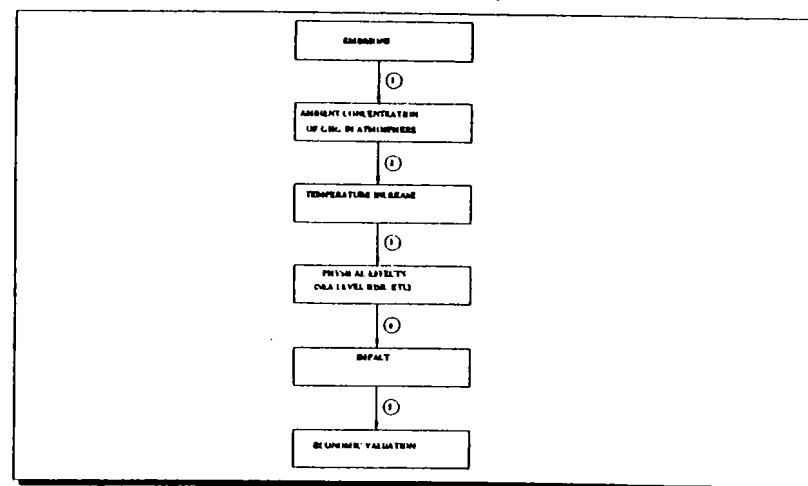


Figure 3.1: The chain of causality

The first link (1) is between emissions and the resultant ambient concentration of CO_2 in the atmosphere. Unlike other pollutants that are subject to complex chemical transformations in the atmosphere,¹¹ the calculation of the ambient concentration increase that follows from a given increment of emissions of CO_2 is relatively simple. However, because of the role of natural sources and sinks (particularly the ocean), even this calculation is subject to a considerable degree of complexity and uncertainty.¹²

¹¹ The acidity of precipitation is influenced by complex interactions between sulfur oxides, related oxidation products, and NO_x .

¹² For example, the presence of CFCs could affect global warming not only directly through its greenhouse warming potential, but also indirectly by its impact on biota like nanoplankton -- which in turn influence oceanic CO_2 uptake. Similarly, the degree of reliance on fossil fuels would affect CO_2 directly, and CO_2 absorption indirectly -- via the effects of acid rain on forests and biomass.

The next link (2), between atmospheric concentration and temperature, is subject to much greater scientific uncertainty. The greenhouse effect itself, i.e. the trapping of incoming solar radiation, is subject to all kinds of additional factors that are highly complex. For example, if temperatures rise, and cloud cover increases, feedback effects involving increased reflection of incoming radiation will complicate the calculation of equilibrium temperatures.

The next linkage (#3) involves many different components. Some are relatively straight forward for example, calculating the rise in sea level may be quite simple given assumptions about increases in mean sea temperature. Much more complicated are estimates of how precipitation patterns might change, especially the spatial and temporal distribution of rainfall. Perhaps of even greater concern in the developing countries will be the changes in the patterns of extreme weather events, to which they are particularly vulnerable.

If these physical effects are understood in general terms, quantifying the impacts on the flora and fauna is much more difficult (link #4). Suppose it were possible to predict the change in precipitation and temperature regime for some given region. What can be said about the shifts in vegetation patterns? While general northward shifts of vegetation and agricultural production zones can be predicted in general terms, quantifying the effect is quite difficult. What is the impact on biodiversity? On wetlands? On the water table? Clearly these are very difficult assessments to make.

Finally, in order to estimate the damage costs, one needs to be able to value these effects (link #5). Some valuation tasks will be relatively straight forward: for example, the cost of engineering structures to protect against sea level rise are relatively easy to establish, given the existing experience in this field (in such countries as the Netherlands). Other calculations will be more complex, but at least tractable: as for example, the calculation of increased cooling and decreased heating costs on the energy system, or the impact of increased irrigation pumping requirements associated with drier climates in some regions upon electricity demand. But a very large number of potentially important impacts are very difficult to value such as the impacts on forests, wetlands, and biodiversity.

Unique features

Beyond the degree of uncertainty, what makes the analysis of the climate change problem so different to other environmental analysis problems? The main reasons can be summarized as follows:

GHGs are stock, not flow pollutants:

Many pollution phenomena are relatively short-lived, such that the damages are closely related to the current rate of emissions. This is because the rate at which most pollutants are removed from the atmosphere is relatively rapid (say in the case of particulates by dry or wet deposition). Reducing emissions at major sources will likely have a relatively immediate impact. In the case of GHGs, however, the damages occur as a result of the total atmospheric concentrations at any one time, in other words, are related to the stock of the pollutant, not to the current rate of emissions.¹¹

Therefore, in the context of the climate problem, the global climate is a lagged function of the various greenhouse gases. At any point of time, these atmospheric concentrations (which are stock concepts) depend on the whole time path of emission of the greenhouse gases up till *until*

¹¹ There are of course some exceptions, notably for radioactive wastes, which also have an extremely long life, thus the total environmental risk, and the scale of the disposal problem at any one time, is not so much dependent on current rates of production of nuclear wastes, as on the total stock.

the point of time under consideration. Similarly, an increase in current emissions of greenhouse gas at any point of time will affect the atmospheric concentrations of this gas, thus the climate, in all future periods.

To calculate the marginal environmental cost of increased current emissions of a greenhouse gas, one must first calculate the physical impact of such an emission increase on the future development of the atmospheric concentration of the gas. This will depend on physical characteristics of the gas, which affect how rapidly an increased atmospheric concentration depreciates. There are large differences between different greenhouse gases, with atmospheric lifetimes varying from e.g. 11 years for methane to more than 100 years for CO₂, N₂O and some CFCs.

Once the impact of current emissions of a greenhouse gas on future atmospheric concentrations has been calculated, one can in principle calculate the effect of the increase in current emissions on the future climate development. If one has specified a function which measures the monetary cost of climate change, one may thus calculate the incremental costs, and thus obtain a present value measure of the marginal cost of increased current emissions of a greenhouse gas.

It is clear from the description above that the marginal monetary cost of greenhouse gas emissions is a complex concept. Several assumptions of an economic nature must be made, such as the appropriate discount rate and the monetary costs of climate change for the whole future. In particular, the relative importance of different greenhouse gases is much more complex than some simple physical conversion into a common index. In the context of the climate problem, a reasonable definition of the importance of a greenhouse gas relative to, say CO₂, is the marginal environmental cost of current emissions of this gas relative to the corresponding marginal cost of CO₂. It follows from the discussion above that the relative importance of GHGs depends on a number of economic assumptions which must be made.¹⁴

Inertia and irreversibility:

Since the emissions of GHGs in any one year represent a relatively small fraction of the total global stock, the system has great inertia. This means that even if all emissions went to zero, it would be decades, if not centuries, before the stock of GHGs become reduced significantly. Therefore, in effect, decisions about emissions reduction become effectively irreversible, at least over the 100-200 year timespan of interest. In other words, failure to reduce emissions in the short to medium term may be irreversible in the sense that once the effects of global warming become apparent, it will then be too late to do anything about it.

Global characteristics:

Most environmental pollution problems are local in scale.¹⁵ The benefits of emissions reductions generally accrue to the same geographic areas as would otherwise bear the costs. The damage associated with GHGs, however, are dependent upon the total global GHG concentration.

¹⁴ See e.g. Hoel and Isaksen (1993, 1994) for a further discussion and numerical calculations

¹⁵ There are exceptions here as well, most notably the phenomenon of acid rain, which is largely a long-range phenomenon typically involving emissions in one country, and acid rain damage in another (e.g. emissions in the U.K. affect Scandinavia, emissions in the U.S. affect Canada, emissions in China affect Japan). However, to the extent that lake acidification completely destroys aquatic ecosystems, one could argue that at least some of the impacts are irreversible, although even here the impacts are generally of a fairly local nature. Long time periods may also elapse between the onset of acid rainfall, and to actual visible damage.

Therefore the distribution of benefits of emissions reduction is global, not local. Per contra, even a country that emits no GHGs would incur the damages of emissions by other countries.

Geographical distribution of impacts.

Unlike some other trans-national pollution problems, the impacts of global warming are likely to be highly concentrated among poorer nations, who lack the resources to protect themselves against sea level rise, extreme weather events, or desertification. By contrast, the impacts of acid rain tend to be concentrated in richer countries from emissions in poorer countries or regions (Japan from China¹⁶, Germany from E. Europe, the wealthy northeastern states of the US from Appalachia). These richer areas therefore have powerful incentives to promote emissions reductions programs in the source areas, including the provision of financial assistance¹⁷. By contrast, except upon the basis of humanitarian solidarity and equity, it is unclear why countries like the US have any motivation to provide assistance to those who will bear the brunt of the expected cost of global warming.

Absence of actual impact data:

Unlike almost all other environmental externalities, there are no directly relevant data. All predictions of physical impacts are based entirely upon the predictions, judgments, and models of scientists.¹⁸ And there will be only one chance at collecting a data point -- once (or if) global warming does occur, then of course the impacts will be known.

Non-linearity:

Global climate change is determined by complicated interactions involving a chain of non-linear linkages (i.e. GHG emissions - atmospheric concentration - temperature change - physical impact). Therefore, climate change phenomena and risks are likely to be much more non-linear than the relationship between conventional emissions and more local pollution.

¹⁶ For new data on emissions and acid deposition rates in Asia, see *Interim Report, International Collaborative Project on Acid Rain and Emissions Reduction in Asia*, World Bank, Asia Technical Department, September 1993.

¹⁷ For a discussion of the relationship between economic assistance for restructuring in Eastern Europe and assistance to guarantee desired environmental standards, see e.g. M. Amman *et al.*, *Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies*, *Energy Policy*, p.1187-1198, Dec. 1992.

¹⁸ In some cases laboratory experiments -- such as growing plants in CO₂-enriched atmospheres -- do of course provide some actual data for predictions.

4. Cost-Benefit Analysis in the context of global warming

In light of these unique characteristics of the global warming problem, what can we say about the suitability of CBA? How and under what circumstances can CBA make a contribution to the central questions now facing decision-makers: (1) by *how much* should emissions be reduced? (2) *when* should emissions be reduced? and (3) *how* should emissions be reduced?

The fundamental problem in applying CBA to the climate change problem follows directly from the chain of causality discussed above: while estimating the costs of emissions reduction involves the beginning of the chain, estimating the benefits (or the avoided damage costs) involves the very end of the chain. Since there is some level of uncertainty associated with each of the links, estimates at the last stage of the chain are subject to compound uncertainties which may be very large indeed.

Estimates of the marginal cost curve

A number of studies confirm the shape of the marginal abatement cost (MAC) curve shown on Figure 4.1 for the specific case of GHG emission reductions. London Economics (1992) reviewed eleven studies, and determined the "average" MAC curve as shown on Figure 4.1¹⁹.

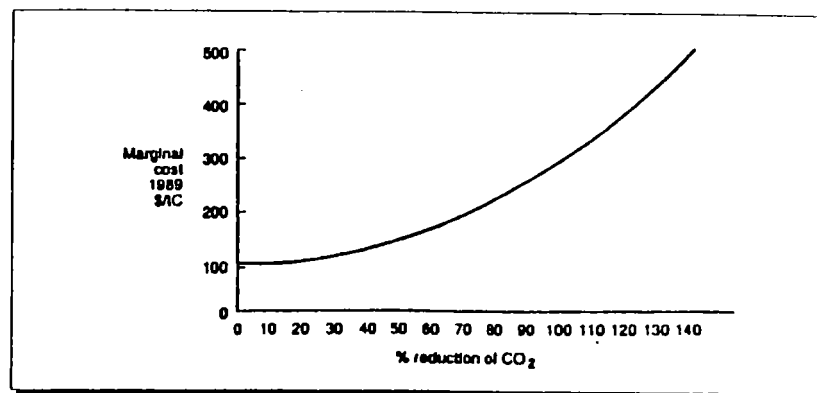


Figure 4.1: Marginal cost of CO₂ reduction (from GEF, 1992, p.31)

Such MAC curves have been derived for many industrialized countries, but for only few developing countries²⁰. On Figure 4.2 we show the cost for the U.K., as estimated by Jackson (1991). The curve is derived by a rank ordering of the individual measures considered by cost per ton of CO₂ saved (the height of each block), with the width of each block representing the

¹⁹ The most comprehensive review of cost studies is that by UNEP, *Greenhouse Gas Abatement Costing Studies*, UNEP Collaborating Center on Energy and Environment, Riso National Laboratory, Denmark, August 1992.

²⁰ A recent UNEP review on GHG abatement costing studies concluded "...the state of abatement costing studies in developing countries is wholly inadequate even to draw preliminary conclusions concerning possible costs and the impact of different abatement options. It is a body of analysis which is only just beginning, and which may take many years to mature towards consensus even on very rough estimates and understanding of the key issues (UNEP, *op cit.* p. 66)

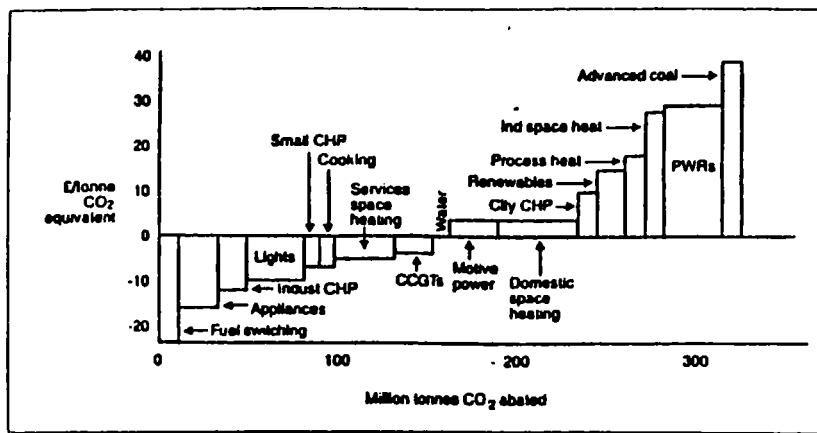


Figure 4.2: The marginal cost curve for the U.K.

tons of CO₂ so saved. The shape of the MAC curve, when smoothed, is indeed of the type indicated on Figure 4.1. Generally, these studies rely on known or near-term technical options, and ignore effects due to joint products, economies of scale, and capacity building, that might reduce the upward slope of the cost curve.

What is interesting in these (and other studies²¹) is the significance of "below the line" options (i.e. MAC is negative but still upward sloping). These are measures that appear to have negative costs associated with them – in other words, when these options are implemented, both costs and emissions go down, relative to the reference case.²² Compact fluorescent lighting, other energy efficient devices, and demand side management measures typically fall into this category, and in developing countries, measures such as reducing T&D losses, or instituting vehicle maintenance programs, also appear here. These, then, are measures that should be implemented in a least cost energy development strategy, even in the absence of any desire to reduce GHG emissions. The fact that they are not implemented reflects either market failures, or other factors, such as high transaction cost (which might exceed the potential benefits)²³

²¹ See e.g. J. Moreira et al., 1992 for Brazil; S. Sitnicki et al., Opportunities for Carbon Emissions Control in Poland, *Energy Policy*, 19,10, p.995-1002, 1992; or P. Meier, M. Munasinghe and T. Siyambalapitiya, *Energy Sector Policy and the Environment*, World Bank Environment Department, 1993, for Sri Lanka.

²² Unfortunately there is some confusion in terminology here. Some (e.g. London Economics, *Economic Costs of Carbon Dioxide Reduction Strategies*, Global Environment Facility Working Paper Series 3, Washington, DC, 1992), use the term "no regrets" to describe policies for which MB > MAC, i.e. for which the marginal benefits exceed the marginal costs. Others use the term only where MAC < 0, i.e. to those options that are "below the line" in the empirical cost curves of the type shown on Figure 4.2. However, since on both the cost and the benefit side there will be some netting out (e.g., to account for joint costs and benefits), the criterion MAC < 0 is arbitrary, whereas MAC < MB is well defined.

²³ The fact that such "no-regrets options" are in fact observed is much debated. What may be calculated as monetary benefits need not necessarily be regarded as benefits to decision-makers -- there may be other, non-monetary costs involved. The huge subsidies given to European agriculture illustrate the point that more than monetary benefits might be involved. In the case of developing

This issue highlights a practical problem for the Global Environment Facility (GEF). The GEF has been set up as the funding mechanism, on an interim basis, to provide financial resources needed by developing countries to meet the "full incremental costs incurred" in complying with their obligations under the Convention on Global Climate Change.²⁴ If the GEF is to fund the "incremental costs" of GHG reduction measures, this presupposes that a baseline can be unambiguously defined, against which such incremental costs are to be measured.²⁵ But under such a definition, should demand side management programs which have negative incremental costs-- such as energy efficient lighting -- be funded by GEF?²⁶

The marginal benefits curve

It follows from the discussion of the previous section that the level of uncertainty in benefits is much greater than the level of uncertainty in the cost curve. The practical implication of this, depicted in Figure 4.3, is that the optimum point of emissions reduction is also subject to significant uncertainty (indicated by points A, B, and C): whether the marginal benefits curve is MB1, or MB2 or MB3 has a much greater impact on the location of the optimum point of emissions reduction than the much smaller uncertainties in the marginal cost curve. Therefore, with such wide uncertainty about the economic optimum, CBA may not be very helpful. On the other hand, a "precautionary" level of emissions reduction, at P, has a very high probability of at least meeting the criterion that MB > MC.

In fact, there exist few if any estimates of the benefits curve, and most of the estimates that do exist are not much more than single point estimates for some presumed level of GHGs in the atmosphere. Well known for the US is the work of Nordhaus, who begins by classifying the

countries, the unavailability of finance may constrain the ability to implement some of these options. For example, until recently, obtaining finance through export credits for power generation expansion has been much easier than financing energy efficiency measures.

²⁴ These methodological problems have been recognized by GEF, who has initiated a research program to find an operational approach for measuring and agreeing upon full incremental costs within the context of the Climate Change Convention: the so-called PRINCE study (Program for Measuring Incremental Costs for the Environment). See K. King, *Issues to be Addressed by the Program for Measuring Incremental Costs for the Environment*, Global Environment Facility, Working Paper 8, Washington, DC 1993.

²⁵ Moreover, another problem here is that the concept of "least cost" as well as the integrated planning process to achieve it, may be quite complex (see e.g. M. Munasinghe, *Energy Analysis and Policy*, Butterworths Press, London, UK, 1990; P. Meier, *Power Sector Innovation in Developing Countries: Implementing Investment Planning under Capital and Environmental Constraints*, *Annual Review of Energy*, 15, pp.277-306, 1990; or E. Crousillat, *Incorporating Risk and Uncertainty in Power Sector Planning*, Industry and Energy Department Working Paper, Energy Series Paper 17, World Bank, Washington, DC, 1989). Such a solution, typically obtained by fairly sophisticated optimization models, may be "least cost" only for a very narrow band of input assumptions, and if these assumptions prove to be different, then an investment program predicated upon the "least cost" plan may ultimately be distinctly non-optimal.

²⁶ In the words of King, *op.cit.*, "...How can the adoption of apparent win-win solutions be stimulated? Such solutions are sometimes referred to as negative incremental cost projects because they are economically viable in their own right. The dilemma arises because these projects are often not being funded. On the one hand, if the GEF restricts itself to those projects that have positive incremental cost while the bulk of negative incremental cost options remains unfunded, it risks becoming irrelevant to the main solution to the global environmental problem. On the other hand, providing grant finance for economically viable projects effectively makes a net transfer to the country, which is not the purpose of new and additional funding, worse, it provides a perverse incentive to potential recipient countries to delay economic reform. (p.17)"

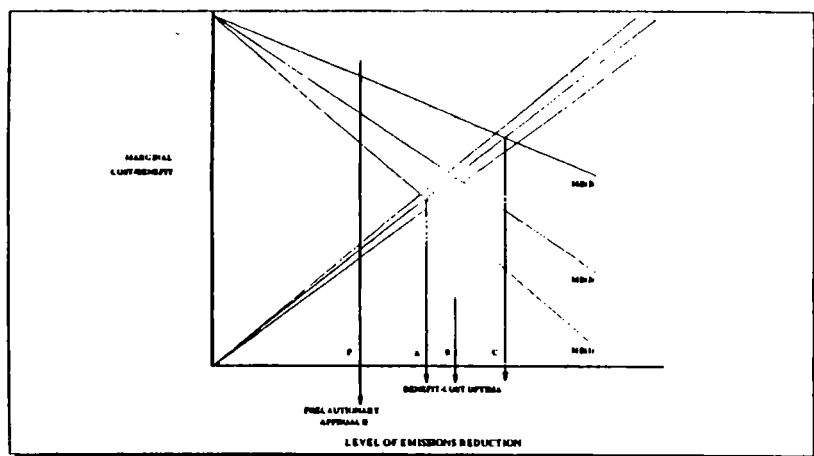


Figure 4.3: Uncertainty in the benefits curve.

components of economic activity (national income) into three groups: (1) those potentially seriously impacted; (2) those with moderate potential impact; and (3) those having negligible effect.

For the sensitive sectors, Nordhaus then goes on to estimate the impacts associated with a doubling of CO₂ in the atmosphere (Table 4.1). He concludes that in fact damage from sea level rise is the most certain major impact, since estimates on the most sensitive sector, agriculture, range from a significant net cost to a significant net benefit. Overall, the central point estimate of impact is 0.26% of national income.

The implication is that countries in which manufacturing and services are the dominant activities are not likely to be greatly affected in overall macro-economic terms (e.g. in the U.S., only some 3% of GDP is in the farm and forestry sector).

Whether this type of approach in fact captures all the relevant costs is of course subject to debate, since a whole range of costs like damage due to extreme weather events and potential non-market impacts, such as loss of biodiversity, is ignored. Moreover, it is entirely unclear whether some of the areas that have been included in Nordhaus' analysis have been given adequate attention.²⁷ For example, municipal water supply, which presently accounts for a very small part of national GDP, may be potentially extremely sensitive to small changes in climate in the western US — where even under present conditions costs are growing very fast.²⁸ However, as shown on Table 4.2, other estimates of the impact of global warming, including those which attribute much larger impacts to wetlands, species loss etc, do not result in significantly larger losses of output.

²⁷ For a critique of Nordhaus' estimates, see e.g. Williams (1993).

²⁸ A study of the impacts of global warming in California points to the severe problems that might be encountered in that state. Because of changes in the distribution of rainfall, resulting in winter runoff and lower spring runoff, water supply from reservoirs in the Central Valley Basin would significantly decrease. See EPA, *The Potential Effects of Global Climate Change on the United States*, Report to Congress, Office of Policy, Planning and Evaluation, Washington, DC, 1989.

Table 4.1: Estimates of the impact of global warming on the US GDP

	% of GDP	% of total	cost billion 1981 \$
Total national income			
Potentially severely impacted		3.1	
farms	2.8		10.6 to 19.7
forestry, fisheries, other	0.3		small
Moderate potential impact		10.1	
construction	4.5		negative
water transportation	0.3		?
energy (electric, gas, oil)	1.9		
electricity demand			1.65
non-electric space heat			-1.16
water and sanitary	0.2		positive?
real estate (land rent)	2.1		
loss of land			1.5
protection of sheltered areas			0.9
protection of open coasts			2.8
hotels, lodging, recreation	1.1		?
Negligible effect		86.8	
mining	1.9		
manufacturing	24.1		
other transport & communications	5.5		
finance, insurance	11.4		
trade	14.5		
other services	13.5		
government services	14		
rest of world	2.1		
Total impact			6.2

Source: W. Nordhaus, *Economic approaches to greenhouse warming*, in Dornbusch and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA, 1991.

Table 4.2: Estimates of the impact of global warming

	U.S.			Global		
	Nordhaus	Cline	Fankhauser	Other	Fankhauser	Other
Heavily affected sectors						
agriculture	1	15.2	7.4	1.2	39.1	12.3
coastal areas	10.7	2.5	2.3			
energy	0.5	9				
Other sectors						
wetlands and species loss		7.1	14.8			
health and amenities		8.4	30.3			
other	38.1	11.2	12.1			
total	50.3	53.4	66.9			
total as % of output (GDP)	1	1.1	1.3		1.5	2.8(a)

Blanks denote not available. (a) from Nordhaus's survey of experts. Sources: Nordhaus (1991), Cline (1992), Fankhauser (1992), for agriculture under "other" Retilly and Hohnmann, 1993.

Source: Nordhaus (1994), p. 369

Despite the suggestion that the economic impact of global warming on the industrialized countries is quite small, Nordhaus, as well as others, are quick to concede that such results may not apply to developing countries, where typically much larger shares of national income

are in agriculture, and much of it in subsistence farming in marginal areas where even small changes in climate may have devastating effects, and where the ability of the farming population to adapt may be very small indeed.²⁹ The types of human settlement most vulnerable to climate change are concentrated in developing countries, including low-income communities, residents of coastal lowlands and tropical islands (such as coastal Bangladesh, or the Maldives), populations in areas already significantly affected by desertification, and the urban poor in squatter settlements³⁰.

Unfortunately, to date, most of the discussions of impacts of global warming on the developing countries have been qualitative in nature,³¹ and there is an urgent need for more quantitative estimates for developing countries. According to a recent GEF survey of country studies³², there are now almost as many studies underway on effects as on mitigation, but it is difficult to ascertain how many of these studies, most of them now underway, will result in the sort of quantitative information necessary to construct an impact cost curve. Certainly none of the studies and papers published to date for developing countries contain quantitative estimates of the type derived by Nordhaus for the US.³³

Measuring costs and benefits

Nordhaus' work on the benefit (avoided cost) side, and much of the work on the cost side, assumes that the relevant measure by which to evaluate options is loss of GDP. This raises a separate set of questions about the extent to which GDP, (or loss of GDP growth) is the appropriate measure.³⁴ It is well established (Weitzman, 1976, Brekke, 1994) that GDP is not

²⁹ This is likely to be true even though higher CO₂ concentration itself may promote plant growth.

³⁰ For further discussion, see e.g. J. T. Houghton *et al.* (Eds). *Climate change--The IPCC Scientific Assessment*, World Meteorological Organization and the United Nations Environment Program, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 1990, or L. B. Lave and K. Vickland, *Adjusting to Greenhouse effects: the Demise of Traditional Cultures and the Cost to the USA*, *Risk Analysis*, 9, 283-291, 1989. However, as also noted by Nordhaus (1994), the fertilizing effect of atmospheric CO₂ is a particularly strong mitigating factor for Agricultural nations, particularly where water is a limiting factor: while the extent and quantitative importance of CO₂ as a fertilization agent are controversial, the balance of the evidence is positive (Nordhaus, 1994, p.369).

³¹ see e.g. the discussions of P. Gleick, *Climate Change and International Policies: Problems Facing Developing Countries*, *Ambio*, 18, 6, p.333-339, 1989; or R. K. Pachauri, *Global Warming: Impacts and Implications for South Asia*, Tata Energy Research Institute, New Delhi, 1991).

³² J. Fuglestad *et al.*, *A Review of Country Case Studies on Climate Change*, Global Environment Facility, Working Paper 7, Washington, DC, 1994. This report identifies 39 studies (or elements of studies) focused on inventories of GHGs, 48 studies of effects, and 46 studies on mitigation.

³³ For example, in a report prepared by the Tata Energy Research Institute for the India Ministry of Environment and Forests, the Chapter on Adaptive Strategies for India in the Perspective of Climate Change, which elaborated the impacts associated with given levels of sea level rise and mean temperature, was entirely qualitative in nature, and no cost estimates were attempted (TERI, *Report on Global Warming and Associated Impacts*, Report to the Ministry of Environments and Forests, January 1991). Similarly, neither Volume on Global warming published by the Asian Energy Institute (Pachauri and Behl, (Eds), 1991), nor the country studies conducted by UNEP (Reported in UNEP, 1992) contain any country specific estimate of costs associated with specific levels of GHG accumulation in the atmosphere. ADB is currently sponsoring a multi-country project in Asia that is attempting to establish costs of potential effects.

³⁴ There are several related issues. For example, should one use nominal exchange rates,

a welfare measure per se, but rather a convenient way to aggregate goods and services which clearly contribute to welfare.

Thus it is well recognized that GDP is an imperfect proxy for social welfare. One recent Norwegian study (Alfsen, Brendemoen and Glomsrod, 1992) showed significant differences in cost-effectiveness of different policy options for GHG emissions reduction policy when consumer surplus effects were also included in the analysis³⁵. These effects have found to be significant in developing countries as well, as shown by Meier *et al.* (1993) in the case of Sri Lanka (see Table 4.3).

Table 4.3: Impact of welfare losses of GHG abatement options in Sri Lanka
(in \$/ton of avoided carbon)

	no coal	wind	CFL
supply cost impact	16	67	-472
consumer impact	10	66	-66
total	26	131	-538

source: Meier, Munasinghe, and Siyambalapitiya, *op. cit.*, 1993.

notes: negative numbers indicate a benefit
CFL= compact fluorescent lighting

Of course, the magnitude of such impacts is a function of how much of the technology is adopted, how soon, and what discount rate is used. The effect of a single 25Mw wind plant will obviously be much less than if a 300 Mw wind farm displaces an imported coal plant in the near-term. Generally, what these results do underscore is the need for great caution when interpreting the so-called costs of GHG-emission reductions attributable to specific technologies.

Equally important are the concerns over the extent to which conventional measurements of GDP growth take into account the depletion of natural resources ("Green Accounting"). For many developing countries this is a particularly important issue, and there is a growing literature suggesting that conventional accounting substantially overstates GDP growth: the corollary is that estimates of GDP impacts of climate change that fail to take into account changes in the rate at which natural resources are depleted, or in environmental impacts, may be understating the true effect.³⁶

Some of these problems are evident from the numerical estimates. On Figure 4.4 we display the results of recent studies of the impact of emissions reduction strategies on loss of GDP³⁷. As is evident, these impact estimates show considerable variation: even so, none of

trade-weighted rates, or purchasing power parity rates in making cross-country comparisons of costs or impacts?

³⁵ Consumer surplus impacts have been vigorously debated in the United States in terms of how to evaluate the costs and benefits of demand side management (DSM) programs. For example, Hobbs(1991) shows that some programs may have positive benefits under a simple "least cost" criterion from the utility perspective (avoided supply costs exceed program costs to the utility), but have negative benefits when changes in consumer surplus are taken into account.

³⁶ The question of "green accounting" is one of valuing and aggregating marketable and non-marketable goods. The many different proposals for "green accounting" reflect the difficulties involved. Rather than speculate about valuation, or poorly founded proxies for non-marketable goods, MCA provides an alternative approach.

³⁷ These results are for studies that estimate both emissions reductions and GDP impacts relative to some baseline, i.e., relative to the trajectory of emissions in the absence of the policies followed. For many countries, particularly the developing nations, even significant reductions from such baselines

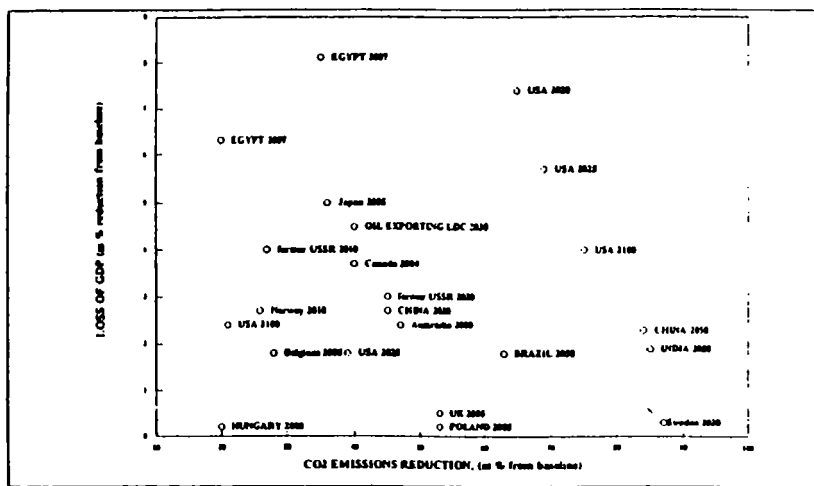


Figure 4.4: Impact of GHG emissions reductions on GDP

these estimates reflect "green accounting", and only one takes into account joint products.¹⁸ Most of these studies are national studies. Many researchers argue that unilateral action by the US or by OECD countries are likely to be less effective than global action, and that unilateral actions are likely to exaggerate the impact on GDP.¹⁹ However, these studies also neglect the benefits of the development of advanced technologies in the market economies, which could then be more quickly adapted in the developing world.

The joint products problem

A related question concerns the joint benefits and costs of emissions reduction. Options that reduce GHG emissions may also provide significant changes in other pollutants whose impacts are of a quite different scale. For example, the substitution of renewable energy technologies for coal will reduce not just CO₂ emissions – a *global* benefit – but also SO₂ and particulate emissions that bring a reduction in *local* environmental damages. On the other hand, the increased use of renewable energy technologies (such as hydroelectric generation), which also reduce CO₂ emissions, may also impose new and different local environmental *costs* (such as loss of biodiversity associated with reservoir inundation).

Estimates of the importance of joint benefits and costs vary widely (in part because valuing the costs and benefits of other environmental impacts may be subject to similar

may still imply increases in the absolute quantity of GHGs emitted. Other studies report results in terms of GHG emissions in some future target year, relative to emissions in some prior year (e.g. 2010 emissions 10% less than 1990 emissions).

¹⁸ S. Glomsrød, H. Vennemo, and T. Johnson, *Stabilization of Emissions of CO₂: a Computable General Equilibrium Assessment*, Central Bureau of Statistics, Discussion Paper 48, Oslo, Norway, 1990.

¹⁹ For further discussion see UNEP, *op.cit.*, p.72. Studies that have examined the question of unilateral v. multilateral approaches include Proost and van Regemorter (1990) for Belgium, and Edmonds and Reilly (1983) and Rutherford (1992).

Box 1: Valuation of joint products in the U.S.

The importance of joint products can be gauged at least in part from the practices of some regulatory commissions in the United States. A growing number of these now require that electric utilities take into account the value of air emissions in their cost-benefit analysis of alternative supply and demand side resources. The table below shows the current monetary values for some States

Externality values for air emissions, in \$/ton

	CO ₂	NO _x	SO ₂	particulates
New York	1.1	1,832	832	333
Massachusetts	22	720	1,700	4,400
Nevada	22	6,800	1,560	4,180
California (PG&E)	26	7,105	4,060	2,380

That the values assumed for CO₂ vary by an order of magnitude is to be expected, given the uncertainties on the benefits side of a unit reduction in emissions. But the wide differences in values for other emissions do reflect strong locational differences. Unlike for GHG, for most other air pollutants it *does* matter *where* they are emitted – indeed, values for the Los Angeles area for NO_x emissions are even larger than those shown on the table, reflecting the seriousness of the smog problem in that air basin. The point is that when joint products of GHG emission options are also included in the analysis, then *location* does play a role. Phrased differently, if one is going to reduce GHG emissions, it should be done in those places where the joint benefits of reducing related emissions is highest.

It should be noted, however, that while the CO₂ values are based on avoided costs (e.g. in Massachusetts and Nevada based on the cost of planting trees on otherwise unforested land), the externality values for the other pollutants are based on control costs, the conceptual basis for which is very weak. It is obvious from Figure 2.2 that using the abatement cost function as a proxy for the damage cost function, even in the vicinity of some health-based standard, is likely to involve substantial error. The use of damage control costs as a proxy is justified by these regulatory commissions solely on the basis that damage cost estimates are highly uncertain.

However, in one or two cases we do have consistently estimated damage cost-based externality values. On the table below we show that using estimates derived by the California Energy Commission, for every dollar in benefits resulting from the reduction of CO₂ emissions, there is another \$3 resulting from the reduction of conjoint pollutants. Whatever the uncertainties that may surround the actual values used, it is certainly a reasonable conclusion that joint benefits will significantly affect the overall cost-benefit assessment of GHG.

Estimated benefits of reducing electricity demand by 1 Mwh

	\$/ton	emission rate (lbs/mwh)	total benefit \$
CO ₂	26	1,820	23
joint products			
NO _x	14,483	6	43
SO ₂	7,425	6	22
TSP	57,620	0.3	9
total joint products			74

Emission rates based on a notional, new coal-fired plant meeting new source performance standards (NSPS). Externality values for NO_x, SO₂, and particulates based on 1992 California Energy Commission Report (Hahnen, Barakat and Chamberlain, California State Summary, EPRINET Environmental Externalities Clearinghouse).

Why do the benefits of pollution reduction for CA differ in these areas? Could they be made consistent?

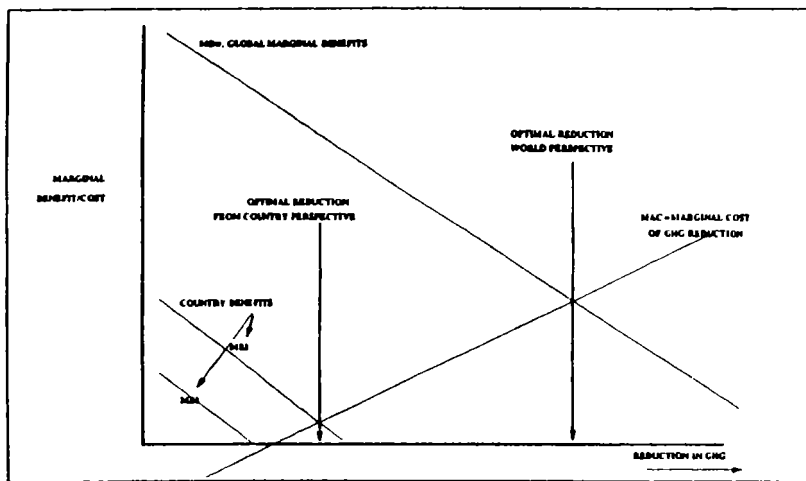


Figure 4.5: The marginal cost and benefits curve for an industrial country

difficulties of valuation and scientific uncertainty as for GHG emissions), but most lie in the range of 1 to 10\$ of additional benefits for every dollar of benefit from GHG emission reduction. (see Box 1). A recent Norwegian study (Alfsen, Brendemoen and Glomsrod, 1992) indicated that when the joint products of carbon reduction were taken into account (reduction in environmental damages to forests and lakes, health damages, reduced traffic congestion, road damage etc.), then such benefits go a long way toward compensating the economic loss measured as reduction in GDP.⁴⁰

Adding the benefits of reductions in conjoint pollutants to the MB measure is one possibility. The other is to subtract these benefits from the MC measure. Since most of such benefits go to the country that bears the costs of abating the CO₂ emissions, while the benefits of less CO₂ emissions go to all countries, it follows that the preferred approach is to adjust the marginal cost curves.

✓ Second point

The aggregation problem

We now turn to the matter of implementing policy. Consider first Figure 4.5, which depicts the situation faced by some country. Its marginal cost curve is upward sloping, in the manner discussed above; it begins with negative values (the "no regrets" or "win-win" options) again in the manner indicated earlier.

Suppose Figure 4.5 depicts the situation for an industrialized country, say the US. Suppose that indeed Nordhaus is correct in his estimates that the benefits to the US are rather small. If MB₁ were true, then the optimal policy would be only to implement the win-win policies – demand side management, more efficient end-use devices, economically efficient pricing, and the like. If MB₂ were true, for the US perspective, then perhaps only small

⁴⁰ For example, in one alternative (the "Treaty Alternative"), loss in GDP was estimated at 3.1 billion Kroner, and the loss of private consumption at 2.6 billion; however joint product benefits were estimated at 2.4 billion (with a range of 1.0-3.8 billion). (Alfsen, Brendemoen and Glomsrod, 1992, p.28).

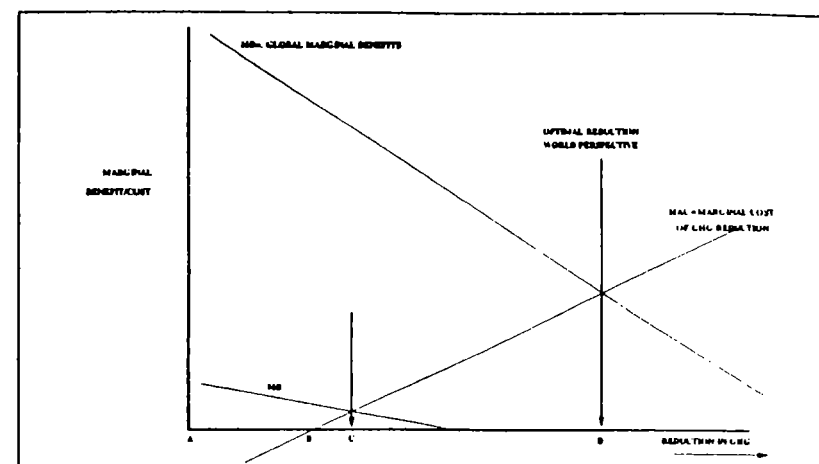


Figure 4.6: The marginal cost and benefits curve for a developing country

emissions reductions are warranted. We assume, of course, an appropriate adjustment for the valuation of the benefits of the reduction of joint costs.

However, the benefits to the rest of the world of emissions reductions are likely to be much higher: and hence the curve MB_w lies as shown, far above the MB₁ and MB₂ curves. Therefore, when global benefits of emission cost reductions are taken into account, the optimum level of emissions reduction shifts to the right, as shown. How one persuades decision-makers in the US (and in other industrialized countries) to take a global perspective is the main question.⁴¹

Consider now the situation for a developing country (Figure 4.6). Again the global benefits curve lies far above the curve for an individual country. Evidence from empirical studies suggests that a far larger portion of the MC curve is in the no-regrets zone. Several multi-country studies point to the same result.⁴²

⁴¹ In Figure 4.5 we have drawn, for clarity, only a single marginal cost curve (MAC). It is quite possible, however, that different countries will also have different marginal cost curves (although the differences in costs are likely to be smaller than the differences in benefits).

⁴² For example, studies by Burgess (1990) and by Larsen (1993) address the impact of eliminating price subsidies: they estimate the level of reduction in GHG emissions by application of assumed price elasticities to the difference between the subsidized and unsubsidized price. Burgess uses the difference between actual average cost of electricity and the estimated long run marginal cost (LRMC), applies an assumed long run price elasticity of -1, and estimates the reduction in GHG emissions for eleven countries, including the USA, China, India, and some small developing countries such as Tanzania and Peru. Not surprisingly, the bulk of the total carbon emission savings of 124 million tons/year (mtpy) come from coal fuel savings, of which India accounts for 11.9 mtpy, China 26.6 mtpy, and the USA 85.4 mtpy. Larsen does the same analysis but from the perspective of fuel prices, applies estimated own- and cross-price elasticities for the different fossil fuels to the difference between an appropriately adjusted border price and the domestic subsidized fuel price, and, more significantly, includes the countries of the former USSR and Eastern Europe. In this analysis, the former USSR (917 mtpy) and Poland (105.2 mtpy) dominate the results; indeed, the combined estimated impact in India (54 mtpy), and China (45.4 mtpy) together is less than that for Poland.

In the case of developing countries, it is the GEF mechanism that provides the means for shifting the level of emissions reduction undertaken by any specific country to the right. But in what range does the GEF mechanism operate? Conceptually, it should operate in the range CD, i.e. provide funding only beyond the optimal level from the country perspective. But since the MB curve is so difficult to determine, operationally, an easier definition is for GEF to operate in the range BD, i.e., from the conventional "least cost" point that would normally apply, and in which any benefits, even locally, from GHG reductions are simply taken as zero. For example, wind plants would not normally lie in the least cost expansion path for an electric utility (if environmental externalities are valued at zero); GEF provides the mechanism to fund such technologies. Yet in fact, GEF has also funded projects in the range AB -- such as the energy efficient lighting project in Mexico.⁴³

The difference between optimal level of reduction from the national perspective, and that from the global perspective, lies at the heart of the practical problem of implementation. A related but different issue -- related to equity -- concerns one of the premises of CBA, namely that sunk costs and past actions are not relevant. Yet developing countries argue that in the case of the climate change problem, past emissions are relevant, because it is the industrial countries, not the developing countries, that have accounted for the bulk of the man-made GHGs present in the atmosphere.⁴⁴

Systemic evaluation. The above results for Sri Lanka also point to the importance of systemic evaluations: the cost per ton of avoided emission for both wind and the no coal option are much lower than those estimated by others, for the exact same technology (see Table 4.4). The answer, of course, lies in the fact that the incremental cost of, say, wind power, depends upon what technology is being substituted: and these will be very different from case to case. For example in Sri Lanka, imported coal baseload plants largely determine the future system expansion cost. This is much more expensive than in India, which has available relatively large quantities of low cost domestic coal. Similarly in the generic cost estimates made by GEF for no coal options, the presumed substituting fuel is domestic oil or gas, not imported oil (as is the case for Sri Lanka). The point is that there likely exist very large, country-specific variations in the estimates of the cost of GHG emissions abatement through given technologies. Joint costs and benefits that are local in nature will very likely vary even more from place to place.

⁴³ GEF has recently introduced the term "Type I project" for those in which operate in the range AC (i.e. for which national economic benefits are greater than national costs), and "type II project" for those in the range CD, (i.e. for which national economic benefits are less than national economic costs, but the global benefits are such that the project is justified under GEF criteria). For further discussion, and arguments for why GEF should give priority to type II projects, see e.g. D. Anderson and R. H. Williams, *The Cost-Effectiveness of GEF Projects*, Global Environment Facility, Working Paper 6, Washington, DC., 1993.

⁴⁴ See, e.g. M. Munasinghe, Sustainable Energy Options for Developing Countries, *World Energy Council Journal*, 1, Dec. 1991, p.69-87.

Table 4.4: Comparisons of cost estimates for CO₂ abatement.

	study type	wind	no coal
Sri Lanka	systemic, single 300Mw windfarm	67-131	16-26
GEF	generic	116-223	45-89
India	supply cost	150-600	

Sources: For Sri Lanka, Meier, Munasinghe and Siyambalapitiya, *op cit.* for India J. Hossain and C. Sinha, *Limiting CO₂ emissions in the power sector of India* *Energy Policy*, Oct. 1993, p.1028. Generic estimate from London Economics, *Economic costs of carbon dioxide reduction strategies*, GEF Working Paper Series 3, Washington, DC, 1993

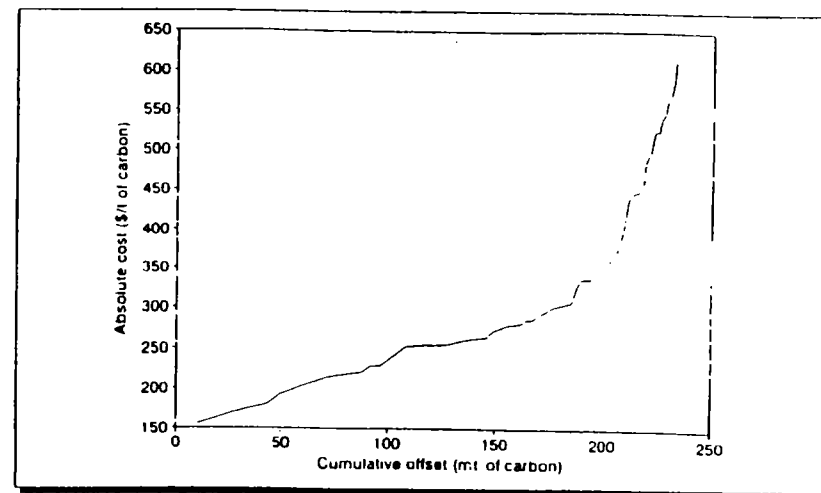


Figure 4.8: supply cost curve for windfarms in India

source: J. Hossain and C. Sinha, *Limiting CO₂ emissions in the power sector of India* *Energy Policy*, Oct. 1993, p.1028

Another way of making the same point is by noting that single point cost estimates for many technologies can be quite meaningless, because the supply curve for even an individual technologies is not flat. For example, in the previously presented GHG emission cost curve of Figure 4.1 (for the UK), "renewables" is shown as a single block, with a single marginal cost. Yet as shown in a recent study of wind and hydro for India⁴⁵, the supply curves have the expected classical upward sloping shape as illustrated on Figure 4.8 for the supply cost of windfarms in India. Such static cost curves neglect the counter-argument that in a more dynamic analysis, cost may decline due to economies of scale and technological advances.

⁴⁵ J. Hossain and C. Sinha, *Limiting CO₂ emissions in the power sector of India* *Energy Policy*, Oct. 1993, p.1028

5. Issues

Risk, uncertainty and irreversibility

Our knowledge about how anthropogenic emissions of greenhouse gases affect global temperature, what kind of effects a change in global temperature may have, and how efforts to mitigate climate change may work is clearly restricted. How different greenhouse gases react in the atmosphere are not fully understood, and exact predictions of the average increase in global temperature will have different regional effects which are exceedingly difficult to foresee, even if the effect on the average temperature were taken as given. There is also considerable uncertainty about the economic and social effects of abatement measures, which are decisive for the costs and benefits of the measures.

One cannot, therefore, evaluate climate measures without taking these uncertainties into account. On the other hand, acknowledgment of vast uncertainties should not lead to an inert attitude, but rather to develop rational strategies for how to act under uncertainty. Economic analysis under uncertainty aims at developing strategies for decision makers that face uncertainties in their future costs and benefits. The uncertainty in the outcome of a variable is often described by a probability attached to each possible outcome. In some cases the probability distribution is objectively presented, in which cases one normally talks about risk. More often, subjective probability distributions are assumed, in which cases one talks about uncertainty.

The attitude towards risky outcomes is often expressed in terms of a risk premium, which is the minimum compensation required to accept a lottery with expected return x to a certain return of x . Such a premium may be required because the decision maker prefers certain to uncertain outcomes, but may also occur if the net benefit of his investment is non-proportionate in quantity. For instance, suppose a country commits itself to reduce emissions by 100 tons, and considers two alternative measures. One alternative reduces emissions by 100 tons with certainty. The other measure has a 50 percent chance of reducing them by 100 tons. Even if the expected reductions are equal, it is evident that a decision maker will prefer the certain alternative unless the uncertain alternative is considerably less costly, as there is a chance of having to impose additional measures if unlucky. Assessments of the uncertainty involved in the analysis of climate change may therefore be of great importance to decision making.

However, given the uncertainty it is also important to emphasize that some actions will be less attractive than others. The mirror of the above argument is that some actions may be acceptable even with negative net expected benefit if they reduce the uncertainty. One way to do so is to spread the risk among several measures. Then, if one fails to meet its expected target, another may satisfy the achievements that were expected. The total risk would thus be lower than if all efforts were concentrated on one single measure.

One is scarcely able to account for all the uncertainties involved when analyzing climate change. In some cases it may be equally difficult to assess a probability distribution of a variable as a single expected estimate. Ignorance about certain effects of a measure indicate that they should be left out of the analysis. However, CBA may be of great help to decision making even when limited to effects on which reasonably well-founded value-estimates can be provided.

One issue that has attained a lot of interest in the literature of environmental economics is the problem of irreversible decisions under uncertainty. The reason is that environmental effects, such as climate change are regarded as irreversible. If the effects turns out to be worse

(or even many)

It's not clear this is a useful comparison -- you might want a distribution with 50% chance of 700-ton reduction and 50% chance of <100-ton reduction

than expected, the world is stuck with a permanent, perhaps unwanted, climatic change, which clearly is worse than if the climate could be reestablished after such a change.

Provided that the CBA is worked out correctly, however, the cost of irreversible effects would be included. This requires a vast amount of information, such as how the uncertainty evolves over time. Such information, is rarely available, but we may assume that increased knowledge about climate change will narrow the range of uncertainties in the future. If so, it has been shown that measures causing irreversible effects have an extra cost, called quasi option value. This value can be interpreted as the value of keeping future options open, and suggest that decision makers follow flexible strategies when faced with uncertainty.

The strategy that leaves most future options open is, however, difficult to determine. Investing in abatement of climate change opens possibilities for increasing emissions at a later stage if the effects turns out to be less serious than expected. On the other hand, it reduces the potential use of adaptation. In addition, it is difficult to predict the effect of increased knowledge, especially whether the outcomes become more certain. When dealing with many of the effects of climate change, ignorance is perhaps a more appropriate concept than uncertainty. Increased knowledge may change ignorance to uncertainty, but the range of possibilities will not necessarily narrow for that reason.

In applying CBA to the global climate change problem, and in particular to the evaluation of alternative policies to optimize net benefits, there are ~~two~~ major sources of uncertainty that need to be considered:

seven

1. Uncertainty over the actual rates of emission. All of the many studies cited earlier make assumptions about current and future rates of emissions in some "business-as-usual" case as a starting point. Current projections of CO₂ emissions from fossil fuel use may be reasonably well known, but the level of uncertainty increases as one moves to levels of possible fossil fuel use in the more distant future, the impact of deforestation, or to other GHGs such as methane.⁴⁴
2. Uncertainty over the costs of emissions reduction. Again there are significant differences between estimating the costs in electric utility systems (relatively well known for conventional technologies) and those elsewhere, particularly for reforestation.
3. Uncertainty about scientific linkages. As already noted in section 3, there exists a chain of scientific uncertainty (see Figure 3.1). The extent to which these uncertainties can be resolved by further research is itself subject to uncertainty (especially in light of the previously noted fact that by its very nature, *ex ante* verification of models by actual data is impossible). Thus it is unclear that similar arguments invoked in the context of other environmental problems have validity for global climate change. For example, the argument that further research was necessary on an understanding of atmospheric chemistry, or of the chemistry of lake acidification, or of the exact nature of the damage mechanisms on forests, before very costly efforts are undertaken to control SO₂ and NO_x emissions, did at least have the merit that data on the actual damage of acid rain could be found.
4. Uncertainty in valuing the costs and benefits of the physical impacts. Here there may exist quite large variations in the level of uncertainty: for example, evaluating the cost of protective dikes to protect against sea level rise, or of estimating the opportunity cost of inundated land is subject to significantly less uncertainty than estimating the impact

⁴⁴ For a full discussion of uncertainty in emissions, see e.g. Ebert and Karmali (1992)

This does not seem to be in the references

Box 2: Applications of decision analysis

Option analysis: In conventional CBA analysis, the usual decision rule is to take some action if the expected benefits exceed the expected costs. Depending on the degree of irreversibility present, a more appropriate rule is to take the action when benefits exceed costs by an amount at least equal to the value of the forgone option. Suppose some investment depends upon some assumptions that are subject to great uncertainty – such as future world oil prices. If one makes some investment decision that is largely irreversible – such as building a large hydroelectric power project – then one loses the flexibility associated with waiting to learn more about the factors that affect oil prices. Preserving that flexibility has some economic value, namely the so-called option value. In financial and commodity markets such options to buy (and sell) are traded, with option prices determined by the market itself. But option value theory is now being applied to other fields involving capital intensive investments – such as power generation.¹ In applying these concepts to the climate change problem, there are of course many key differences. First, in one sense the problem is exactly opposite to that faced, say, by the power sector: in climate change, one loses flexibility if one does *not* make short-term investments to reduce GHG emissions. Second, unlike in the financial and commodity context, there is no marketplace to set the value of the option.²

Decision analysis and hedging strategies: Among the foremost exponents of applying decision analysis to the global warming problem are Manne and Richels,³ who have developed an approach for determining the optimal hedging strategy. The paradigm they use is that of a portfolio of insurance options:⁴ what combination of insurance should be bought, if indeed any at all? "...what portion goes to R&D to resolve scientific uncertainties? What portion goes to the development of new supply and conservation technologies to reduce abatement costs? And what portion goes to immediate abatement of emissions? Particularly they focus on the value of information: how much accuracy is needed in climate modeling and impact assessment? Clearly, with perfect information, the best course of action can be charted immediately, and there is no need to hedge bets. Manne and Richels conclude that the need for precautionary near-term emissions reductions is inversely related to the sustained commitment to R&D to develop better climate information (which reduces the need to hedge against an uncertain and potentially hostile future).

¹ See e.g. E. Crousillat and S. Martzoukos, *Decision-making under uncertainty: An option valuation approach to power planning*, Industry and Energy Department Working Paper, Energy Series Paper 39, World Bank, Washington, DC, 1991. This study reviewed power sector investment decisions in Costa Rica, Hungary and West Africa.

² A marketplace might of course emerge if a tradable emissions permit system were to be instituted. Chao and Wilson (1993) outline a means of using option values to quantify the flexibility associated with the purchase of a tradable emissions permit instead of fixed capital investment in control technology.

³ See e.g. A. S. Manne and R. Richels, *Buying greenhouse insurance: the economic costs of carbon dioxide emission limits*, MIT Press, Cambridge, MA, 1992.

⁴ L. Lave (*Are economists relevant? The efficiency of a carbon tax*, in Doranbusch and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA, 1991) notes that the concern about global climate change is not merely concentrated in the rich nations, but in the upper income groups in those nations; these are the same groups that voluntarily purchase insurance to protect themselves against other losses: health, flood, earthquake. Persuading poor people to buy flood or earthquake insurance is exceptionally difficult even in the developed countries.

⁵ The value of information under uncertain conditions is a concept much used in the private sector. For example, in oil exploration, before drilling a wildcat well – a very expensive proposition – the question arises as to how much ought to be spent in much less expensive prior survey work: general magnetic surveys, or more expensive seismic surveys? Neither yields perfect information. For details of how such decision-theory models are applied in this field, see e.g. Newendorp (1976).

on agriculture, or on biodiversity.

5. **Uncertainty about the assumptions underlying policy options:** For example, a number of studies have estimated the impact on GHG emissions of eliminating subsidies on coal, or on electricity, using assumed values of price elasticity.⁴¹ General equilibrium models require all kinds of assumptions about the elasticities of substitution, whose actual values used in the numerical simulations are either based on historically estimated elasticities, or upon the judgment of the modeler. In either case there is uncertainty about the extent to which such values match actual behavior.
6. **Uncertainty over the effectiveness of policies:** For example, the proposition that a certain level of carbon tax will in fact result in the hypothesized fuel substitution makes a number of assumptions about the functioning of markets. As noted earlier, the very fact that many apparently "no regret" options are not being implemented suggests a higher level of market imperfection than economists like to admit, and/or substantially higher transaction costs or discount rates.
7. **Uncertainty about joint benefits and costs:** As noted earlier (see Box 1), joint benefits and costs may be a very significant factor in evaluating options for greenhouse gas abatement. However, these joint benefits and costs are also subject to significant uncertainties (and also measurement problems).

The application of valuation techniques is difficult even where the impacts themselves can be quantified with relative confidence. But in the case of global climate change, however, uncertainties in economic valuation techniques may be significantly smaller than the scientific uncertainties that surround the impacts of increasing concentrations of greenhouse gases. Advocates of immediate mitigation action to reduce emissions argue that even if the probability of some of the important impacts are unknown, and subject to great uncertainty, they are not zero. Low probability, high impact events are especially complex to model, and may also elicit counter-intuitive public reaction due to extreme risk-averse behavior (e.g. nuclear accident). Further, the process of global warming, once underway, will be irreversible (at least during a period measured in centuries), and the damages which may result are so catastrophic, that action may be warranted even in the absence of more precise scientific knowledge about the impacts.

A good analogy is a nuclear power plant accident. The Chernobyl incident notwithstanding, the risk of catastrophic accident is extremely small. But the cost of a major accident is undoubtedly very large. Both the probabilities⁴², as well as the cost of the impacts, are very difficult to estimate. But even if one could agree on appropriate values to use, and one were able to calculate an expected value, decision-making on the basis of the expected value may still not reflect the preferences either of the public or of decision-makers. The consequences of even an extremely unlikely event may be perceived as so undesirable (especially in the case of extreme risk aversion), that "normal" decision rules may simply not be viewed as appropriate. In other words, cost-benefit analysis must deal not just with expected values, but also with risk preferences of the decision-makers, and those they represent.

⁴¹ see note 42, *supra*.

⁴² The US Nuclear Regulatory Commission has made repeated attempts to establish probabilities for specific kinds of accidents through a technique known as fault tree analysis. Despite the appearance of scientific rigor, the resultant probability estimates remain highly controversial. For examples of the use of cost-benefit analysis by the US NRC, see e.g. Mubayi *et al.* (1991) or Abrahamson *et al.* (1989).

✓ *not necessarily true - the investments made to reduce GHG's could themselves be perfectly reversible - e.g., to build a hydro dam and flood an area*

The traditional and simple way of incorporating uncertainty considerations in CBA has been through sensitivity analysis. Using optimistic and pessimistic values for different variables can indicate which variables will have the most pronounced effects on benefits and costs. While sensitivity analysis need not reflect the probability of occurrence of the upper or lower values, it is useful for determining which variables are most important to the success or failure of a project (Dixon *et al.* 1988). Indeed decision-makers often assign (even if only implicitly) probabilities to the various outcomes. Admittedly, the sheer magnitude of the costs of catastrophic climate change will make the sensitivity analysis problematic.

One might note that for certain types of uncertainty, something akin to risk insurance is available in the form of futures and options markets. For example, one can hedge against uncertainty in the future price of oil by transactions in the oil futures markets, but their efficient functioning depends upon there being some balance between those who are buyers of oil (who are primarily interested in protecting themselves against a rise in the price), and sellers of oil (who are interested in protecting themselves against a fall in the price of oil) (See Box 1).

Finally, extreme uncertainty might also influence the nature of the economic instruments employed for policy purposes. For example, a price-oriented mechanism (such as a carbon tax) which limits economic dislocation might be preferred over a quantity-based mechanism (such as tradable permits) in a situation where there are both uncertain control costs and an uncertain environmental response (see Lave and Gruenspecht, 1991).

Valuation

The robustness of a cost-benefit analysis depends critically on how reliable the values attached to each item are. The prices of marketable goods and services express social values as long as the goods in question are not rationed and there are no externalities. For non-marketable goods and services, such as many environmental services, values have to be estimated in order to aggregate costs and benefits and obtain an overall evaluation of choice of policy. "Synthetic" prices will depend on the methodology chosen to create them, and one should therefore interpret results which include such prices with caution.

One reason why avoiding climate change may have a value is that climate change will cause a change in economic activities. Sea level rise will force people to move, more turbulent weather conditions may increase the need for rebuilding of damaged materials etc. A second reason is that people attach subjective values to the climate where they live, to some extent reflected in the notions of "good" and "bad" weather.

However it is difficult to assess these values. To simplify somewhat, one may base an estimate on the anticipated costs of achieving a certain target at observed market prices, for instance the minimum abatement cost of attaining the same level of greenhouse gases emissions as a previous year. Alternatively, one may estimate the willingness to pay for reaching such a target. In neither of the cases, however, would one be able to assess the equilibrium price, or the value. The choice of approach might therefore be strictly decisive for the conclusion, for instance if pollution that causes severe damage (high willingness to pay) could be avoided by low costs.

Valuation of environmental effects in CBA may be helpful in attaining cost-effective decisions. However, the valuation should be based on a reasonably well founded methodology. Speculative assumptions will not contribute to decision making. A measure which yields negative net benefits according to an analysis may be worthwhile to accept if effects that are

* Precautionary expenditures may also be influenced by aversion to catastrophic risks. A recent example is the hundreds of billions of dollars per year spent in the U.S. to avert Soviet nuclear attack

assumed to be positive but not explicitly valued in the calculation are well documented. Decision makers will normally manage to consider more than one measure simultaneously. CBA usually simplifies the decision by aggregating several effects, but there is no necessity for all effects to be aggregated into one single measure.

There are several fundamentally different types of costs and benefits that must be addressed, each of which requires somewhat different approaches to quantification and valuation:

1. Mitigation actions taken before the actual impacts are observed. These are primarily a matter of emissions reductions, or of removing GHGs through reforestation. The vast majority of the applications of cost-benefit analysis have addressed the question of how best to achieve given levels of emission reduction reductions. Valuation issues generally do not arise in this category.
2. Costs of mitigation actions taken after impacts become apparent. These will necessarily occur in the future, and would be undertaken only if (1) global warming actually does occur, and (2) that global warming does indeed result in specific impacts. The cost of dikes to prevent inundation of coastal areas is a typical example in this category: based on actual experience (such as in the Netherlands) the cost of such mitigation actions are relatively easy to establish. Climatic engineering options also fall in this category, such as painting roads and roofs white, or putting particles into the stratosphere. Again there are few valuation issues here.
3. Costs (and benefits) of Adaptation. Society will adapt with varying degrees of pain to many of the impacts of global warming. For example, climate change will affect crop yields, and result in Northward shifts in cultivated land. Some areas will gain, and some will lose, which becomes an equity issue (between regions and countries) as much as a cost issue. Estimates of net losses for U.S. agriculture, for example, suggest a tolerable impact for the U.S. as a whole, but significant regional variations.³⁰ Some of the costs of adaptation will vary, depending on ex-ante actions (e.g. more agricultural R&D expenditure to develop drought or saline resistant crops).
4. Costs (and benefits) of non-adaptation. In some cases, adaptation may not be possible, and/or the cost of mitigation may be higher than the loss incurred in its absence. For example, in some areas, the cost of construction of dykes may be far higher than the value of the land lost to coastal flooding, in which case the relevant cost to be estimated for purposes of CBA is the value of the land lost.

It is thus in the third and fourth of these categories that valuation issues arise. Table 5.1 lists the specific categories of impacts that may be encountered as a result of global climate change, together with an indication of the degree of valuation difficulties likely to be encountered.

Conceptually, the total economic value (TEV) of a resource consists of its use value (UV) and non-use value (NUV).³¹ Use values may be broken down further into the direct use value (DUV), the indirect use value (IUV) and the option value (OV) (potential use value). One needs to be careful not to double-count both the value of indirect supporting functions and the value of the resulting direct use. One major category of non-use value is existence value (EV). Thus

³⁰ "Preliminary results suggest that although US crop production could decline, supplies would be adequate to meet domestic needs" (EPA, *op cit.*, 1989, p.93).

³¹ For further details, see Munasinghe (1993).

is this reference correct?
is this partially because under a tax is simpler than a tradable permit system?
redefining property rights necessary to under a tradable permit system?

Table 5.1: Potential impacts to be valued¹

Systems	Potential Impacts
forests/ terrestrial vegetation	migration of vegetation reduction in inhabited range altered ecosystem composition
species diversity	loss of diversity migration of species invasion of new species
coastal wetlands	inundation of wetlands migration of wetlands
aquatic ecosystems	loss of habitat migration to new habitat invasion of new species
coastal resources	inundation of coastal development increased risk of flooding
water resources	changes in supplies changes in drought and floods changes in water quality+hydropower production
agriculture	changes in crop yields shifts in relative productivity and production
human health	shifts in range of infectious disease changes in heat-stress and cold-weather afflictions
energy	changes in fertility due to stress increase in cooling demand decrease in heating demand changes in hydropower output
transportation	fewer disruptions in winter transportation increased risk for summer inland transportation risks to coastal roads
also considered in EPA study	
air quality	
other impacts not considered in OTA or EPA studies	
weather-related damages	damages related to changes in the frequency and severity of extreme weather events like storms
amenity value	
construction	
industry	

¹ Systems and potential impacts as listed in OTA, *op. cit.*, p. 15.

$$TEV = UV + NUV$$

or

$$TEV = [DUV + IUV + OV] + [NUV]$$

Figure 5.1 shows this disaggregation of TEV in schematic form. Below each valuation concept, a short description of its meaning and a few typical examples (based on a tropical rainforest) of the environmental resources underlying the perceived value, are provided. Option values and non-use values and existence values are shaded, to caution the analyst concerning some of the ambiguities associated with defining these concepts — as shown in the examples, they can spring from similar or identical resources, while their estimation could be interlinked also. However, these concepts of value are generally quite distinct. Option value is based on how much individuals are willing to pay today for the option of preserving the asset for future (personal) direct and indirect use. Existence value is the perceived value of the environmental asset unrelated either to current or optional use, i.e., simply because it exists.

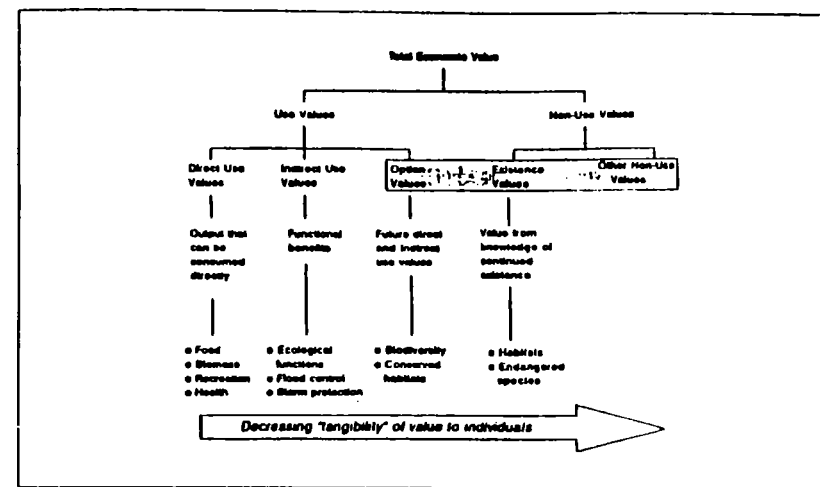


Figure 5.1: Categories of economic values attributed to environmental assets

A variety of valuation techniques may be used to quantify the above concepts of value.³² The basic concept of economic valuation underlying all these techniques is the willingness to pay (WTP) of individuals for an environmental service or resource, i.e., the area under the compensated or Hicksian demand curve. As shown in Table 5.2, valuation methods can be categorized according to which type of market they rely on, and by considering how they make use of actual or potential behavior.

Table 5.2: Taxonomy of relevant valuation techniques

	conventional market	implicit market	constructed market
based on actual behavior	change of productivity loss of earnings defensive or preventative cost	travel cost wage differences property values proxy marketed goods	artificial market
based on potential behavior	replacement cost shadow project		contingent valuation

source: Munasinghe (1993)

We note that these valuation techniques have been developed for more conventional environmental impact analysis, and would require significant modification and/or careful interpretation when applied to global climate change (e.g. long-term intergenerational impacts, biodiversity loss, welfare comparisons across cultures, or where there are wide gaps between gainers and losers, etc.).

³² For a recent overview of techniques suitable for valuing environmental costs and benefits, see M. Munasinghe, *Environmental Economics and Sustainable Development*, World Bank Environment Paper 1, Washington, DC, 1993

Discount rate

We noted in the introduction that CBA requires a very specific and explicit way of dealing with time. The first principle is that past (or "sunk") costs are ignored, based on the premise that since past decisions cannot be changed, they have no bearing over decisions regarding the efficiency of resource use that are to be made in the present or in the future.³³

The second principle is that a discount rate is applied to future costs and benefits to yield their present values. The issue of choosing an appropriate discount rate has been discussed in the context of general CBA for many years (Dasgupta et al. 1972, Harberger 1976, Little and Mirrlees 1974, Sen 1967). The long term perspective required for sustainable development suggests that the discount rate might play a critical role in intertemporal decisions concerning the use of environmental resources (Lind and Arrow 1982).

Compared with most other economic investment decisions, the time perspective of measures aiming at mitigation of climate change is considerably longer. Cline (1992) suggests a 200 - 300 years time horizon for climate policy decisions, while investments in economic activities seldom need more than a 25 years horizon. This makes assumptions about how the economic and the environmental systems will develop, and the discounting of values that occurs in the future critical to the evaluation of measures.

The discount rate denotes the social opportunity cost of capital. It reflects total social benefits if one unit of present output is withdrawn from consumption and rather is invested for instance in production or abatement. The criteria for optimal social and economic development is that the marginal total benefits from the investments should be equal regardless of what the investment is aiming at. In other words, the social discount rate should be equal for all investments. If not, it would be possible to reallocate resources and attain a higher social benefit without any cost. Thus, the discount rate expresses a condition for dynamic (or intertemporal) efficiency.

The discount rate provides a signal to decision makers who evaluate single projects or measures to take decisions in accordance with dynamic efficiency. Although the requirement to apply an equal discount rate for marginal projects is inevitable, there are many potential optimal levels of the discount rate. This level depends, *inter alia*, on the social preferences about present versus future consumption which may be reflected by an intertemporal welfare function. The formulation of this function has been the subject of an extended debate in which questions about intertemporal comparisons as well as current welfare contributors have been raised.

Two concepts mainly help to shape the discount (or interest) rate in a market economy. First, there is the personal rate of time preference of individuals which determines how they compare present-day with future consumption. Second, there is the rate of return on (or opportunity cost of) capital, which determines how an investment (made by foregoing today's consumption) would yield a stream of future consumption (net of capital depreciation or replacement). In an ideally functioning market, the interest rate which equilibrates savings and investment, also equals both the marginal rates of time preference and return on capital. In practice, government policy distortions and market failures lead to divergences between the rates of time preference and return on capital. Furthermore, the social rate of time preference may be less than the individual time preference rate, because long-lasting societies are likely to have a bigger stake in the more distant future than relatively short-lived individuals.

³³ One needs to take note of the fact that this principle is also not universally accepted, particularly by political leaders: the principle that "past sacrifices ought not to be in vain" is frequently invoked as relevant to present decisions.

Box 3: Discount rate and inter-temporal choice

In order to illustrate some important intertemporal choices when deciding about the social welfare function, however, it suffices to apply the additive one, which indeed represents the standard choice.

$$W(c(t), \dots, c(T)) = \sum_{s=t}^T U(c(s)) / (1+\delta)$$

$W(c_t, \dots, c_T)$ is total utility from t to T , which is the sum of the utilities at each time s from t to T , as evaluated at t . $U(c(s))$ is the utility of consumption at s , evaluated at s . δ is the rate of impatience. For simplicity we do not distinguish between total consumption and consumption per capita in this illustration.

The marginal utility of consumption, which is the quality gain from a given increase in consumption, is assumed to be decreasing. In an intertemporal context, this means that an increasing consumption path yields less utility per unit consumption as time passes. How much, depends on the elasticity of marginal consumption, denoted ω . This expresses the attitude towards the distribution of consumption among generations (formally $\omega = -cU'/U'$, where accents denote partial derivatives). The more weight the society gives to inter-generational equity, the higher the value of ω .

The other intertemporal implication of the choice of a welfare function is the choice of δ . Impatience means that preferences over given consumption levels to be consumed in each future year implies the highest level the first year, the second highest next year and so forth till the lowest level the last year. There is empirical evidence that δ is positive, meaning that people seem to be impatient with respect to their own consumption. However, the climate change issue is a genuine intergenerational problem, and one may ask whether individual impatience ("from me to me") is of relevance in such a context ("from me to my descendants"). It should be emphasized, though, that impatience does not imply decreasing consumption. This is because output withdrawn from consumption can be invested and yield a social return next year, thus making the consumption potential higher. The problem is to balance these respects. Optimal economic development requires the following relation between the social rate of return, denoted $\gamma(t)$, and the rate of consumption growth c/c to be fulfilled:

$$\gamma(t) = \delta + \omega c/c$$

Assuming that we know the parameters δ and ω , we can assess the social rate of discount if the optimal rate of consumption growth is known, or vice versa. This means that a high discount rate reflects a high rate of growth in consumption. Accordingly, a rapid decline in consumption due to an "environmental disaster" in the far future would, if optimal, result in a low, perhaps negative, discount rate. This would make decision makers take such effects into account, even in present day decisions. Note that in general, there are no reasons why the discount rate should be constant over time even if δ and ω are constants, since c/c need not be constant. In fact, if we assume a gloomy scenario where future output and consumption decline, then c/c may be negative and $\gamma(t)$ could decline over time (Munasinghe, 1993, Sterner, 1994).

By observing the variables of the above equation, one will normally find that the left hand side differs from the right hand side. There may be several explanations to this, and there is a broad literature discussing how to assess the "correct" social discount rate (see Lind (1982) for a survey). Applying the return on private investments, for instance, one has to take into account that the observations will be affected by the existing tax system, which normally is not "perfect" in the sense that it reflects all the social consequences of a private investment, such as the consequences of climate change.

The rate of capital productivity is very high in many developing countries, because of capital scarcity, and the rate of time preference also is elevated because of the urgency of satisfying immediate food needs rather than ensuring long term food security (Pearce and Turner 1990). Projects with social costs occurring in the long term and net social benefits occurring in the near term will be favored by higher discount rates. Conversely, projects with benefits accruing in the long run will be less likely to be undertaken under high discount rates. Thus, some environmentalists have argued that discount rates should be lowered to facilitate environmentally sound projects meeting the CBA criteria. However, this would lead to more investment projects of all types, thereby possibly threatening fragile environmental resource bases. Norgaard (1991) argues that lowering discount rates can in fact worsen environmental degradation – by lowering the cost of capital and thereby lowering the cost of production, more is consumed in the near-term relative to the case where discount rates were higher. Further, using a very low discount rate to protect future generations is inequitable, since it would penalize the present generation and increase inequalities across time periods – especially when the present contained widespread poverty (Pearce 1991).

In order to facilitate such intergenerational transfers, one option is to impose a sustainability constraint, whereby current well-being is maximized without reducing the welfare of future generations below that of the current generation. In practice, this would entail monitoring and measurement of capital stocks (man-made, human and natural), and a broad investment policy which sought to ensure that compensating investments offset depreciation of existing assets (Pearce 1991). Theoretically, the aim would be to ensure that the overall stock of assets is preserved or enhanced for future generations, but practical application of this principle would be difficult.

It is worth emphasizing that although externalities related to climate change will affect the social rate of discount, it is not sufficient to merely adjust this discount rate in order to take full account of climate change in a CBA. One must include also the "price" of the environment, which may increase substantially over time. As a consequence, future impacts from climate change may be quite important to present day decisions, even in "discounted terms". A five per cent increase in the price of the environment will fully counteract the effect of a five per cent discount rate.

To conclude, discounting is necessary to attain a socially optimal development. Attempts to avoid discounting or to apply a different discount rate for climate measures than other investments will inevitably result in an inefficient policy. However, it is difficult to pick out the correct level of the optimal social rate, as there are no observations of such a rate. Furthermore, discount rates may depend on the future scenario that is assumed, and could vary over time – in particular very long term discount rates may be lower as growth rates saturate (see Box 3).

CBA and Equity

CBA can provide answers on who should engage in how much abatement based solely on the criterion of maximizing economic efficiency. It must however be recognized that some deviation from the global least-cost solution as obtained by CBA may have to be accepted in order to get international agreement. As indicated earlier on Figure 2.1, there will likely be a trade-off between equity objectives and economic efficiency.³⁴ CBA can help define the trade-off curve, but it cannot provide an answer to what combination of economic efficiency and equity is necessary to get international agreement. However, whether there is a trade-off between equity and efficiency (and the properties of this trade-off) depend upon what policy

³⁴ Equity Issues are dealt with in detail by Writing Team 4

instru... availa... For example, if one permits side-payments (of some kind) between countries, the efficient allocation of emissions across countries is independent of the equity issue.

Several concerns shape equity perceptions and the ability to obtain international agreements. Effective action to control global warming is dependent on a degree of international agreement. Therefore a first obstacle to whatever mechanism might be agreed upon is national sovereignty – to what extent will sovereign nations subject themselves to enforcement actions by others? Even simple agreements for joint implementation of projects involving two countries have run into difficulties (see below).

The second obstacle is the heterogeneous nature of the effects of greenhouse warming. Although the most widely cited measure of global warming is the average increase in global temperature, global warming affects different countries differently. In addition, the costs or response measures and their economic implications vary greatly among countries, particularly as a function of the level of development. Therefore the perceptions of benefits of global cooperation will differ greatly.

A third obstacle is posed by strategic incentives. If some countries take the lead and set up a greenhouse gas agreement, others have an incentive to free-ride and abstain from joining, as they cannot be excluded from the benefits such an agreement creates. If countries act selfishly in this way, few will become party to an agreement. Most countries will therefore not cooperate and no general agreement will be reached even if all countries were to benefit from it. (This is the well known prisoner's dilemma from game theory).³⁵ Some argue that the overwhelming historical contribution to the build-up of GHGs from developed countries constitutes an "environmental debt", that cannot be conveniently ignored using the traditional "sunk cost" approach. If past contributions to GHG emissions are considered from an equity viewpoint, establishment of appropriate side-payment mechanisms from developed to developing countries, including financial assistance and technology transfer, could facilitate the more enthusiastic cooperation of developing countries in global warming mitigation efforts.

The question of joint implementation illustrates the limits of CBA in this regard. The motivation for joint implementation is a straight forward result of CBA. If a country – say the U.S. – decides to make an effort to reduce GHG emissions, and if reductions can be obtained at lower costs abroad, then the US should initiate projects in other countries in order to minimize overall costs (Aaheim, 1993). The receiving country has nothing to lose if the additional cost of such a joint implementation project is covered by the investing nation. Yet many countries and organizations have reacted with skepticism, for reasons that are political, and based on equity concerns, rather than on economic efficiency. The reasons include the mistrust of the true willingness of the industrial countries to mitigate climate change, the belief that the ultimate reduction in GHGs under such a regime would be negligible; and the suspicion that joint implementation gives industrial countries an opportunity to "buy themselves out of their problems" at the expense of the developing countries.³⁶ Indeed, some developing countries fear that joint implementation investment might partly substitute for traditional forms of financial and donor assistance, and that such agreements might preclude the right of future generations to emit GHGs.

³⁵ However, for a criticism of this argument, see e.g. Brown (1992), who points out that some European countries have already taken unilateral action to reduce greenhouse gases, in hopes that others will follow.

³⁶ For a discussion of these issues, and a discussion of how CBA can make a contribution to the evaluation of such projects, see Aaheim (1993). Concerns about "market justice" and related considerations are outlined by Rose (1990).

Multicriteria analysis

Even the staunchest advocates of cost-benefit analysis would concede that economic efficiency (or economic value) is not the sole criterion in setting public policy, and that policy-makers rightfully need to consider a broader set of objectives. Unfortunately there is much confusion about what constitutes a coherent set of objectives. Table 5.3, taken from a major EPA study, lists the criteria suggested there as constituting the basis for selecting public policy. Economic efficiency is one of fifteen so listed.

Simple applications of CBA tend to focus only on economic efficiency. However, in more recent extensions, traditional CBA concepts are embedded in MCA, that expressly allows more than one objective, and expressly addresses risk and uncertainty – thereby providing an integrating mechanism for most of the criteria listed. Multicriteria analysis techniques first gained prominence in the 1970s, when the intangible environmental externalities lying outside conventional cost-benefit analysis (CBA) methodologies were increasingly recognized. It also met one objective of modern decisionmakers, who preferred to be presented with a range of feasible alternatives – as opposed to one "best" solution. MCA also allows for the appraisal of alternatives with differing objectives and varied costs and benefits, which are often assessed in differing units of measurement.

Table 5.3: Criteria for choosing a strategy

1. Flexibility
2. Urgency
3. Low cost
4. Irreversibility
5. Consistency
6. Economic Efficiency
7. Profitability
8. Political feasibility
9. Health and Safety
10. Legal and administrative feasibility
11. Equity
12. Environmental quality
13. Private v. Public sector
14. Unique or critical resources

Source: EPA, *The Potential effects of global climate change on the United States*, EPA-230-05-89-050, Washington, DC, December 1989, p.390.

Thus, upon closer examination of the criteria listed on Table 5.3, criteria 1, 2, 3, 4, 5, 6 can all be treated by modern decision-analysis: indeed, questions of timing (urgency), flexibility (or robustness), capital constraints ("low cost") are all central elements of the approach. Criterion 13 is really part of 6 (in the text the authors of the EPA report amplify the criterion as follows: "Does the strategy minimize governmental interference with decisions best made by the private sector" ?). Furthermore, modern valuation techniques permit substantial parts of Criteria 9 and 12 to be included in the economic analysis as well. As conceded by the EPA report (p.393), "if the principal costs and benefits can be quantified in monetary terms, economic theory provides a rigorous procedure for making trade-offs between present and future costs, and for considering uncertainty, profitability, and most of the other criteria".

There is also a need to separate the basic goals of public policy – such as economic efficiency and equity – which surely have primacy, from implementation issues such as legal and administrative feasibility, which are generally secondary. The premise of CBA analysis is

that one looks first at the primary objectives, and then asks how much of the primary objectives one may have to sacrifice to achieve practical implementation. This principle has become accepted in many areas of policy-making. For example, the starting point for setting electric utility rates is to calculate the economically efficient tariff (based on marginal costs), and then make adjustments to protect low income groups (through lifeline rates, special provisions for disconnection in the event of non-payment, etc.). The essence of the approach is not that non-economic issues are ignored, but that the trade-offs between economic efficiency and equity (or indeed other objectives not readily monetized) are explicitly quantified and displayed in such a manner that decision-makers are made aware of how much of one objective is traded off in the interests of the other.

The application of MCA methods involves the following steps:

1. Selection and definition of attributes, say A_i , $i=1, \dots, N$, selected to reflect important planning objectives. While the two major relevant attributes in the context of the global climate change problem are cost and GHG emission reductions, we have already noted that strategies to control GHG emissions may have other side-effects, some positive, and some negative, which may also difficult to value, and which might therefore require additional attributes (such as, for example, for biodiversity).
2. Quantification of the levels A_{ij} of the i attributes estimated for each of the j alternatives. In this quantification, full consideration must be given discounting issues, for non-economic and economic attributes alike. At this stage of the analysis, trade-off curves are powerful tools to communicate with decision-makers: they are particularly relevant in a situation, such as the climate change problem, where the quantification of benefits may be difficult, and where decision-makers must act largely on the basis of trading-off short-term costs against certain levels of GHG emission reduction.
3. Determination and application of a decision rule, which amalgamates the information into a single overall value or ranking of the available options, or which reduces the number of options for further consideration to a smaller number of candidate plans. Where amalgamation is contemplated, attribute levels are first translated into a measure of value, $v_i(A_{ij})$ (also known as the attribute value function).¹⁷ This is sometimes combined with a normalization procedure usually on a scale of zero to one (in which the lowest value of the attribute value function is assigned zero, the highest one). Subsequently weights w_i for each attribute must be determined to arrive at the overall amalgamation.

Trade-off curves are a particularly useful tool for analysis of energy-environmental policy options. Figure 5.2, taken from a recent study of options for greenhouse gas (GHG) emission reductions in Sri Lanka (Meier, Munasinghe and Siyambalapitiya, 1993), illustrates the essential concepts. The figure is a plot of two attributes – GHG emissions and total system costs – for the technology options identified on Table 5.4. Each point represents a perturbation of the reference case, defined as the official 1993 basecase capacity expansion plan of the CEB.

The *trade-off curve* is the set of options that are not dominated by others (sometimes referred to as the "non-inferior set"). These are the options that are "closest" to the origin, and therefore represent the "best" set of options that merit further attention.¹⁸

Several useful concepts arise here. First is the concept of *dominance*.¹⁹ PFBC (a clean coal technology) is said to dominate the options in the sector shown, namely FGD, wind and

¹⁷ MCA deals with attitudes toward risk and uncertainty at this stage by the use of multi-attribute utility functions, which explicitly capture attitudes toward risk (see Keeney and Raiffa, 1976; Keeney and Wood (1977) for an application in water resource planning, or Keeney and von Winterfeldt (1987) for application to electric utility planning).

¹⁸ We note also that the trade-off analysis and surfaces will be much more complex as the number of attributes increases.

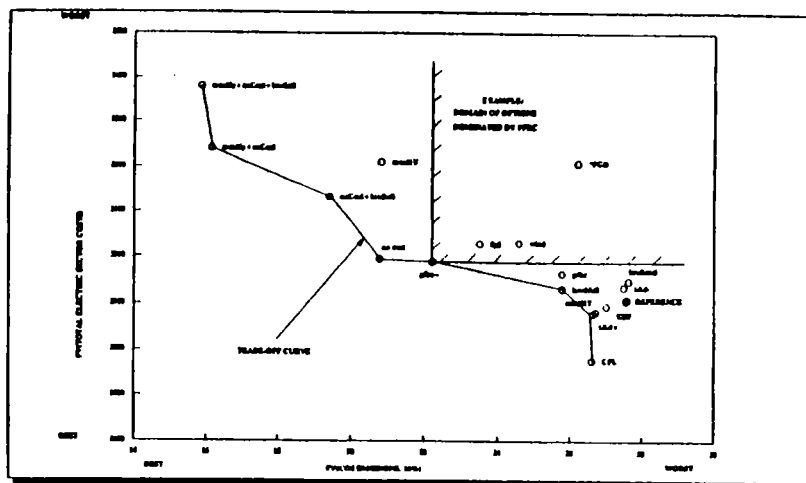


Figure 5.2: Trade-off curve

source: Meier, Munasinghe and Siyambalapitiya (1993)

*FGD PFBC has better costs and better (lower) GHG emissions, and is thus preferred over these options under both criteria. If only these two attributes mattered, then there would be no reason to select any of the dominated options in place of PFBC.

Another perspective is gained by dividing the solution space into quadrants with respect to the reference case (Figure 5.3). The options that fall into quadrant III are the "win-win" options, which are better than the reference case in *both* attributes. In this case, mini-hydro, energy efficient refrigerators (T&D) system loss reduction and compact fluorescents all fall into this quadrant, providing both cost and emission gains. Such win-win solutions were mentioned earlier, in Section 4, in connection with the empirical estimates of the MAC curves (e.g. Figure 4.2): these "below-the-line" options in the MAC curves are equivalent to the options in quadrant III of a multi-attribute analysis.⁶⁰

defined?

⁶⁰ Decision analysis distinguishes among several types of dominance – such as strict dominance and significant dominance – see e.g. Meier and Munasinghe (1994) for an application of these concepts to environmental decision-making.

⁶¹ In general, of course, the trade-off curve may extend into quadrant II, and quadrant III may contain fewer, or need not contain any solutions at all.

options and

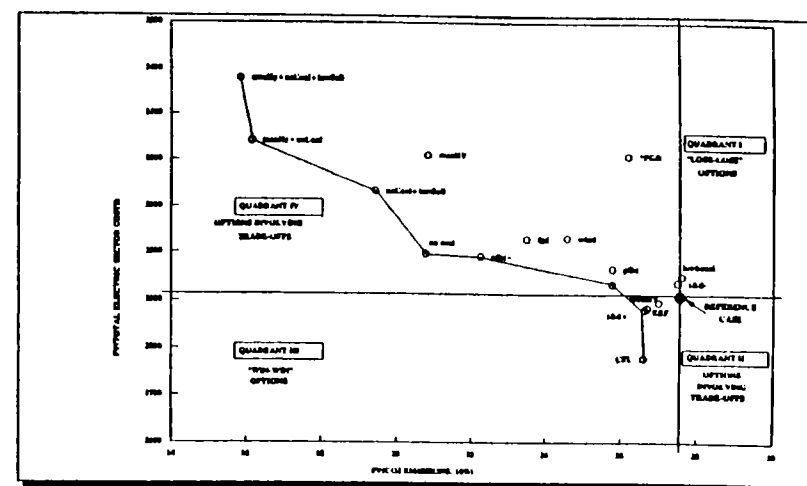


Figure 5.3: "Win-win" options

source: Meier, Munasinghe and Siyambalapitiya (1993)

Table 5.4: Technology interventions for GHG emission reductions

option	comments	symbol
wind energy	305 Mw total	wind
mini-hydro		minihy
DSM: energy efficient refrigerators		EEF
DSM: compact fluorescents		CFL
T&D loss reduction	10% T&D loss goal (in place of 12%) by 2000. 12% goal delayed to 2003	TD+
max hydro	builds both reservoirs in the Upper Kotmale project; 144Mw high dam version of Kukule.	maxHy
clean coal technology	pressurized fluidized bed combustion-combined cycle units; assumed for all coal units after 2000; with pessimistic capital cost assumptions	PFBC
clean fuels	use imported low-sulfur residual oil for diesels (0.5% S by weight rather than 2.5% S).	low S oil
FGD systems	use low sulfur (0.5%) coal (rather than 1% S coal) model free to choose optimal generation mix; coal plants must have FGD systems.	low S coal
	FGD systems forced onto basecase solution	**FGD
no coal	model free to choose least-cost combination of diesels + hydro	noCoal

Concluding Remarks

Cost-benefit analysis has many advocates but also many detractors. Certainly the rather narrowly defined, traditional approaches to CBA, developed originally for project level decision-making with planning horizons typically no more than 20 years, *clearly are* dealing with the very long time frames, non-marginal impacts, and high levels of uncertainty, encountered in the appropriate context of climate change.

In the introduction we noted that there were four essential questions facing decision-makers regarding climate change: (1) by how much should emissions of GHGs be reduced?; (2) when should emissions be reduced?; (3) by what methods should emissions be reduced?; and (4) who should reduce emissions?

The first question is answerable in principle, using CBA -- the measures whose marginal costs are less than the marginal damage costs should be implemented. Clearly, it matters what perspective is taken, since the result will be different if restricted to a consideration of national costs and benefits than if the perspective is global. It is a fundamental result of CBA that the global perspective is the proper one, in the sense that it maximizes net benefits worldwide. The national perspective is relevant when equity issues related to the incidence of costs and benefits are considered (see question 4 below).

The second question is a more complicated one, because it involves judgments about uncertainty. If the marginal damage (benefit) cost were known with certainty, or if future technological advances that might significantly change the marginal cost curve were known with certainty, then the timing of abatement is given by that portfolio of implementation options that maximizes the (deterministic) present value of avoided damage costs (benefits) less abatement costs -- a relatively straight forward calculation. But since neither damages nor costs are known with certainty (for example, if fusion technology were to be commercially available at a cost comparable to fossil-fueled technology by 2020 then the optimal timing and structure of abatement actions looks very different than if the date were 2070), extensions of CBA -- such as decision analysis -- are required. As indicated in Section 4 (see e.g. Box 2), recent developments have begun to deal with the question of timing, particularly with respect to the balance between R&D (on both the cost and benefit side) vis-a-vis immediate commitments to emission abatements.

The third question is closely related to the first. As we have seen (for example in Figure 4.2), most attempts to answer question 1 necessarily require consideration of the specific methods that might be used to reduce emissions. A bottom-up, empirical estimation of the marginal cost curve involves analysis of the broad spectrum of possible abatement options, from which marginal cost curves can be derived. Top-down models, typically using national or regional general equilibrium models (recall the results of Figure 4.4), also necessarily require explicit consideration of specific policy or technology options.

CBA cannot itself resolve the fourth question -- which involves equity -- but it does provide a framework for understanding the trade-offs to be made between equity and economic efficiency. CBA, when applied globally, can identify in which countries abatement costs are lowest, since the global perspective identifies all measures whose marginal costs are less than the global marginal benefits (recall Figures 4.5 and 4.6). But how such a program can be implemented in practice involves putting in place appropriate transfer payment mechanisms, the amount and structure of which is a matter of equity.

Nevertheless, despite its many imperfections, CBA remains the best guide to policy-making for dealing with the essential questions that must be faced in dealing with climate change. CBA forces decision makers to compare the consequences of alternative actions, including that of no action, on a quantitative rather than intuitive or rhetorical basis -- and

may need to be modified for

can certainly make a contribution to resolution of the first three of these questions. And where impacts on non-monetary objectives (social and environmental) must also be considered, extensions of the traditional CBA approach, such as multi-criteria analysis, permit quantitative expression of the trade-offs to be made. At the same time, issues of risk, uncertainty and discount rate may be addressed through an expanded CBA/decision analysis framework that incorporates recent advances in dealing with such difficulties.

BIBLIOGRAPHY

- Aaheim, A., 1993. Benefits and Costs of Climate Measures under Joint Implementation, CICERO, University of Oslo.
- Abrahamson, S., et al. 1989. Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, NUREG/CR-4214, Sandia National Laboratories, Washington, DC.
- Alfsen, K. H., A. Brendemoen and S. Glomsrod, 1992. Benefits of Climate Policies: Some Tentative Calculations, Discussion Paper, Central Bureau of Statistics, Oslo.
- Amman, M. et al. 1992. Economic restructuring in Eastern Europe and acid rain abatement strategies, *Energy Policy*, p.1187-1198.
- Anderson, D. and R. H. Williams, 1993, The Cost-Effectiveness of GEF Projects, Global Environment Facility, Working Paper 6, Washington, DC.
- Arrow, K. J., 1966. Discounting and Public Investment Criteria, in Kneese and Smith, Eds., 1966.
- _____, and M. Kurtz, 1970. Public Investment, the Rate of Return and Optimal Fiscal Policy, Johns Hopkins University Press, Baltimore.
- Baron, W. and P. Hills, 1990. Greenhouse Gas Emissions, Issues and Possible Responses in Six Large Lower Income Asian Nations, Working Paper #45, Center for Urban Planning and Environmental Management, University of Hong Kong.
- Bernstein, M., 1992. Costs and Greenhouse Gas Emissions of Energy Supply and Use, Environment Department, Working Paper 1993-40, World Bank, Washington DC.
- Blitzer, C., R. Eckhaus, S. Lahiri, and A. Meeraus, 1993. Growth and Welfare Losses from Carbon Emissions Restrictions: A General Equilibrium Analysis of Egypt, *The Energy Journal*, 14, 1, pp.57-81.
- Bohm-Bawerk, E. von, 1889. Kapital und Kapitalzins: Zweite Abtheilung: Positive Theorie des Kapitals, Wagner, Innsbruck.
- Brekke, K. A., 1994. Net National Product as a Welfare Indicator, *Scandinavian Journal of Economics*, 96, 2, p.241-252.
- Bromley, D., 1986. Natural Resource Economics: Policy Problems and Contemporary Analysis, Kluwer/Nijhoff Publishing, Boston, MA.
- Brown, P. G., 1992. Climate Change and the Planetary Trust, *Energy Policy*, p.208-222.
- Burgess, J., 1990. The Contribution of Efficient Energy Pricing to Reducing Carbon Dioxide Emissions, *Energy Policy*, p.449-455.
- Butlin, R. (ed.), 1981. Economics of the Environmental and Natural Resource Policy, Westview Press, Boulder CO.
- Center for Energy and Environment, University of Pennsylvania, 1992. Costs and Greenhouse Gas Emissions of Energy Supply and Use.
- Chao, H. P. and Wilson, R., 1993. Option Value of Emission Allowances, *Journal of Regulatory Economics*, 5: 233-249.
- Cline, W. R., 1992. The Economics of Global Warming, Institute for International Economics, Washington, DC.
- Coppel, J. 1991. An Analysis of Energy Policy Measures and their Impact on CO₂ Emissions, Proceedings, ESCAP Conference of Greenhouse Research, Bangkok, August 1991, p. 263-286.
- Crousillat, E., 1989. Incorporating Risk and Uncertainty in Power Sector Planning, Industry and Energy Department Working Paper, Energy Series Paper 17, World Bank, Washington, DC.
- _____, and H. Merrill, 1992. The Trade-off/Risk Method: A Strategic Approach to Power Planning, World Bank, Industry and Energy Department, Washington, DC: p. 16-17.
- _____, and S. Martzoukos, 1991. Decision-making under uncertainty: An option valuation approach to power planning, Industry and Energy Department Working Paper, Energy Series Paper 39, World Bank, Washington, DC.
- Dreze, J. H. and A. Sandmo, 1971. Discount Rates for Public Investment in Closed and Open Economies, *Economica*, Vol. 38, (November), pp. 395-412.
- EPA, The Potential effects of global climate change on the United States, EPA-230-05-89-050, Washington, DC, December 1989, p.390.
- Fuglestad et al., 1994. A Review of Country Case Studies on Climate Change, Global Environment Facility, Working Paper 7, Washington, DC.
- Glick, P., 1989. Climate Change and International Policies: Problems Facing Developing Countries, *Ambio*, 18, 6, p.333-339.
- Glomsrod, S., H. Vennemo, and T. Johnson, 1990. Stabilization of Emissions of CO₂: a Computable General Equilibrium Assessment, Central Bureau of Statistics, Discussion Paper 48, Oslo, Norway.
- Goto, N. and T. Sawa, 1993. An Analysis of the Macro-economic Costs of Various CO₂ Emission Control Policies in Japan, *The Energy Journal*, 14, 1, pp.83-110.
- Gregory, R., S. Lichtenstein and P. Slovic, 1993. Valuing Environmental Resources: A Constructive Approach, *Journal of Risk and Uncertainty*, Vol 6, pp.177-197.
- Heal, G. M. (1981). Economics and Resources, in R. Butlin (1981).
- Hoel, M., 1992. The Role and Design of a Carbon Tax in an International Climate Agreement, in Climate Change. Designing a Practical Tax System, OECD, Paris.
- _____, and I. Isaksen, 1993. Efficient Abatement of Different Greenhouse Gases, Memorandum No. 5/93 from Department of Economics, Univ. of Oslo.
- _____, and I. Isaksen, 1994. The Environmental Costs of Greenhouse Gas Emissions, Mimeo, Department of Economics, Univ. of Oslo.
- Hogan, W., 1990. Comments on Manne and Richels' CO₂ emission limits: An Economic Cost Analysis for the USA, *Energy Journal*, 11, 2, pp.75-85.
- Hossain, J. and C. Sinha, Limiting CO₂ emissions in the power sector of India, *Energy Policy*, Oct. 1993, p.1028.
- Houghton, J. T., et al. (Eds), 1990. Climate Change—the IPCC Scientific Assessment, World Meteorological Organization and the United Nations Environment Program, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.
- Hueting, R., P. Bosch and B. de Boer, 1992. Methodology for the Calculation of Sustainable National Income, Statistical Essays, M44, Centraal Bureau for de Statistiek, Gravenhaage.
- ICF, Inc., 1990. Preliminary Technology Cost Estimates of Measures Available to reduce U.S. Greenhouse Gas Emissions by 2010, Report by ICF to the U.S. Environmental Protection Agency.
- International Energy Agency, 1988. Emission Controls in Electricity Generation and Industry, Paris.
- Jackson, T., 1991. Least-cost Greenhouse Planning: Supply Curves for Global Warming Abatement, *Energy Policy*, (Jan-Feb).
- Jones, B. and E. Wheeler, Editors, 1992. Greenhouse Research Initiatives in the ESCAP Region. Proceedings of a Conference, Bangkok, August 1991, ESCAP.
- Keeney, R. L. and H. Raiffa, 1976. Decisions with Multiple Objectives. Preferences and Value Trade-offs, New York. Wiley.
- _____, and D. von Winterfeldt, 1987. Optimal Procedures to Evaluate Decisions with Multiple Objectives, EPRI EA-5433, Electric Power Research Institute, Palo Alto, CA.
- King, K., 1993. Issues to be Addressed by the Program for Measuring Incremental Costs for the Environment, Global Environment Facility, Working Paper 8, Washington, DC.
- _____, and M. Munasinghe, 1992. Global Warming: Key Issues for the Bank, World Bank Environment Department Divisional Working paper 1992-36, Washington, DC.
- Kneese, A., 1984. Measuring the Benefits of Clean Air and Water, Resources for the Future, Washington D.C.
- _____, and S. C. Smith (eds.), 1966. Water Research, 13-32, Johns Hopkins University Press for Resources for the Future, Baltimore, MD.
- Koopmans, T. C., 1960. Stationary Ordinal Utility and Impatience, *Econometrica*, Vol. 28 no.2, pp. 287-309.
- Kreps, D. M. and E. L. Porteus, 1979. Temporal von Neumann-Morgenstern and Induced Preferences", *Journal of Economic Theory*, Vol. 20, pp. 81-109.
- Larsen, B., 1993. World Fossil Fuel Subsidies and Global Carbon Emissions in a Model with Inter-fuel Substitution, World Bank, Washington, DC.
- Lave, L., 1991. Are Economists Relevant? The Efficiency of a Carbon Tax, in Dornbusch

- and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA.
- _____, and Gruenspecht, H., 1991. Increasing the Efficiency and Effectiveness of Environmental Decisions: Benefit-cost Analysis and Effluent Fees: A Critical Review, *Journal of the Air Waste Management Association*, 41, 5, pp.680-693.
- _____, and K. Vickland, 1989. Adjusting to Greenhouse Effects: the Demise of Traditional cultures and the Cost to the USA, *Risk Analysis*, 9, pp.283-291.
- Lind, R. C., 1984a. Discounting for time and Risk in Energy Planning, Johns Hopkins University Press for Resources for the Future, Baltimore, MD.
- _____, 1984b. A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options", in Lind (1984a).
- London Economics, 1992. Economic Costs of Carbon Dioxide Reduction Strategies. Global Environment Facility Working Paper Series 3, Washington, DC.
- _____, A., 1992. The Rate of Time Preference - Implications for the Greenhouse Gas Debate, mimeo. Stanford University.
- _____, A. and R. Richels, 1990 CO₂ emission limits: An Economic Cost Analysis for the USA, *Energy Journal*, 11, 2, pp.51-74.
- _____, 1992. Buying Greenhouse Insurance: the Economic Costs of Carbon Dioxide Emission Limits, MIT Press, Cambridge, MA.
- _____, A. Mendelsson and R. Richels, 1992. MERGE - A MODEL for Evaluating Regional and Global Effects of GHG Reduction Policies, mimeo. Stanford, Yale and EPR.
- Marglin, A., 1963. The Social Rate of Discount and the Optimal Rate of Investment", *Quarterly Journal of Economics*, Vol. 77, pp. 95-111.
- Markandya, A., 1990., Environmental Costs and Power System Planning, *Utilities Policy*, 1, p.13-27.
- _____, and D. Pearce, 1988. Environmental Considerations and the Choice of the Discount Rate in Developing Countries. Environment Department Working Paper #3, World Bank, Washington, DC.
- Meier, P., 1990. Power Sector Innovation in Developing Countries. Implementing Investment Planning under Capital and Environmental Constraints, *Annual Review of Energy*, 15, pp.277-306.
- _____, and M. Munasinghe, 1994. Incorporating Environmental Concerns into Power Sector Decision-making, World Bank, Washington, DC.
- _____, M. Munasinghe, and T. Siyambalapitiya, 1993. Energy Sector Policy and the Environment: A Case Study of Sri Lanka. Environment Department, World Bank, Washington, DC.
- Mubayi, V., L. Neymotin and V. Sailor, 1991. Cost-benefit Considerations in Backfit Analysis, Brookhaven National Laboratory, Upton, NY.
- Munasinghe, M., 1990. *Energy Analysis and Policy*, Butterworths Press, London, UK.
- _____, 1991. Sustainable Energy Options for Developing Countries, *World Energy Council Journal*, 1, December, p.69-87.
- _____, 1993. Environmental Economics and Sustainable Development, World Bank, Washington, DC.
- Newendorp, P., 1976. Decision Analysis for Petroleum Exploration, Pennwell, Tulsa, OK.
- Nordhaus, W., 1991. Economic approaches to greenhouse warming, in Dornbusch and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA.
- _____, 1991. The Cost of Slowing Climate Change: a Survey, *Energy Journal*, 12, 1, 37-65.
- _____, 1994 Expert Opinion on Climatic Change, *American Scientist*, 82, 45-51.
- _____, 1993. Running the DICE: An Optimal Transition Path for Controlling Greenhouse Gases, *Resources and Energy Economics*, Vol. 15 pp. 27-50.
- _____, 1994. Climate Change and Economic Development: Climates Past and Climate Change Future, Proceedings of the World Bank Annual Conference on Development Economics, Washington, DC.
- Office of Technology Assessment, 1992. Fueling Development: Energy Technologies for Developing Countries, OTA-E-516, Washington, DC.

- _____, 1993. Preparing for an Uncertain Climate, OTA-O-568, Washington, DC.
- Ogawa, Y. and H. Awata, 1991. Simulation Study of Greenhouse Gas Emissions due to Future Energy Consumption, Proceedings, ESCAP conference of Greenhouse Research, Bangkok, August 1991, p. 234-262.
- Pachauri, R. K., 1991. Global warming: impacts and Implications for South Asia, Tata Energy Research Institute, New Delhi.
- _____, and A. Behi, Editors, 1991. *Global Warming: Mitigation Strategies and Perspectives from Asia and Brazil*, Tata McGraw-Hill for Asian Energy Institute, New Delhi, India.
- Page, T., 1977. Conservation and Economic Efficiency, Johns Hopkins University Press, Baltimore.
- Proost, S. and D. Van Regemorter, 1992. Economic Effects of a Carbon Tax: With a General Equilibrium Illustration for Belgium, *Energy Policy*, p. 136-149.
- Putta, S., 1990. Weighing Externalities in New York State, *Electricity Journal*, July 1990.
- Ramsey, F., 1928 A Mathematical Theory of Saving, *The Economic Journal*, Vol. 38 no 152, pp. 543-559.
- Randall, A., 1986. Valuation in a Policy Context, in Bromley, 1986, pp. 163-200.
- Rawls, J., 1972. A Theory of Justice, Oxford University Press, Oxford.
- Repetto, R., 1989. Wasting Assets: Natural Resources in National Income Accounts, World Resource Institute, Washington.
- Richels, R., and J. Edmonds, 1993. The Economics of Stabilizing Atmospheric CO₂ concentrations.
- Rose, A., 1990 Reducing Conflict in Global Warming Policy: The Potential of Equity as a Unifying Principle, *Energy Policy*, December, pp. 927-935.
- Ryder, H. and G. Heal, 1973. Optimal Growth with Intertemporally Dependent Preferences, *Review of Economic Studies*, Vol. 40, pp. 1 - 31.
- Sen, A., 1979. Personal Utilities and Public Judgments: Or What's Wrong with Welfare Economics?, *The Economic Journal*, 89, pp.537 - 558.
- _____, 1984. Approaches to the Social Discount Rates for Social Benefit-cost Analysis, in Lind (1984a).
- Sitnicki, S. et al., 1991. Opportunities for carbon emissions control in Poland, *Energy Policy*, 19, 10, p.995-1002.
- Steinberg, M. and H. Cheng, 1985. A Systems Study for the Removal, Recovery and Disposal of Carbon Dioxide from Fossil Fuel Power Plants in the U.S., Brookhaven National Laboratory, BNL 35666, July 1985.
- Stern, T., 1994. Discounting in a World of Limited Growth, *Environmental and Natural Resource Economics*, 94, 4.
- Tata Energy Research Institute, 1991. Report on Global Warming and Associated Impacts. Report to the Ministry of Environment and Forests, New Delhi, India.
- Turner, R. K., 1991. Environment, Economics and Ethic, in *Blueprint 2: Greening the World Economy*, D. Pearce, (Ed.), Earthscan Publishing, London.
- United Nations Environment Programme, 1988. Assessment of Multiple Objective Water Resources Projects: Approaches for Developing Countries, New York.
- _____, 1992. UNEP Greenhouse gas abatement costing studies, Riso National Laboratory, Denmark.
- United Nations, 1992. Handbook of National Accounting: Integrated Environmental and Economic Accounting, Draft, Department of Economic and Social Development, Statistical Division, New York, NY.
- Weitzman, M., 1976. On the Welfare Significance of National Product in a Dynamic Economy, *Quarterly Journal of Economics*, 90, pp. 156-162.
- Williams, R. H., 1993. Comment on "Climate and Economic Development" by Nordhaus, Proceedings of the World Bank Annual Conference on Development Economics, Washington, DC.
- World Commission on Environmental and Development, 1987. Our Common Future, Oxford University Press, Oxford, UK.
- Yamagi, K. et al. 1993. A Study on economic measures for CO₂ reduction in Japan, *Energy Policy*, February 1993, p.123-1319.

MEMORANDUM FOR SALLY KANE, CEA

FROM: Ray Squitieri

SUBJECT: Comments on IPCC WG3 Draft Chapter 3:
Costs of Mitigation ⁴

General Comments

The chapter is a valuable summary of existing thinking about the costs of mitigation, with concise discussions of the issues relevant to assessing costs. The exposition is, on the whole, clear, balanced, and thorough, although I understand the final version will be considerably shortened, and thus perhaps less thorough.

In some places, the draft displays unwarranted confidence in the government's ability to improve on market outcomes. In one section, the draft sides with bottom-up models against top-down models -- although this section is in other ways commendable. I have identified these items in the specific comments below. Because of the length and complexity of the draft, I have not reviewed every subsection.

Specific Comments

- p. 5 Second bullet would read better as follows: "Incurring storm or environmental damage and then cleaning up increases GDP without increasing welfare; and"
- 7 "In fact, the existence of a 'no regrets' potential implies (i) that markets do not behave perfectly because of market failures..." This is a straw man, as no market has ever behaved perfectly ever, anywhere. Almost everything we do has some external effects, however small and remote (even buying a toothbrush raises the price to others by some microscopic amount).
- 14 "Chinese homes are not bound to adopt the same model of energy-wasteful refrigerators that have been installed in American houses." "Wasteful" is needlessly prescriptive, and suggests that consumers are either irrational or deliberately squander their money. Economists generally believe that consumers are rational, given the prices they face, and the incomes and information they have; economists also assume that consumers act in their own best interest. The phrase should say, "Chinese homes are not bound to adopt

refrigerators that use as much energy as those found in American homes."

- 18 The full paragraph leaves the impression that bottom-up models are devised by new and innovative thinkers, while top-down models are devised by old stodgy economists. The paragraph should be revised for balance.
- 21 Description of Brazil alcohol program leaves the impression that some think it a success, some not. In fact, every economist who has written about the program believes it to be thoroughly misguided, imposing high costs, while delivering inconvenience but few (or no) environmental benefits.
- 24 Top down/bottom up discussion: wasn't this discussed immediately above?

"The optimism of the engineering paradigm [versus] the pessimism of the economic paradigm." Leaves the reader to conclude that, if optimism is better than pessimism, then we should do with the engineering (bottom up) paradigm.

"The professional reflex of an economist will be to call attention the reasons why consumers do not adopt technologies that appear to be optimal, and will tend to suggest that accounting for these reasons would reduce the magnitude of ... the efficiency gap." The paragraph might also say "Conversely, the professional reflex of an engineer is to conclude that every individual and firm that do not make the same choices he does is misguided."
- 27 Discussion of optimal degree of disaggregation is good, but might also point out: first, that very simple models often outperform more complex models in forecasting trials (see MacNees' model comparisons in the New England Economic Review, various years); second, that because error propagation, more complex models generally have wider error bands than simple models.
- 28 "For example, there is a gap between the findings of Jorgenson (1983) ..." Good point in here, but its too cryptic for the non-specialist reader to understand. Spell it out or leave it out.
- 29 "3.1.3 Representing economic behavior...." Section is a good discussion of the different types of models, but it gives undue preference to bottom-up models.
- 32 "it may be that the bill for energy services cannot be

lowered ... because energy service markets and technology diffusion processes are already functioning optimally." Again, this sets up a straw man. The sentence should say instead " ... because government intervention would not on balance improve the functioning of energy service markets and technology diffusion processes."

- 33 " ... the greatest market share is held not by end-use devices with the lowest life cycle costs ..." This conclusion gives too little credit to consumers, for it implies either 1) that consumers consistently and systematically act against their own self-interest; or 2) that other factors not included in the engineer's analysis are affecting the consumer's decision.
- 37 "But the universal application of high discount rates ... by firms is problematic ..." Similarly, this claim gives too little credit to firms -- otherwise, any of us could assume management of some firm, double the amount of investment, and make far more money for the firm.
- 41 "Al Manne" should be "Alan Manne."
- 48 Discussion of revenue recycling should clarify the difference between environmental taxation and simple tax reform. Economists have long agreed that the current U.S. tax system could be made more efficient by shifting of some of the tax burden from labor and capital to consumption. So while we should not be surprised that a proposal to increase a green tax (say on CO₂) and "recycle" that revenue by reducing payroll or capital gains taxes works better than the same green tax that is simply rebated as lump-sum transfers. But the environmental tax cannot be credited with the benefits of simple tax reform.

In addition, Lawrence Goulder has recently shown (unpublished draft, Stanford University Dept. of Economics, 1994) that green taxes do not provide net economic benefits apart from their effect on emissions -- i.e., that green taxes are no free lunch.

cc: R. Gillingham
R. Peeler
J. Hambor
A. Krupnick, CEA

Chapter 5



United States
Department of
Agriculture

Economic
Research
Service

1301 New York Avenue NW
Washington, D.C.
20005-4788

MEMORANDUM

August 26, 1994

TO: Sally Kane, CEA

FROM: David Schimmelpfennig
Economist
Land and Global Resources Branch
Resources and Technology Division

SUBJECT: Preliminary Review of IPCC WGIII Chapter
"Equity and Social Considerations"

I am pleased to have an opportunity to review the work being done by the IPCC in this important and sensitive area. I understand that the chapter is in an early stage of development with several subsections unwritten at this time. I will focus my comments on the organization of the chapter and where the chapter appears to be headed.

The major sections listed in the "Table of Contents" seem to me to be the logical sections to split the problem up into. I would establish in the introduction a framework from which to evaluate the problem in terms of each those sections. I would probably cover "intergenerational equity" last instead of first because I think the most complicated issues in distributive justice are in here and the necessary caveats would play better after a more concrete analysis of equity between and within countries.

The "intergenerational equity" section gives a non-specialists review of the relevant literature in economics of the topics that the author chose to cover. Expected utility, risk and irreversibility are all relevant topics for the "intergenerational equity" section and the discussion is technically correct. The links to climate change are few and far between, and the discussion of ties to the other sections in the chapter are nonexistent.

The problem starts in the introduction where a unifying framework needs to be given, that the following sections refer to, and gives the reader a frame of reference. A simple dichotomy that would require less rewriting than other options could be to establish in the introduction that equity would be evaluated in the various discussions in all three sections in terms of utilitarianism, including Rawlsian distributive justice, and another broader concept of equity that includes natural environments. The idea here is to bring sustainable development into the introductory framework.

Sally Kane, CEA

2

This is only one simple-minded approach to giving the chapter more structure. The specific unifying framework that would work best is open to debate. It is clear that some framework is needed to make some "common" (between the sections) sense out of the widely scattered, but interesting points that have been made in the chapter up to this point. A major part of the problem is that this chapter should be a review of the literature on the specific topic, "equity and climate change," but unfortunately such a literature does not exist. The authors are being asked to write the background papers and the review all at once.

With no real framework in the literature to draw from, a more ambitious approach and one that would certainly yield dividends, would be to apply a framework from another subdiscipline of economics to the problem of the evaluation of equity concerns with respect to climate change response strategies. It is possible to argue that the question of who is treated fairly when a response to climate change is chosen, or evolves, comes down to an assignment of rights to the different parties. The institutional or industrial organization framework of "situation," "structure" and "performance" would provide a framework in which the present three sections of the chapter could be discussed.

You may not have access to an institutionalist willing to undertake this scope of a project on short notice. An alternative, call it institutional approach light, is to examine in the introduction various rules for assigning rights. These rules could then be applied to the climate change problem to see what they imply for equity within and between countries, and between generations. This approach would highlight the present inequity in the distribution of rights between the less developed and the developed countries and probably between future generations of the inhabitants of the same countries.

The important thing is that whatever framework is discussed in the introduction be applied uniformly across the three sections. This is important for several reasons. The reader needs a frame of reference for considering different discussions, and for comparing the various alternatives. Without it the reader is left with a jumbled accumulation of interesting anecdotes. The subsection III.7 "International equity considerations in responding to climate change," comes the closest to evaluating equity in terms of the relevant topics, but "Equity Within Countries" is completely missing and I will reserve any further judgments about the strengths and weaknesses of specific sections until all the sections have been written.

I hope that these comments are of some help to you.

cc: Margot Anderson



Pacific Northwest Laboratories
370 L'Enfant Promenade, S.W.
901 D Street, S.W., Suite 900
Washington, DC 20024-2115
Telephone (202) 479-0500

To: Sally Kane, CEA
President's Council of Economic Advisors

From: Steve Rayner,
Leader, Global Climate Change Group

REVIEW OF DRAFT 1.1 CHAPTER ON EQUITY AND SOCIAL CONSIDERATIONS

Below I address the specific review questions that you posed for this chapter. Please see also the attached markup which provides more detailed reactions. While I recognize that the draft is in a very early stage of preparation and that substantial and important parts are missing, I do have some significant concerns about the narrow scope of the material supplied and the direction in which the chapter seems to be heading.

Is the appropriate body of literature considered?

Since a good third of the text is missing (the Banuri contribution on equity within nations) and the section on international equity is still largely in note form, it is not possible to answer this question for the entire chapter.

However, the section on intergenerational equity, which seems fairly complete, considers only the perspective of rational choice theory within economics. While this is an important perspective it is far from the whole story that needs to be told in this chapter. The discussion provided here seems technically sound, although much of the literature cited is from the 1970s or earlier.

The extensive literatures in psychology and anthropology that are critical of rational choice theory (especially in the context of moral choices) are glossed over or ignored altogether. In particular, the work of Lola Lopes and Mary Douglas seems relevant here.

Philosophical discourses on equity are very partially and inaccurately rendered. For example, Young's three principles of priority, parity, and proportionality cannot each be directly compared to major philosophical traditions such as utilitarianism, etc. Young's categories can be viewed as a typology of preferences. Utilitarianism purports to be a universal principle for choosing among preferences.

Legal discourses and insights from cross-cultural studies are not considered at all. For example, as demonstrated by the work of Sally Falk Moore, the procedural equity principles of African traditional law are diametrically opposite to those of the Anglo-American common law tradition that is proposed here as a universal principle.

Furthermore the text takes no account of differing religious principles with respect to intergenerational responsibility . My conception of my responsibility to the future may be quite different if I am a Hindu or Buddhist than if I come from the Judeo-Christian tradition. In the eastern tradition I expect to be part of a future generation. In the Judeo-Christian approach I do not have the same expectation. The IPCC is supposed to be an international assessment. Such flagrant ethnocentrism on the delicate topic of equity can and should be avoided.

There is no consideration of the social context of ethical theories in the draft chapter. Yet without such a discussion of context theories can only be compared on criteria of internal consistency and the analyst's personal preferences for principles and outcomes. It is after all, social institutions that establish and embody the distribution of rights and responsibilities and the rules of procedure that constitute any public system of values. Hence, a scientific presentation of equity issues must include an anatomy or cartography of values and the institutions that uphold them.

There is no discussion of the social structuring of time. This is odd since my perception of the historical time dimension is likely to have a significant influence on my discount rate.

Issues of intergenerational trust, liability, and consent are ignored. Yet the literature on these topics in relation to risk analysis indicates that populations which uphold principles of explicit consent (as opposed to revealed preferences or hypothetical consent approaches) have unique difficulties in imposing any costs on future generations who are not presently available to give consent.

The section on equity among regions and countries is less constrained by a narrow disciplinary focus. To the extent that it confines itself to the climate change issue its use of the literature is more appropriate. However, it largely ignores the relevant literature in international law and is too cavalier in its dismissing the moral philosophy literature as irrelevant. Although the author is an exceptionally able individual who is well qualified as a participant in these debates, this section suffers from a lack of formal disciplinary expertise in law, philosophy, and international relations.

Are the right topics and questions addressed?

Again, a major section of the document is missing. However, as indicated above, the most complete part of the text on intergenerational equity significantly misses the mark. This is not due to lack of technical expertise in the discipline represented but to overspecialization and academicism. Several pages are devoted to a detailed exegesis of rational choice formulae. Even the natural science assessments prepared by the IPCC WG I resist this practice. It is my judgment that these abstract formulae will have absolutely no impact whatsoever on the international debate on climate change policy. That policy will be made based on fairly straightforward perceptions of fairness rooted in a combination of self-interest in outcomes and institutional preferences for procedures.

While occupied with the minutiae of abstract principles in rational choice theory, the author misses the larger intellectual and political terrain within which real world decisions are being made.

Fairness is ultimately a subjective judgment based on values, yet nowhere does the text address the issue of where values come from, how they are borne and transmitted in discourse and behavior, and how they influence policy choices. The text simply assumes a single metric rationality of utility maximization which may be sufficient to explain mature markets but cannot explain the behavior of hierarchies or egalitarian institutions. The chapter cannot come to grips with the real issue for decision and policy makers while it conducts the discourse about equity at this level. The issue for climate change is how to manage conflicting interests and priorities among a global population in which there is not (and probably cannot) be unanimity about what is a fair process or a fair outcome.

The entire chapter adopts the perspective of methodological individualism. This is appropriate for neoclassical economics and individual psychology, but is hotly contested by sociologists, anthropologists, certain schools of European political science, and the emerging school of socio-economists. The issue of methodological individualism is particularly important in evaluating the dispute over the concept of "basic needs" which is accepted entirely uncritically in this chapter, although not across social science. The basic needs approach is couched entirely in terms of the individual human organism. However, there seems to be widespread disagreement about the level at which satisfaction of that need ceases to be basic and no demonstrable relationship between the basic biological functioning of an individual and the allocation of social rights and responsibilities. In fact, rights and responsibilities seem to arise from the process of collectively creating social solidarities, of individuals binding themselves to each other, rather than from individual behavior. While I recognize that WG III is dominated by neoclassical economists, it was my understanding that this chapter in particular was supposed to be an opportunity to consider some complementary or even competing paradigms for explaining and predicting human behavior.

I am particularly concerned by the author's admission on page 9 that he focuses on intertemporal equity "not because I believe this to be the most important of the issues but because that is the item for which I can claim some expertise." This is absolutely the wrong principle for selection of issues to be discussed in a state of the science assessment. The IPCC does not exist to showcase individuals because of who they are but to select contributors who can address the most important issues.

Are there gaps or redundancies?

There is little redundancy in the sense of repetition, although several pages of detailed rational choice equations seem superfluous, especially when entire issues and literatures and controversies are otherwise ignored. There are major gaps. Particularly, it is difficult to evaluate the section on equity between regions in the absence of the discussion of internal equity. For example, talking about the poor and rich as if they represent whole nations (page 26) begs the fact that the emissions of the Indian middle class

(conservatively defined) exceed those of the "rich" nation of Australia. Yet some claim that India's emissions are "survival" emissions that should be exempted from control while Australia's are luxury emissions that should be controlled.

Are the controversies in the literature correctly described?

Significant areas of relevant social science are ignored altogether. This gives a misleading impression to any reader who is unfamiliar with this literature. Information about significant controversies is actively suppressed by this text.

Are there areas with which you disagree strongly?

The introductory text quite wrongly characterizes the FCC as providing "a substantial context for the interpretation of equity." In fact the FCC is a masterpiece of ambiguity rife with diplomatic weasel words like "equitable and balanced" which are susceptible to a multitude of interpretations and nuances.

In summary

The whole purpose of this chapter should be to provide a clear map of the intellectual and political terrain that must be negotiated if competing principles for fairness in processes and outcomes are to be operationalized in any protocols. The chapter fails to do this precisely because it lacks the necessary broad systematic framework for mapping issues of process and issues of outcome onto a socioeconomic and institutional taxonomy of decision makers.

While I believe that Banuri's contribution will go some way towards addressing my concerns, I do not believe that this writing team as presently constituted possesses sufficiently broad expertise to address the full range of appropriate issues. It requires the addition of an international legal scholar, a philosopher and probably a sociologist or anthropologist.

A much broader range of literature, including that addressing issues of equity in societal risk management needs to be addressed.

The chapter needs to be more sharply focused on mapping the terrain for decision makers. Any prescriptive approach purporting to represent the "correct" way to make fair decisions or judge the fairness of outcomes will be wrong!

MEMORANDUM FOR SALLY KANE, CEA**FROM:** Ray Squitieri**SUBJECT:** Comments on IPCC WG3 Draft Chapter ⁶ #: Decision-making Framework**General Comments**

The draft contains a wealth of valuable concepts and insights. I expect it to make an important contribution to the vital subject of how to think logically about climate change, and how to look rationally at policy alternatives.

In its current form, however, it will need much work before it meets the high standards set by the IPCC's 1990 Assessment Report.

Organization and logic. I found that although the presentation included most of the important concepts, and although the drafters did a fine job with several sections, they sometime fail to present or even identify the chapter's major themes. Also, space should be allocated to the various sections in proportion to their importance, as many readers use relative section length to gauge relative importance.

Purpose. The chapter sometimes moves away from being an objective scientific assessment, becoming instead a justification for one political position.

Language. The draft is uneven, and would benefit from the assistance of a professional editor.

The chapter should aim for the high ground -- scientifically and editorially. To get there, the lead authors and the staff director should take the following steps: First, identify the central themes of the chapter. Second, determine the desired length of the chapter. Third, nominate a chapter editor (this could be a staff member or an outside editor). The editor must have the authority to redraft the document, organizing it around the central themes. This will require some hard calls. Large sections should be redrafted from scratch. Some sections of the existing document should be discarded. The editor should trim the entire chapter to the required length, and trim different sections in accordance with their importance.

Citations. The frequency of citations in the current draft bears no relation to the relative contributions of the authors cited.

Authors of Classic Articles on Decision Theory

Number of Citations

Arrow	4
Simon	3
Savage	1
Raiffa	1
R. Wilson	0
Pratt	0
R. Howard	0

Other Authors

G. Chichilnisky	28
-----------------	----

I suggest a more appropriate balance.

Specific Comments

- p. 10 Reference to Starr (1989) should probably be Chauncey Starr's 1969 article, "Social Benefit versus Technological Risk," Science, 165 (1969), pp. 1232-1238.
- 11 "Risk aversion: Higher expected return...." Right-column entries are not parallel.
- 13 "... for which probabilities cannot be defined." Does this mean no information at all? Or little enough information that it would be misleading to assign a probability?
- 14 "Getting back ..." Paragraph is loosely organized and carelessly drafted; e.g., "These losses are not so readily quantifiable." Perhaps the issue is how much of the risk private markets could be expected to insure against.
- "Climate change, however, suggests ..." This sentence restates a point appearing immediately above.
- 15 "To say the least ..." Restates a point from preceding pages. On pages 13-16, the text jumps back and forth unpredictably from one argument to the next.
- 16 "According to various contributions ..." ?
- "--to illustrate ..." Two sentences improperly spliced together with a dash.
- 20 "6.2.1.1 Information, value of information" Well-reasoned; states the key issues well.

- 22 " ... the case for leaving more resource [sic] to the next generation, for conserving an ecological asset, when consumption is [sic] an irreversible depletion of stock." By the same argument, economists note that future generations may well be better off if our generation leaves them more wealth-creating assets.
- 23 " ... Preventing climate change ... should thus be credited with an option value." As the text acknowledges below, not making costly ("irreversible") investment decisions on climate mitigation (and perhaps locking in old technology) should also be credited with an option value.
- 24 Discussion of irreversibilities should cite the big-ticket items, such as the possible interruption of the North Atlantic Conveyor Current. Otherwise the reader will wonder why this is relevant at all.
- 25 "Climate change, as already said, is big at the scale of the economy." ?
- 26 "One another [sic] implicit argument against impatience has been forged by Chichilnisky (1993)." . "Forged" brings to mind heroic acts such as Siegfried's forging of his own sword in the German legend.
- 27 Discussion of discounting endorses Cline's argument, which most of the economics profession does not.
- 30 "It is a cheap and therefore widespread excuse against taking measures to reduce greenhouse gas emissions, delegating any decision to the next generation that will better see what happens [sic]." This paragraph seems to endorses one policy position, which is not the purpose of a scientific assessment.
- 34-5 Chaos argument is used endorse stronger government actions to mitigate climate change than would otherwise be taken. But chaos can just as well imply less action than would otherwise be taken.
- 35 New scenarios argument implies that the presence of irreversibilities implies a more conservative decision (i.e. more control of greenhouse emissions); this is probably correct. But the text also seems to state that any additional underlying uncertainty that we become aware of also requires a more conservative decision; this is incorrect.
- 43 "Where is the trouble." This section reads like the transcript of a talk rather than part of an essay. It also contains several overly sweeping generalizations. For example: "A benefit-cost analysis is designed for a

go/no go decision on a well-defined project." Similarly: "With respect to climate change, the objective is to move away from the standard benefit-cost decision-making framework." There is no reason that a benefit-cost analysis should not consider more than two alternatives, some of which might be of the form "go [or don't go] if it is learned that" Manne and Richels, cited in the draft one sentence earlier, have often written on just such complex decisions.

- 46 "6.3.3 Insurance Analysis." This important section seems to have been written in haste. It contains omissions and redundancies, its arguments are sometimes muddy, and it often moves away from science and toward advocacy of specific political positions. It should be redrafted according to the guidelines above. Also, in 10 pages I find 21 references to one author (Chichilnisky), which seems out of line.
- 47 "Policy makers should decide how to divide greenhouse insurance dollars among these competing needs." Good point. Should be more prominent.
- 48 Most of this page seems to be advocating one policy position rather than explaining analytically the idea of insurance, as would be appropriate for a scientific assessment.
- 49 "The floods of 1993 in the U.S., in Bangladesh, and in Europe (France, Switzerland) have reminded us of the profound vulnerability of human settlement to climate." This overstates the case. The Bangladesh economy is vulnerable to storms, but modern industrial economies are not. Only 3% of U.S. GDP comes from the climate-sensitive sectors: agriculture, forests, and fisheries (I suspect the percentage in France and Switzerland is even lower). No storm or drought in modern history has affected the U.S. economy as much as even modest changes in the other 97% of the economy.
- 55 " ... CAT Futures ..." Redundant; already discussed.
- 58 "6.4. Risk Analysis of Climate Change." This section is generally sound.
- 63 " ... assuming independence of each factor ..." Assumption not necessary. Probability trees can include covariances. What they cannot include -- at least what the Rasmussen report did not include -- is common mode failures. This, together with the lack of attention to human factors (e.g. control room operators falling asleep) was the big gap in the WASH-1400 analysis.

- 67 "Energy conservation represents a set of low-cost, quickly-implemented actions." This overstates the case. All sorts of things are labeled "energy conservation" that in fact are high-cost and difficult to implement. Economists who have looked at tighter appliance standards, for example, have often concluded that tighter standards would be a high-cost method of reducing energy consumption.
- 68 "Fuel switching represents a more aggressive-reduction policy." Stated this way, this is a policy conclusion. More accurate would be: fuel switching represents a higher-cost policy.
- 68 "... act-then-learn strategies ..." This is a crucial point and deserves emphasis.
- 68 "6.4.2.2 Anticipatory behavior exploration" What are the major points of this section? The argument is difficult to follow.
- 69 "The purpose of any true environmental tax is to steer such a behaviour, not to let the tax be paid (as taxpayers do)." This is wrong. The purpose of an environmental tax is to reduce the total cost of pollution control by taking advantage of inter-firm or inter-plant differences in control costs. This is true whatever level of control is sought. Firms with low control costs will control their emissions; firms with high control costs will pay the tax. Compared with standard command-and-control regulations, this achieves lower costs for any chosen level of control.
- 71 "insurance orchestration to hedge against strong/unexpected uncertainties." What does this mean?
- 75 "Incorporating options values into the benefit-cost analyses of the policy measures indicates that some action on climate change is economically justified by every country." First, this is a policy conclusion. Second, it seems wrong (does it apply to China?).

cc: R. Gillingham
R. Peeler
J. Hambor
A. Krupnick, CEA

To: Sally Kane CEA 395-6853

MEMORANDUM FOR SALLY KANE, CEA

FROM: Ray Squitieri

SUBJECT: Comments on IPCC WG3 Draft Chapter 7:
Generic Assessment of Response Options

General Comments

The chapter is, on the whole, a fair and balanced presentation. Cost estimates for renewables and conservation (Table 7) may be optimistic (I'm not sure), and should be checked with other sources. I suggest asking Richard Richels how these estimates compare with Stan Vejtasa's estimates incorporated into Global 2100 model.

Specific Comments

- p. 4 "... the possibility to use the same land for agricultural purposes is foregone." True, but this should be built into cost estimates under the engineering efficiency approach too.
- 6 I cannot read the labels on the curves, so I cannot evaluate the graph.
- Table 6 Table is difficult to interpret, e.g., what is the meaning of "5-10" "4-8" "6(8)" and the like in the rows labeled Swisher et al.?
- 14 Table uses different discount rates. Why is this? Also, do other sources (Manne/Richels, EMF-14) adopt discount rates closer to actual observed household discount rates, which are far higher than the 6% to 7% rates used in the table.
- 28 Footnote 39: "Note that the distinction between bottom-up/top-down employed here does not coincide with a similar distinction elsewhere in the literature." I'm not sure that's true, but why would one choose to use a non-standard definition of these terms?

cc: R. Gillingham
R. Peeler
J. Hambor
A. Krupnick, CEA



EXECUTIVE OFFICE OF THE PRESIDENT
COUNCIL OF ECONOMIC ADVISERS
WASHINGTON, D. C. 20500

August 26, 1994

SENIOR ECONOMIST

MEMORANDUM FOR: JOSEPH STIGLITZ
SALLY KANE

FROM: ALAN KRUPNICK

SUBJECT: Thoughts on Chapter 8

I have only had a few hours to review this critical chapter, whose purpose is to lay out the economics of policy choice for reaching given GHG emissions reduction goals. My margin notes indicate where I have problems, although I will hit the highlights here. Overall, this chapter contains most of the important pieces, but needs serious rewriting and reorganizing, with some parts dropped and some new sections added. I agree with the major conclusion that tradable carbon permits are a more promising approach than international carbon taxes. My problems are:

- This chapter is very heavy on carbon taxes and tradable permits, and very light on everything else, particularly command and control approaches. Yet, to be realistic, much of what we are likely to see in the future, both in the U.S. and worldwide, will be voluntary measures, efficiency standards, technology development, information provision, and command and control measures. This chapter should do a lot more in providing some economic advice on how to use these tools in a smart (i.e., efficient) way, rather than strongly implying that adopting any approach other than tradable permits and carbon taxes will be a mistake.
- The chapter does address somewhat the features of LDCs and transition economies that argue for caution in transplanting developed country instruments to these countries. There is a particularly good discussion of emissions fees. But this idea needs to be expanded to other instruments and elaborated more systematically. Further, along the lines of the comment in the first bullet, LDC's and transition economies need advice on how to improve their regulatory regimes, given their special circumstances, not just the palliative that they ought to remove energy subsidies. At least the chapter should acknowledge that we don't have much to tell them in this respect.
- The ideas that are presented almost as a stream of consciousness, rather than as a logical progression. This comment applies at a macro and micro scale. At the macro scale, I found it redundant and confusing to read about comparisons

between instruments in many paragraphs randomly sprinkled throughout the report, and then to read about it in a more systematic fashion again in section 8.7.2. I also found it redundant to read so many different discussions of taxes and tradable permits, rather than have one large section on each. In addition, the Weitzman argument appears at the end of the chapter. Shouldn't this be at the beginning? The basic points about performance versus design standards don't appear until page 20. Doesn't this belong up front? At the micro level (i.e., within sections), the arguments are frequently structured from the specific to the general; for this exercise, it is far more appropriate and easier on the reader to make the general statement first and support it with specifics. Also, small points are often brought up first, rather than more basic points. The first point brought up with tradable permits is the time denomination of the permits. Isn't this a detail?

The chapter would be improved if the authors ask themselves what the basic messages are, both at the macro and micro scale, and lead with them.

- The discussion of the criteria for judging policy instruments is misplaced. It should come much earlier than 8.2.3. It should also be more comprehensive. The list of criteria in the Bohm and Russell article in the *Handbook*, which is in the chapter's reference list, should be presented and explained.
- Some specific points.
 - I don't think the double dividend debate is being characterized appropriately.
 - On pg 21, monitoring and enforcement costs should be no different for technology-based standards than for economic incentive approaches. This difference might only occur if inspectors have a false sense of security when they check to see if equipment is in place. If they check to see that it is being operated properly, the costs would be the same.
 - Drop the deposit-refund system discussion or scale it to a footnote or a paragraph. It's not that important in this context.
 - On pg. 32, why target revenues from surplus permits only to increase imports relative to exports? Use these revenues to get the greatest increase in welfare.
 - The U.S. JI Initiative should be discussed in some detail, as it addresses many of the problems noted in the chapter's discussions of JI.
 - The tax regressivity discussion is hinged on use of lump sum rebates. Since we won't see such rebates in use, the argument lacks practical force. Poterba's argument (base calculation of regressivity on expenditures rather than income) is more useful.
 - On pg. 40, chapter 1's arguments about taxes on oil are relevant here and should be moved to this spot.

Clinton Presidential Records Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a tabbed divider. Given our digitization capabilities, we are sometimes unable to adequately scan such dividers. The title from the original document is indicated below.

Chap 1 SCOPE

Divider Title: _____

UNIVERSIDADE DE SÃO PAULO
INSTITUTO DE ELETROTÉCNICA E ENERGIA

Av. Prof. Almeida Prado, 925 - Cidade Universitária
05508-900 - São Paulo - SP - BRAZIL
Tel: (55-11) 818-5053 / 818-5054 Fax: (55-11) 818-5031 / 818-5056
e-mail: goldemberg@nhl.lead.org.br

DATE: 9/5/94 NUMBER OF PAGES: 04

FROM: Prof. José Goldemberg

TO: Joe Stiglitz / Sally Kane

FAX: (001-202) 395-6853

MESSAGE: URGENT

Dear Joe / Sally,

I have received a number of comments on our draft of the OVERVIEW via Sally Kane and had a long conversation with Jim Bruce over the phone. A few months ago I discussed also a preliminary version on our draft with a few representatives of LDC's who attended the IPCC Fortaleza Meeting. They complained that I was not "facing the NORTH as aggressively as they wished". The central point of the discussion is well exemplified by the content of the first paragraph of section 1.4.2.1 (General Equilibrium Perspectives from Economics).

"Imposing limitations on the less developed countries" is not accepted by many. This is a rather painful point for me because as a Representative of the Brazilian Government at the Ministerial level I have argued - in a number of the Preparatory Meetings to the Rio Conference - that targets and timetables for greenhouse gases should be established for all countries. Such position was not accepted by the Group of 77 which really was using - in my view - environment as an additional weapon in the NORTH-SOUTH confrontation and wanted to obtain additional AID (e.g. raising ODA from 0.35% of GDP of the developed countries to 0.7%).

To be realistic, one should be more tactful than the present text is since our document will be sent to all Governments for review and, as it is, will reopen old wounds.

My own work on "technological leapfrogging" and "accelerated development" offers the way out for the present semi paralysis for action on the global warming front and I tried hard to impress you (and your collaborators) to give it more space in the OVERVIEW since my position is rather constructive and not confrontational. The present draft as it is sort of dismissed it in paragraph 1.8.5.2.

For these reasons I prepared alternative versions for a number of paragraphs - which I suggest - be introduced in the text.

Sincerely yours,

José Goldemberg
1.1 - OVERVIEW - paragraph 5

(suggested wording)

Estimates have been made of the costs for adapting to climate change as well as the cost of actions needed to prevent or mitigate climate change. Such estimates are more reliable for developed rather than developing or economies-in-transition countries. Costs for adaptation in developed countries are of the order of 1% of GDP but much larger for a number of developing countries. Therefore costs of mitigation which are also of the order of 1% of GDP in the countries where they have been studied are to be given preferential considerations as is indeed embodied in the FCCC (article 3, item 3) ("The parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects").

1.2.3 - Uncertainties in Policy Responses - paragraph 1

(stress the fact that uncertainties of atmospheric scientists are as great as uncertainties of economists).

(suggested wording)

There are uncertainties both about what policies will be adopted and what their consequences will be. Part of the problems are social and political but their solution is not helped by the wide discrepancies of the costs of suggested policies resulting from economic models and analysis, particularly the influence of new technologies in the future energy systems of modern societies.

1.4.2.1 - General Equilibrium Perspectives from Economics - paragraph 1

(suggested wording)

The Framework Convention on Climate Change implicitly recognized that climate change is an international public good in calling for all the nations of the world to take actions to reduce gas emissions. Three quarters of present-day emissions have their origin in developed countries where one quarter of mankind lives. The remaining three quarters of the world population contributes only one quarter of present-day emissions. The increase in Carbon concentrations in the atmosphere from 280 ppmv (parts per million in volume) to 350 ppmv originated mainly from developed countries. This is not a very significant increase since the population growth and economic development of the developing countries will most likely lead to a doubling of pre-industrial level of 280 ppmv in the next few decades unless mitigation measures are adopted.

As a consequence the idea of the "guilt" of developed countries for the present problems of global warming is really a non-issue because the real problems are the ones to come. Facing such problems will require a combination of efforts to reduce emissions in developed countries - which are not growing anymore - to allow for a moderate growth of emissions in developing countries which is unavoidable. There are strong indications from modelling economic studies that technology can open the way for a successful combination efforts to work (Edmonds et al 1994 and section 1.6.4, EMF 1993 and section 4.1.1.7 WT 6/7 Report).

If such efforts do not work, the situation as far as global warming is concerned will only get worse: a major set of controls on one part of an integrated system (the developed countries) leaving other parts uncontrolled (the developing countries) may simply lead to a change of the location of certain greenhouse economic activities.

Actually this is why it is in the self-interest of developed countries to help developing countries to grow along trajectories that are less damaging to the global environment, i.e., to "leapfrog" the path followed by them in the past.

1.4.6.1 - paragraph 3 - delete

(This paragraph might be dropped considering the remarks made above).

1.4.6.2 - Lessons from the past

(Morissette et al (1991) five critical points are somewhat displaced particularly when speaking of "Incentives for widespread participation". The FCCC is universal and has been signed by all UN members so "sauctions against non-members" does not apply here).

1.5.4.5 - No regret policies

(suggested wording)

"No regrets" policies have positive net benefits independent of any considerations of climate change. No analysis is needed to determine that these policies make sense; they make society unarguably better off. The difficulty is in identifying them. One of them is clearly the removal of government subsidies to fossil fuel production in many countries around the world, such as the former Soviet Union republics, Germany, Canada and the United States.

The other one is the introduction of cost-effective energy efficiency measures which proved to be one of the important factors in reducing the "energy intensity" (i.e. the ration of GDP and total energy consumed) in the OECD countries after the oil crisis of the 70's. The wide application of such measures in developing countries could have highly beneficial results in moderating greenhouse emissions around the world.

Reference to E.D. Larson, M.H. Ross and R.H. Williams - "Beyond the area of materials". Scientific American Vol 254, no. 6, pp 34-41 June 1986;

and A.K.N. Reddy and J. Goldemberg - "Energy for the Developing World". Scientific American, September 1990, pp 111-118.

1.6.4 Investment and returns to energy savings technology

Add a few sentences essentially repeating section 4.1.1.7 of the Report of Writing Team 6/7 WGIII.

A closely related issue is the potential role of R&D in reducing the costs of a carbon constraint. In a separate set of experiments, the EMF modelers were asked to examine an "accelerated R&D" scenario in which the cost of nonelectric backstop is reduced from \$100 to \$50 per barrel and the cost of the electric backstop is reduced from 75 to 50 mills/kWh. In such a scenario, the carbon free backstops are economical in their own right. That is, they will enter the marketplace even in the absence of a carbon constraint.

Four models (ERM, Fossil2, Global 2100 and CRTM) were used to examine the accelerated R&D scenario. The models were remarkably consistent in their estimates of the potential savings. With the more optimistic technology assumptions, GDP losses for the 20 percent emissions reduction scenario were reduced by approximately 65 percent.

The implication is that approximately 35 percent of the discounted losses are incurred during the transition. The remaining costs accrue once we enter into the backstop phase. That is, once the backstops are available in unlimited quantities.

1.8.5.2 - Energy use

Drop last sentence "whether this (technological leapfrogging) is a practical development path remains to be seen".

and add

This strategy is slowly becoming current policy in a number of developing countries and the basis of the actions of some international agencies and Funds particularly the Global Environment Facility (GEF). "Golden carrot" programs in the USA and Sweden are leading to the adoption of cost-effective energy efficient lighting fixtures, refrigerators, washing machines, etc.. Such programs usually are more successful when changes in equipment are introduced either to conform to new environmental regulations or when the time comes for renewal of old and obsolete equipment. The same rationale is being used in developing countries to make the right choice when equipment is first introduced. Technological leapfrogging in reality goes hand in hand with modernization.

Moreover evidence shows that multinational corporations based in the USA or Western Europe are not "exporting" pollution when setting subsidiaries in developing countries but tend to adopt state-of-the-art environmentally - friendly technologies in their new production centers abroad. The reduction of trade barriers and the increased integration of the world economy works also in the same direction.

Reference

UNITED NATIONS Environment and development Branch. United Nations Center for Transnational Corporations (UNCTC). "Options to increase transfer of environmentally sound technologies to developing countries on favorable terms". New York 1991, 89 p.

A.K.N. Reddy and J. Goldemberg - "Energy for the Developing World" - Scientific American, September 1990, pp 11-118.

rec'd
8/29/94

cc:SK

August 24, 1994

Professors Joseph E. Stiglitz and José Goldemberg
Executive Office of the President
Council of Economic Advisers
Washington, D.C. 20500
U.S.A.

Dear Professors Stiglitz and Goldemberg:

I have just been able to review the draft for the IPCC Working Group III Writing Team 1. It is a very good introductory chapter to the report. I thank you for your great trouble.

I have some comments and suggestions, which I send to you with this facsimile. I look forward to seeing you again at Geneva.

Best regards.

Sincerely yours,

Akihiro Amano

Akihiro Amano

August 23, 1994

Comments on "WRITING TEAM1: SCOPE OF THE ASSESSMENT"

Akihiro Amano

The present reviewer finds this draft for the Scope Chapter quite illuminating, covering very appropriate topics in an well-organized manner. The following pages present some comments of the reviewer, listed according to the order of the discussions in the draft. He hopes that due considerations will be given to them in the final version.

1. On page 9 and elsewhere, a familiar decomposition equation for greenhouse gas emissions is shown. It shows that changes in GHG emissions can be decomposed into four factors: (a) changes in GHG intensity of energy use, (b) changes in energy intensity of output, (c) changes in output per capita, and (d) changes in population. (The same equation appears on page 100.) A paper by Y. Ogawa summarizes interesting findings within this framework. (Cf. Yoshiki Ogawa, "Analyses of Factors Affecting Carbon Dioxide Emissions Due to Past Energy Consumption Around the World," in Barry P. Jones and Edward F. Wheeler, eds., *Greenhouse Research Initiatives in the ESCAP Region: Energy*, Proceedings of a conference, Bangkok, 21-23 August 1992, ABARE, Australia, 1991.) A reference to this paper might be appropriate.

On page 75, however, it seems that a different decomposition scheme is called for. That is, by focusing on CO₂ emissions the methods of reducing CO₂ emissions are classified into three types: (a) reducing emissions from energy supply (e.g., fuel switching and increased conversion efficiency), (b) increasing end-use efficiency, and (c) shifting consumption patterns away from energy-intensive goods and services. These different approaches suggest that there exists a more general framework which can indicate various important channels through which we can influence CO₂ emissions. For example, we can write

CO₂ emissions

$$\begin{aligned} &= \sum_h (\text{Carb. Emis}_h / \text{Prim. Energy}_h) (\text{Prim. Energy}_h / \text{Tot. Prim. Energy}) \\ &\quad \times \sum_i (\text{Prim. Energy}_i / \text{Second. Energy}_i) (\text{Second. Energy}_i / \text{Tot. Second. Energy}) \end{aligned}$$

$$\begin{aligned} & \times \sum_j (\text{Second. Energy}_j / \text{Output}_j) (\text{Output}_j / \text{Tot. Output}) \\ & \times \sum_k (\text{Output}_k / \text{Population}_k) (\text{Population}_k / \text{Tot. Population}) \\ & \times \text{Population.} \end{aligned}$$

Thus, a reduction of carbon emissions is possible through

- (1) a reduction of carbon intensity of primary energy h through technological change or carbon-fixing;
- (2) use of a less carbon-intensive technique for the production of primary energy h through price inducements;
- (3) a reduction in the share of carbon intensive energy in primary energy supply;
- (4) a reduction of carbon intensity of secondary energy i through technological change or carbon-fixing;
- (5) use of a less carbon-intensive technique for the production of secondary energy i through price inducements;
- (6) a reduction in the share of carbon intensive energy in secondary energy supply;
- (7) a reduction of secondary energy intensity for output j through technological change or carbon-fixing;
- (8) use of a less carbon-intensive technique for the production of output j through price inducements; or
- (9) a reduction in the share of carbon intensive output in total output through price inducements to demand.

This kind of explanation can illuminate important nodes upon which we can operate, such as (a) energy conversion or energy end-use; (b) choice of techniques or technological change; (c) exogenous effects or endogenous, price-induced effects; and (d) supply-side (choice of production methods) or demand-side (composition of inputs or outputs).

2. The last sentence of 2) on page 17 seems to neglect the experiences in Nordic countries after 1990. Or, does it mean to say "an *international* carbon-tax scheme"?

3. The content of the third paragraph of 3) on page 17 does not seem to fit the title of this sub-section. It seems to be better included under 1) on the previous page.

4. Section 1.3 on page 19 attempts to cover important cost items of global warming. As I summarized in my earlier contributing memorandum to the Writing Team 1, Fankhauser and Cline also estimated the magnitudes of various damage items other

than covered in this draft. The items not covered in this draft are, for example, migration, Hurricanes, Construction, Leisure activities, Urban infra-structures, Air pollution, etc. There seems to be no reason to disregard them, even though they need not be mentioned item by item.

5. On page 22, the first line of 1.3.1.3 reads, "A warmer climate implies both northward movement of forests and changes in forest composition." I am afraid this is a view of the people living in the northern hemisphere.

6. In Section 1.3.3 on pages 27-28, irreversibilities are treated as something parallel to catastrophic events. However, I understand that global warming itself is an irreversible phenomenon within a human time scale, because of cumulative effects of GHGs with a quite long time-lag. I should like to have the role of irreversibilities in the present context a little bit more clarified.

7. The sentence starting at the second line of page 29 reads, "For intertemporal planning, this implies that consumption per head should be the same for all generations." I wonder if this statement is correct. Consider a developmental path along which per capita income at the highest income bracket remains the same, whereas the per capita income level of the poorest bracket improves over time. Suppose also that income distribution ultimately becomes perfectly equal. This kind of situation is quite consistent with the max-min criterion, even though consumption per head would not naturally be the same for all generations except at the steady-state.

8. The draft quotes a view that justifies discounting the future on a basis of the possibility that future generations may not exist (the first paragraph on page 31). There are a couple of arguments, however, against such a view advanced by Clive Spash (see Clive L. Spash, "Economics, Ethics, and Long-Term Environmental Damages," *Environmental Ethics*, Vol. 15, No. 2, Summer 1993, pp. 117-132). It would be fair to mention this literature as well.

9. In discussing the sharing of tax burdens, it is stated, "As we have noted, it is possible to ascertain the economic benefits of mitigation, and these are likely to be quite unequally distributed." (The first paragraph on page 45.) There is a question, however, whether people in developing countries take the effects of mitigation as benefits to them, as they might consider that the mitigation simply restores the old

status quo which is naturally to be expected. This is the so-called initial point problem to be addressed somewhere.

10. In the middle of page 45, the implications of population policy for income distribution policies are discussed, and, in relation to that, the question of initial allocation of tradable permits is taken up. However, in the section where the tradable permit system is the main subject, the initial allocation has not been discussed. Since the discussion above only relates to the population problem, it seems to be necessary to give a full exposition concerning pros and cons of allotting or bidding or whatever methods of allocating the initial emission quotas somewhere. Or, we can explicitly mention that we leave it to other writing teams.

11. The last sentence in the first paragraph of page 48 reads, "Analyzing the optimal intertemporal structure of taxes, to minimize long run ambient levels of greenhouse gases, taking into account both intertemporal substitution and substitution across energy sources, is a complicated technical issue, that to date has not been adequately analyzed." Although much depends on what "adequately analyzed" means, there are many works such as those by Prof. Alan Manne and Dr. Richard Richels that addressed this problem squarely.

12. The word "emissions" in the second line from bottom of paragraph 3 on page 50 should read "concentration."

13. In the middle of the third paragraph on page 51, it is stated that countries with northern climate are likely to find costs of adaptation particularly small. Is this true in view of the fact that the increase in average temperature tends to be higher, the higher the latitude?

14. Discussions on climate engineering are always followed around by some sort of uneasiness (at least to me), because they seldom accompany discussions on environmental assessment of engineering options themselves. If they have other environmental costs (both direct and indirect) with unknown risks, it would be dangerous to build a feeling that they are something that one can rely upon when other options prove to be unexpectedly costly.

15. In discussing the United Nations Framework Convention on Climate Change, the draft touches upon the standard views concerning equity in a fairly abstract manner (the first paragraph on page 56). Readers will find it difficult, however, what "earlier discussions on principles of public finance" really mean in the present context. Discussions could be more explicit.

16. "Table 1" in the second line from the bottom of page 56 is missing. Are CITES and Basel Convention also included in this table?

17. In Section 1.4.6.4 the implications of international trade for the global and local impacts of costs of warming are discussed. This is, of course, an important topic. On the other hand, international trade in forest products may have been encouraging deforestation because international prices of forest products do not fully reflect their social costs. In order to have international prices reflect true social costs, importing countries could introduce import charges on tropical woods, and transfer the revenue to the exporting countries to finance environmental programs. Higher prices in importing countries can limit consumption, and lower international prices will limit excessive deforestation. This kind of discussion should be included somewhere (possibly in Section 1.8.5.3 on page 106).

18. References would be useful for the last point mentioned in the first paragraph on page 64.

19. The argument in the third paragraph on page 64 depends on an implicit assumption that the timing of low-carbon or no-carbon energy sources becoming relatively cheaper is determined exogenously. If it is dependent upon control variables of policy options, i.e., if higher prices of carbon emissions now can hasten the introduction of low-carbon or no-carbon energy sources, then the optimal delay of emission limitation would become shorter.

20. There seem to be two sources of irreversibilities in relation to Section 1.5.3.1 on page 67: first, the fact that emission control investments involve sunk costs, and second, the fact that no action now leads to a higher atmospheric concentration of GHGs which after a long time-lag must bring about global warming. These two irreversibilities work in opposite directions with each other.

21. In the discussion of Section 1.5.3.3 on page 68, it is not quite clear what the phrase "direct expenditures on emission reductions" really implies. Just as we can argue whether direct regulations are more resource-efficient in inducing technological innovation than economic instruments, we can compare the resource-effectiveness of R&D expenditures with economic instruments (i.e., we compare the amount of resources devoted to R&D and economic costs involved in adopting economic measures with due allowance for discounting). Then, the efficient policy would not be of an either-or style, but would involve both at appropriate rates.

22. A sentence in the third paragraph on page 69 reads, "For example, the goal of stabilizing emissions would cost far less if averaging is allowed among different years along the path than if emissions must not rise in any year; to the atmosphere, what matters at any given time is total concentrations, not the emissions path." Two cautions are in order: first, there exists an uncertainty that postponed emission reduction efforts will not be carried out under expected conditions; second, when the time period of averaging is very long, benefits and costs can accrue to different generations. These two considerations would put certain constraints to the use of averaging.

23. Again, the problem of irreversibilities appears in Section 1.5.4.1.3 on page 69. Here, it is stated that in the absence of threshold damage effects, the dominant irreversibility is not in the climate system, but rather in commitments to capital stocks to control emissions. We would like to know the opinions of scientists on the importance of threshold damages. Would it be possible to ask some help from people in the Working Group II?

24. The argument in the last paragraph on page 71 presupposes an independent action of individual countries. It seems that emphasis should also be given to the importance of international approaches. Portfolio of policies to complement or to support those approaches might be quite different from one taken from an individual country point of view.

25. Another question concerning "no regrets policies" discussed in the last paragraph on page 72 would be whether they are enough (or conversely whether they would become too much if pursued all at once).

26. In 8th line of the third paragraph on page 76, the word "permits" should read "permit prices."

27. In 2nd line of the fourth paragraph on page 90, "industrial" should read "household."

28. The definition of "Sustainable Development" by the Brundtland Commission presented on page 99 appears insufficient by itself. One of the important elements of SD emphasized by the commission is intra-generational equity and especially the eradication of poverty. The last sentence in Section 1.8.5.4 on page 109 states exactly this.

29. The third and fourth paragraphs on page 106 just seem to highlight the usefulness of Joint Implementation in attaining "leapfrogging" earlier development paths, in decoupling energy use from economic growth, and in reducing deforestation in developing countries.

W:SK

JAMES P. BRUCE
1875 Juno Avenue
Ottawa Canada
K1H 6S6

Tel: 613 731-5929
Fax: 613 731-3509

September 2, 1994

Dr. J. Stiglitz
Council of Economic Advisors
328 Old Executive Office Building
Washington, D.C. 20500
U.S.A.

Fax: 202 395 6947

Dear Dr. Stiglitz,

After reading Chapter I = the Overview and some of the other chapters of the first draft of IPCC WG III's assessment report, I faxed some comments to Jose Goldemberg and discussed these matters with him by telephone. He asked me to send my initial comments to you before the Geneva lead authors meeting 8-10 September.

First of all, may I say that I found some sections of the draft Overview especially those on the discount rates and on modifying national accounts, very valuable contributions.

Among my concerns are the following.

1. In a number of places the assumption is made that climate change damage is small overall, but costs of emissions reduction large. (e.g. in 1.1 Overview para 5, and section 1.1.1 para 3 and 4). These, as accepted views, are not very consistent with the Chapters on Social Costs of climate change, or with the Costs of Mitigation Chapter, which leaves fairly open the question of whether bottom-up modelers are right, in considering that energy efficiency measures can achieve some reductions at little cost or at some savings. In addition, recent modeling work by Richels and Edmunds suggest that if scheduling of emission reduction is optimal, stable concentration at reasonable levels can be achieved next century at less than 1% GDP cost.

2. Table 1 would be much more useful, in my view, if it showed Annex 1 Country emissions (i.e. including Russia and Eastern Europe) instead of Annex II countries. As it is, it tends to suggest incorrectly that developing countries are now the biggest part of the problem and leads later to criticisms of the FCCC, which will not be well accepted, that its main flaw is not requiring emission controls from the LDC's. Under 1.4.2 the FCCC is again criticized for not imposing emission control obligations on LDC's, whereas many would argue (with considerable justification) that its greatest failure was to not impose real restrictions on the industrialized nations. Perhaps both "failures" could be indicated.
3. The section on Sources of Uncertainty in the science (1.2.2) has many arguable assertions - we'd be best in WG III to just lift an appropriate few paras from WG I, I believe.
4. In my view the section on the Tangible Costs of Warming (1.3.1) and Intangible Costs (1.3.2) could be much shorter, leaving more detailed discussion to the Pearce et al Chapter on social costs. Also the references and discussions are far too heavily biased to U.S.A.
5. On Intergenerational Equity and Discount Rates (Section 1.3.4) there is considerable discussion in both the Equity Chapter - (will be completed by next week) and in the Chapter on Social Costs of Climate Change. The views are quite convergent and we should try to get an agreed statement on what we say about these issues - perhaps we can do so in Geneva next week.
6. Much of Chapter 1.4 General Responses, is very helpful, but the tone and outlook are a problem in some passages:

e.g. the third para of Introduction says we'll discuss the difficulty in upholding the international treaty, rather than saying that we'll suggest some ways of overcoming the manifest difficulties.

The last para of 1.4.4 sounds a bit like a threat of developed countries to pull out of research if not matched by others - I don't think that this has a place in an IPCC report. This paragraph fails to recognize that, proportional to their GDP, great efforts are made by most developing countries just to measure their own climate and related resources and contribute these measurements to the world picture.

The 3rd and 4th paras of 1.4.6.1 need to be modified, I believe.

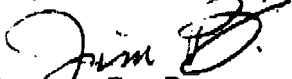
7. Lessons from the Past (1.4.6.2) contains a number of arguable judgements and some omissions. For example, contrary to 1.4.6.2 a, many scientists would argue that the case for greenhouse gas mitigation, or at least reducing fossil fuel consumption, is far stronger than was the scientific basis for CFC and acid rain controls when they were introduced. It should be noted that the Montreal Protocol of 1987 is pursuant to the Vienna Ozone Layer Convention of 1985. The "European protocols" on acid rain are, in part, pursuant to the ECE 1979 Convention on Long Range Transboundary Air Pollutants and the protocols involve North America as well as Europe (although U.S.A. and U.K. didn't sign). It is, in my view, probably not constructive in para 1.4.6.2 c to talk even hypothetically about "sanctions for non-members".
8. 1.5.4.5 on "No regrets policies" again belittles the major energy efficiency opportunities outlined by WT 6/7, by suggesting that government fossil fuel subsidies be removed only in Soviet Union, whereas - Canada, U.S.A. and Germany and several others, are among the worst offenders. The last sentence trivializes the energy efficiency argument. I have asked Prof. Goldemberg if he would provide an alternative draft.
9. Under Economics of Policy Actions, flexible regulatory measures are ignored and "command and control regulations" are probably rightly dismissed. However, many countries have excellent experience with energy targets (regulations) for appliances, cars, etc. which allow full rein to the innovative capability of industry, and are favoured by the public (e.g. 97% of motorists in Canada prefer CAFE standards as a means of reducing auto emissions) See also WT 8 Chapter. Given the political unpopularity of energy or carbon taxes, we should try to give some guidance to countries on how to make regulatory approaches most efficient, (e.g. Grubb 1991) or how to combine them with economic instruments.
10. Under Mitigation Policies for LDC's and their National Action Plans, Sections 1.6 and 1.7, why isn't there more attention to the options outlined in Goldemberg and Reddy's excellent book on this topic. The "leapfrogging" of technologies is dismissed far too quickly in paras 1.8.5.2 and should be a central point in LDC strategies. Prof. Goldemberg has been requested by me to provide some text for these sections.
11. In the discussion of sustainable development, there appears to be no recognition that increasing greenhouse gas concentrations are a clear sign of unsustainable development.

Perhaps I'm over-sensitive on some of these points, but I'm well aware that in presenting the report to countries, including many developing countries, we will be very much on the spot. Thus I think it is very important to get more input quickly from developing country authors of WT 1 and address the concerns noted above.

I will be in Ottawa until 5 Sept. 1700 hr and at Geneva Hotel des Nations Fax: 41 22 733 3884.

Thank very much and best personal wishes.

Yours sincerely,


James P. Bruce
Co-chair, IPCC WG III
cc: Erik Haites, TSU
cc: Prof. Jose Goldemberg, Sao Paulo

**INSTITUTE FOR
INTERNATIONAL
ECONOMICS**

11 Dupont Circle, NW, 6th FL, Washington, DC 20036
(202) 328-9000 Fax (202) 328-5432

FACSIMILE TRANSMISSION COVER SHEET**PLEASE DELIVER TO:**

NAME: Dr. Joseph Stiglitz
COMPANY: Dr. Sally Kane, CEA
FACSIMILE NUMBER: 395-6853
TELEPHONE NUMBER: _____

TRANSMISSION SENT BY:

NAME: Dr. William R. Cline
DATE: 8/24/94 TIME: 10:50

We are sending a total of 4 pages including this cover sheet.

If you do not receive all of the pages, please contact us as soon as possible at
(202) 328-9000. Thank you.

Our facsimile number is (202) 328-5432

C. Fred Bergsten, Director

BOARD OF DIRECTORS

G. Peterson, Chairman
 M. Solomon
 Chairman, Executive Committee

Lazak Balcerowicz
 Raymond Barre
 W. Michael Blumenthal
 Miguel de la Madrid
 Douglas A. Fraser
 Maurice H. Greenberg
 Carlos A. Hills
 Paul R. Jolles
 W. M. Keck II
 Nigel Lawson
 Lee Kuan Yew
 Frank R. Loy
 Donald F. McHenry
 Ruben F. Menaker
 Akio Morita
 Kaneo Nakamura
 Suliman S. Okayan
 Paul H. O'Neill
 I. G. Patel
 Karl Otto Pöhl
 Edvard Ranta
 David Rockefeller
 Mario Henrique Simoesen
 P. Roy Vagelos
 Paul A. Volcker
 Dennis Weatherstone
 Marina v.N. Whitman
 Andrew Young

Ex officio

C. Fred Bergsten
 Richard N. Cooper

Executive Directors
 Greenspan
 Donald H. Jones
 George E. Shultz

ADVISORY COMMITTEE

Richard N. Cooper, Chairman
 Robert Baldwin
 Barry P. Bosworth
 Susan M. Collins
 Rimmer de Vries
 Juergen B. Donges
 Rudiger Doornbusch
 Gerhard Fels
 Robert J. Flanagan
 Isaiah Frank
 Jacob A. Frankel
 Gottfried Haberler
 David D. Hale
 Mahbub ul Haq
 Dale E. Hathaway
 Nurul Islam
 Peter B. Kenen
 Lawrence R. Klein
 Lawrence B. Krane
 Anne O. Krueger
 Paul R. Krugman
 Roger M. Kubby
 Robert Z. Lawrence
 Jessica T. Mathews
 Rachel McCulloch
 Isamin Miyazaki
 Michael Mussa
 Richard R. Nelson
 Joseph S. Nye, Jr.
 Sylvia Ostry
 John A. Oswald
 José Padua-Schioppa
 James J. Polak
 Jeffrey D. Sachs
 Ernest Stern
 Lawrence H. Summers
 Alan Wm. Wolff
 Robert B. Zoellick

INSTITUTE FOR INTERNATIONAL ECONOMICS

11 Dupont Circle, N.W., Washington, DC 20036-1207
 Phone: (202) 328-9000 Fax: (202) 328-5432

August 24, 1994

Dr. Joseph Stiglitz
 Dr. Sally Kane
 Council of Economic Advisers
 Old Executive Office Building
 Room 315
 Washington, DC 20500

Fax: 395-6853

Dear Joe and Sally:

Thanks for sending me the draft of the IPCC "Scope" chapter. I have made marginal notes on the pages enclosed.

I think it is a nice overall review. Your task is complicated by the problem that you risk repeating virtually everything the rest of the study addresses. You asked what I thought should be kept in a drastic slimming-down (I believe, Sally, you said only 15 pages could be kept).

Perhaps three criteria are relevant for paring. First, what sections can go because they are most directly duplicative of what is in the other chapters. Second, what sections should be kept because they set out the conceptual framework that is the tip of the iceberg for the material that follows in the other chapters. Third, what sections should be kept simply because they are unusually good, even though there may be some risk of repetition elsewhere.

On the basis of these three criteria, here are the sections that make my first cut and are good candidates for retention (albeit probably with editing to downsize):

- 1.3.3
- 1.3.4
- 1.4.1.1 through 1.4.2.1
- 1.4.3
- 1.4.6.1 (but with substantive improvements)
- 1.5.2 through 1.5.4
- 1.7.1 through 1.7.4
- 1.8.1

Dr. Joseph Stiglitz
Dr. Sally Kane
August 24, 1994
Page Two

As for my own area, I found most of the points in the section on damages from global warming are already covered in the chapter from my writing team. There are some disagreements on some specifics, in particular the tone of whether agricultural damage is major or not and the diagnosis of net space-climatization effects. I did not include the Gruenspecht piece because it was not yet in the public domain; as you will see in the draft damages chapter, I think there is other evidence to the contrary. Perhaps some of your points on these divergences should be kept in your section. Also, I was sorry to see your section on damages seemed to ignore the longer-term warming beyond $2xCO_2$. I thought by now this was becoming part of the conventional wisdom. It is addressed substantially in my writing team's chapter, but a more explicit cross reference would seem appropriate. The problem, and the calculus, are simply radically different if there is truncation at $2xCO_2$.

I think the discussion of discounting should remain, because this is so central that it is a strength rather than a weakness to have it come up again in the cost-benefit chapter and in the damages chapter. This document is not by faceless bureaucrats; readers know the names of the chapter authors and have a right to expect the unique insights of the different authors.

One aspect that concerned me was that at places the chapter seemed to come over as a lecture by industrial country economists on how the LDCs weren't doing their part. I would prefer that the attack on the Rio convention be rephrased along the following lines. Everyone knows that sooner or later the LDCs will have to be brought into the process of emissions limits. However, this is very much a staged international policy response with a large element of contingent action in response to additional scientific information. In a first stage, there are good grounds for having the countries most able to afford restricting emissions take the lead. Even in this stage, they can often do so most efficiently by projects in LDCs (joint implementation). Then in a second stage (after 2000 and, probably, scientific firming up, for example from earth-satellite observations on cloud properties scheduled for the late 1990s), more generalized efforts including the LDCs would probably be necessary.

You should be forewarned that the LDCs will violently react to the current draft by saying that the DCs caused the problem by their past emissions and now want to thwart LDC growth. The draft basically says this can be handled by tax redistribution, but the dismissal is a bit too casual. You may want to address the

8

Dr. Joseph Stiglitz
Dr. Sally Kane
August 24, 1994
Page Three

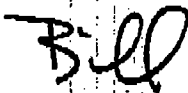
"legacy" issue directly by pointing out that if past emissions were all that were in question, there would be no problem: the rise from 280 to 350 ppm concentration has minimal effect. The real problem is much larger future rises, of which perhaps more than half will come from LDCs over the next century.

A related point is that the draft treats quota allocations in an antiseptic way without explicitly recognizing that there are potentially large distributional differences between tradeable permits and a carbon tax. The latter allocates by dollar voting; the former, by negotiated shares likely to take into account population and thus likely to have a more progressive outcome. My own view is that initial modest carbon taxes would be the right way to start, but if the problem proves as severe as it looks, eventually the international community will be pushed to some form of (tradeable) country carbon rights. Similarly, the current text rather casually refers to grandfathering, but especially over time this basis is inequitable without necessarily being efficient.

I guess a key task at this point is for your team to go through the other chapters carefully and see where there are points you want the other chapters to take up from your current text, so that whole sections from your chapter can be hived off to meet the space constraint without sacrificing key points of view.

I hope these comments are helpful, and I look forward to seeing you in Geneva.

Best regards,



William R. Cline
Senior Fellow

RESOURCES AND TECHNOLOGY DIVISION
Economic Research Service, USDA
1301 New York Avenue, N.W.
Washington, DC 20005-4788

Commercial FAX: (202) 219-0029

Commercial Phone: (202) 219-0455

DATE: 8/24/94

TO: <u>Sally Kane</u>	FROM:
	John Miranowski _____
	Carol Kramer _____
	Margot Anderson _____
	Andy Anderson _____
	John Reilly _____
	John Day _____
	Leslee Lowstuter _____
	Denice Bess _____
	Cynthia Ray <u>✓</u> _____
	Annette Bowie _____
	Deborah Hood _____
	Kimberly Glenn _____

PHONE: <u>395-3997</u>	
FAX: <u>395-6853</u>	
NUMBER OF PAGES BEING SENT, (INCLUDING COVER): <u>4</u>	

MESSAGE: Sorry for the delay. I did my best
with John's handwriting.

From: John Reilly
USDA/ERS

August 24, 1994

Some overall points:

- Much good material - broad ranging and ultimately covering the waterfront.
- As you indicated, still quite rough - much wordsmithing needed.
- I get a very U.S. biased feel from this document. Most of the references are US based economists. I suppose the U.S. has somewhat dominated the field of economics but you need to make an attempt to erase this apparent bias as much as possible or its going to be widely rejected internationally.
- You and Joe are perhaps more in tune with how the document is meant to fit with other chapters, but to me, this looks far more like an executive summary or (slightly) slimmed down version of the entire report than a scope chapter, i.e. you try to reach conclusions about each of the issues you raise which, I would think, should be left for the chapters. You somewhat fail to provide the broader picture in which this assessment fits and why economics/social science insights are important (exactly what broad questions does economics set out to answer that cannot be answered by physical science or other approaches) you have these answers, implicit in what you cover, but it does not come through clearly.
- I think you need to start out with some fairly straightforward, broader questions/issues that a broader audience can top into, thus providing a reason for the secondary chapters rather than answering all the questions so there is no need for the chapters, i.e. here is how I would start:

Climate scientist predict unprecedented rates of climate change resulting from accumulation of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons and other gases in the atmosphere.

- 1) The accumulation of these gases is clearly linked to emissions of gases from various human activities including burning of fossil fuels, land clearing, various agricultural practices from use of refrigerants, and from land fills.
- 2) Climate change is one of a number of unintended effects of these activities. Other effects include ozone depletion, species loss, loss of forests and ecosystems, other air and water pollution, and the dispersal of hazardous and other waste.
- 3) The relationships are complex: CFCs deplete stratospheric ozone leading to increased UVB but less stratospheric ozone has been found to partially effect warming, sulfate emissions from coal use similarly lead to cooling perhaps masking the effects of trace gas.

accumulation - efforts to control sulfate emissions and acid rain may, thus, "unmask" warming; policies and programs to limit erosions and adapt to climate change may conflict - shifting of agricultural zones may conflict with ecosystem preservation and migration and demand for land for agricultural or ecosystem preservation may conflict with efforts to produce biofuels or sequester carbon in standing fruits.

4) The issues are marked by uncertainty not only of the magnitude but of the direction of key efforts and of how different components of the system interact. Will warming benefit some areas and sectors while harming others; how much warming will occur and when; will change be gradual or marked by sharp local discontinuities and distinct changes in climate regions; can developed countries inexpensively shift to fossil fuel alternatives and can developing countries achieve goals of economic growth and human development without a heavy reliance on carbon based fuels.

5) To limit emission will require unprecedented cooperation among countries of the world; developed countries currently contribute x % but developing countries are expected to increase energy use and carbon emissions if they successfully develop reach of x % by the 2000 in some forecasts. How can the world reach a cooperative solution? How can it enforce the solution to which countries agree? How can it equitably share the cost of limiting emissions and the losses imposed by unavowed change?

6) The effects of gases omitted over the past few decades and over the next few will have effects for a century or more into the future. Our efforts to control trace gases are aimed primarily toward limiting potential effects on our children, grandchildren, and great-grandchildren. We face a difficult task in estimating and judging what aspects of climate and environment they will value and how best to preserve those aspects for them. If we take aggressive action to limit climate change, they may regret that we did not use the funds inclined to push ahead development more rapidly in Africa, to increase our understanding of human health such that we were better able to protect ourselves against diseases such as AIDS, or to have created a stable means of destroying, disposing, or containing stockpiles of nuclear materials.

To fully assess these issues is now recognized to require unique new approaches for scientists from traditionally separate disciplines to work together to understand the complex processes and linkages, resolve uncertainties, and to devise effective responses recognizing that some aspects of climate change may be fundamentally unpredictable. The scope of Working Group II is particularly oriented toward summarizing: 1) Our understanding of the human focus leading to trace gas accumulations-how well can we predict future emissions?; 2) our understanding of how climate change will affect human - as natural systems are affected how do these "add up" to affect economic activity and human wellbeing; 3) approaches for how we decide what to do about climate change, particular given the uncertainties, unknowables, and unpredictable aspects of change; 4) how do we equitably share the burdens of climate change and

policies designed to use it both across current cultures and peoples across generations; 5) What are the cost and equity implications of various measures that have been proposed and 6) How does climate change and our responses to it fit within the broader, complex, and set of environmental problems, i.e. how do we achieve sustainable development?

- Economics has a well-developed theory for determining optimal and efficient policies. This theory has some severe limits and require strong assumptions, regarding compensation. I would start by discussing the basic economic framework for policy choice. I think if you do this first, then it is clear why economists care so much about estimating costs and valuing benefits.
- The economic solutions will conflict with politically determined solutions which can be seen as a process separate from the market for determining social choice. Having done the above, you might then go through more of the details but not as much as you do. For example, I do not think you need to review damage estimates for each section-this will be (should be) covered in the social art chapter. You only need to discuss it in a broad sense and why its important.
- In this mode, economic models contribute to the decision of what is the best level of control of emissions. A negotiated solution or solutions proposed by a political process might well diverge from this optimal response. Economic models and analysis can still be very effectively used to analyze the implementation of the policies and proposed policies and identify mechanisms that achieve negotiated solutions most effectively. For example, if a negotiated process were to determine a dangerous level of concentration that should be avoided, economic analysis could help identify how emissions targets should be phased in over time to meet such a target and might also recommend a system of tradable permits or the process of joint implementation to achieve the targets most efficiently. It might also provide an analysis of how the costs of the control policies would be distributed across different countries or income classes and thus provide input into the process of alternating emissions rights in an equitable manner.

This is the first of 7 sheets that were faxed
to Sally Kane & Joe Stigitz
at CEA 202/395-6950
on 8/30/94 by

Richard Schmalensee
20 Malia Terrace
Chestnut Hill, MA 02167

Telephone: 617/566-0664

Fax: 617/566-6492

Note: I'm at 202/966-3510
8/31 & 9/1 if any of this needs
discussion. Good luck!!



**Massachusetts Institute of Technology
Center for Energy and Environmental Policy Research**

**Richard Schmalensee, Director
Gordon Y Billard Professor of Economics and Management**

**One Amherst Street (E40-471)
Cambridge, MA 02139-4307
Telephone: (617) 253-3551 • FAX: (617) 253-8013**

To: Sally Kane and Joe Stiglitz, CEA

From: Dick Schmalensee

Date: August 30, 1994

Re: 8/15 Draft Chapter

This was actually enjoyable to read! It needs some work, as the comments that follow indicate, but it will clearly be a very important and widely-read document. First a few more or less general reactions.

1. I think this chapter should contain early on a very basic paragraph or two on externalities and market failure, just as the scientists gave us "the greenhouse effect for toddlers." The fact is, most people simply do not think about environmental issues, and certainly not this one, as economists do. (Indeed, there are even subtle differences between io/regulation and public finance approaches here.) Page 54 is too late to get to this stuff, though it might make sense to keep that level of detail out of the front end.

I also think you need to have something early on about command and control versus other approaches -- CAFE v. gasoline taxes is my favorite... Since the whole world uses command and control, and since engineers turn right to it, I think you need to put down this marker early. (A carbon tax is simply assumed optimal in passing on page 13: this will blow by most readers. The point that you can't assume that efficient policies will be adopted is crucial; don't lose it by obscuring it in this fashion.)

2. I might also add a brief discussion of the nature of the negotiation problem. A naive application of the Coase Theorem (which should surely be mentioned!) would suggest that negotiation among nations, which can write checks to each other, should lead to a Pareto efficient outcome here, even without any sort of world regulator. I think this fails both because contracts involving future "payments" aren't credible/enforceable (thus there are no real property rights) and because nations aren't rational individuals -- there are limits on their abilities to accept changes that make them better off in aggregate.
3. I think there is way too much space devoted to specific costs of warming and estimates of costs of mitigation for a chapter concerned with framework and principles. We need to know that both are uncertain, potentially huge, and likely uneven in their incidence and

Sally Kane & Joe Stiglitz

2

August 30, 1994

that both involve irreversibilities. (A free idea: to my knowledge, nobody has even attempted to prove that the present climate is the best of all possible climates for humans in any sort of long-run steady-state sense. All the cost estimates of which I am aware amount to costs of adapting to change. Given that we are looking at warming *trajectories*, comparative statics, which dominates most impact analysis, really makes little sense. Some of the language in this chapter seems implicitly to assume comparative statics.) We also need to know that time is measured in decades in this problem, with little impact forecast by anybody until several decades into the next century.

4. There is a good deal of duplication, in that the same point is often discussed (at different levels of detail) in several places. Perhaps this is intentional, given the natures of the art form and audience, but it is a bit off-putting and I think increases length needlessly.
5. The policy discussion needs to be tightened in a couple of respects. First, you need to distinguish more clearly between policy choices at the national and international levels. Page 33, for instance, leaps from a discussion of using the income tax system to deal with equity (presumably within nations) to a discussion of "a pollution permit scheme" that seems to operate between nations. This is a huge leap, particularly since "pollution permits" have not yet been defined. (See my first point above.) One can imagine, for instance, a national-level system based on tradable quotas, with command and control used by national governments to meet their objectives. (Early State Department memos on the Framework Convention envisioned a set of command and control Protocols.) Or, one could adopt a tax approach internationally, and seek to coordinate effective carbon taxes, somehow defined. (This would avoid the problem of a country failing to keep its promises because its economy grew too rapidly...)

Second, your discussion of the Framework Convention treats it as the last step in the policy process, not the first step. Clearly the obligations assumed won't stabilize emissions, let alone (the Convention's ultimate objective) atmospheric concentrations, but it is surely a valid criticism (which you must have chosen not to make) that those goals have absolutely no analytical basis. Just as clearly, there will be international negotiations on this issue for decades (unless the scientists really surprise us), and there will be plenty of time to deal with the developing world, should there ever develop the necessary political will there or in the OECD. In the meantime, reviewing national action plans and experimenting with joint implementation will make it easier to adopt stringent plans that are efficient, should we choose to do so. I think it is useful to talk about the Framework Convention and the associated process as defining a "policy architecture" (in the software sense) rather than a particular policy -- since it is not clear to me (see p. 40) that it would have served any useful purpose to have tried to set a long-term world emissions trajectory.

6. I think you badly need a glossary for non-economists. Hire a good editor who does not do economics work to go through and flag all the technical terms, then write definitions

Sally Kane & Joe Stiglitz

3

August 30, 1994

for idiots. (Do chemists know what a rate of return is? No, they don't. They have given us glossaries.)

I also have a few more detailed comments.

1. Page 9: Table 1 should show percentages of global emissions over time, so the reader doesn't have to try to calculate it.
2. Page 11: Thanks for the cite, but my point is rather different. The IPCC's GWP measure may be convenient, but it is utterly without any economic rationale. The logical starting point is discounted marginal damages, as I discuss. Even if all greenhouse gases have the same decay rate, CO₂ fertilization would complicate comparisons, as John Reilly (who deserves a cite here) has indicated. After this discussion, I think CO₂ is the only gas mentioned, except for one mention of methane on page 70. (Do a search on "nitrous oxide"...). There are good arguments for an exclusive policy focus on CO₂ in the near term; perhaps you should make them implicitly -- or discuss other gases a bit.
3. Page 18: I think these electricity studies are silly in a world in which people in the U.S. have been migrating for decades to warmer areas where air conditioning is required -- as Schelling and others have noted. Changes in the geographic distribution of population (a reversal of this trend, say), can easily swamp any estimated change in electricity demand. In addition, this has nothing to do with utility. People seem to like to live in cool houses located in warm climates, even though this does involve more consumption of electricity: energy is an input into the production of utility.
4. Page 20: The treatment of contingent valuation is a bit brisk. I was surprised not to see Hausman's book or the NOAA panel report cited. There is a shortly forthcoming JEP symposium on this issue.
5. Page 20, at the bottom: "Catastrophic" has two meaning. Catastrophes in the narrow mathematical sense do not necessarily "alter all relationships and necessitate major restructuring of the problem," though catastrophes in the dictionary sense (like a shutdown of the Gulf Stream) would do so. In my view, at least, irreversibilities abound here, and small ones are not cause for alarm.
6. Page 21: The discussion of sustainability in note 1 is too cryptic; refer back to Rawls when you deal with this topic in more depth later.
7. Pages 21-26: The discussion of discounting seems rather longer and more technical than would fit with the rest of the chapter. I have found Broome's *Counting the Cost of Global Warming* to be interesting on discounting, especially its intergenerational aspects. He advocates a zero rate, as does Cline; their arguments at least deserve a cite.

Sally Kane & Joe Stiglitz

4

August 30, 1994

8. Page 23: My sense is that the low productivity growth of the past two decades is "only" an OECD problem -- ?? A cite on this might be useful for non-economists as well as for me. Note 3 also needs some cites.
9. Page 24: You should probably write out the partial derivatives in note 5.
10. Page 26: You should indicate more clearly (probably in a footnote) how the discount rates in the second complete paragraph were derived -- it wasn't clear to me what was being assumed about, e.g., taxes. (I still like my 1976 *JPubEcon* paper on discounting, but I may be alone in this.)
11. Page 26: "No regrets" has nothing to do with risk aversion. Ignoring warming makes sense only if it is impossible or there are no irreversibilities. Since nobody (yet!) argues that warming is likely to be a good thing, the possibility of warming affects means, not just variances, and thus generally has action implications even under risk neutrality. Beat up on "no regrets" all you want (It deserves it!), but for the right reasons.
12. Page 33: Where is the OECD's "polluter pays principle" in this intergovernmental document? Is there a reference for the proposition that Rawls always implies much more progressivity than any utilitarian model? I have some doubts. Broome's book (#7 above) is interesting on population.
13. Page 34, Note 13: How??
14. Page 35: The discussion of taxation here seems a bit too definite for a world in which what seems to matter is the (expected) cost of finding fossil fuels and the oil market at least seems to be heavily influenced by strategic behavior.
15. Page 36: I think aluminum production tends generally to use hydropower, so that carbon taxes may not move it.
16. Page 36, 1.4.2.2.: There have been many studies of the costs of reducing CO₂ from fossil fuels, but there is very little on the costs of other mitigation strategies -- particularly involving other gases. Also, most mitigation studies focus on the developed world, particularly the US.
17. Page 41: Your discussion of the need to "impose commitments" on the developing countries is potentially explosive. **IMPOSE??!!** It is surely clear that if global emissions are to be controlled, theirs will have to be controlled; it is surely also clear that they will not pay for it in my lifetime. They would argue that the rich countries have the obligation to pay for abatement in the poor countries. What is controlled and who has the obligation to pay for control are logically distinct -- and emphasizing that distinction in principle may help you politically.

Sally Kane & Joe Stiglitz

5

August 30, 1994

18. Page 41: I was struck throughout by the lack of cites to Baumol & Oates and other enviro pieces. Also, this is surely a place to tout the US acid rain program.
19. Page 43: "Joint implementation can be viewed as a 'back door' way into tradeable permits" -- this is important and should be elaborated upon for your non-economist audience.
20. Page 46: Technologists (not just environmentalists) always seem morally offended by the universal gap between average practice and best practice. Attempts to legislate away the frictions that cause such gaps usually don't work well, however.
21. Page 50: I very much agree with the conclusion in the first paragraph of 1.5.4.2.2. I'm thus a bit upset that you dismiss it out of hand when you implicitly assume throughout that any serious global regime must involve tradeable permits, not tax harmonization.
22. Page 51: In the first sentence in the second paragraph in 1.5.4.2.4, "most of the next century" seems to imply either that you know that we'll sleep through the first few years after 2000 or that the world will end before the century does...
23. Page 55: Under b), it does not follow from the fact that a permit system cannot be fully efficient that such a system is not optimal unless you have a fully efficient alternative. Under c), as long as demand curves slope down, an industry will oppose a regulation that raises its costs in the short run, even if all firms are under the same regulation. Also, 2) is unclear: giving permits away (the norm empirically, though not in the literature) eases the pain but does not remove opposition -- consider acid rain.
24. Page 57: If climate modelers can come clean about "flux corrections" and other fudge factors, we should come clean about "backstop technologies." (This is the sort of term that begs to be in a glossary.) These are typically inserted into our models without any basis in serious technology forecasting, and their more or less arbitrarily chosen characteristics have a major impact on models' predictions. Backstops are our invention, not the technologists' -- MIT engineers laugh out loud at them.
25. Page 58, top: Carbon tax numbers are almost meaningless to somebody not hip-deep in this literature; percentages of GDP make more sense. If you must include carbon tax numbers, relate them to fuel prices. In the percentage loss numbers that follow, it would be nice to know something about whether costs of, say, stabilization rise or fall over time as a percentage of GDP -- along somebody's long-term forecast.
26. Page 59: Why not discuss the US acid rain program here -- even if the last Administration did invent it? I think b) is a little doctrinaire: full international trading is plainly necessary for full efficiency -- if you go this route -- but it is not obvious that the losses are large if nations trade with each other and use, say, taxes internally. (Do you really

Sally Kane & Joe Stiglitz

6

August 30, 1994

think it is important that households in the U.S. trade *directly* with households in China?) I would add a fourth important lesson: tradable permit systems can deal with equity issues by altering the initial allocation of permits without compromising efficiency. (There were fierce battles over the distribution of SO₂ allowances in 1990; none affected efficiency.) Dealing with equity issues under command and control or tax systems almost inevitably does sacrifice efficiency.

27. Page 60: Your examples of non-greenhouse externalities are one-sided: increasing CO₂ enhances plant growth (is this mentioned anywhere?), and increased SO₂ emissions have a (very short-lived) cooling effect.
28. Page 62: This is a good example of material that is more or less duplicated elsewhere.
29. Pages 71-72: The transition between these pages is abrupt to the point of discontinuity.
30. Page 73: You are critical of the Commerce approach, even though it may not be a bad approximation in a world where finding and extraction are subject to rapid technical progress, but you don't mention that the alternative neglects entirely the expensive processes of discovery and development process. Perhaps I have been overly influenced by my colleagues (including especially Morrie Adelman), but it seems to me that Commerce clearly has the better approximation.
31. Page 80: Removing subsidies is not usually considered "market structure reform"; perhaps you mean "structural reform." Also, the discussion of irreversibilities seems to neglect the awkward fact that there are irreversibilities on both sides of the problem here.
32. Page 81: I'm not sure what the importance of extreme events, with which I agree, has to do with social science. (Forecasting means is hard enough; forecasting variances seems to be beyond near-term hope.)

Clinton Presidential Records Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a tabbed divider. Given our digitization capabilities, we are sometimes unable to adequately scan such dividers. The title from the original document is indicated below.

Chap 2 BENEFIT - COST

Divider Title: _____

**APPLICABILITY OF COST-BENEFIT ANALYSIS
TO CLIMATE CHANGE**

Prepared for WORKING GROUP III
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Draft, July 1994

Prepared by:

Mohan Munasinghe, Michael Hoel, Sung Woong Hong,
Peter Meier, and Asbjorn Aaheim.

1. Introduction

In public policy-making, a comparison between the perceived costs and the perceived benefits of an action is routinely made by decision-makers. However, this choice is frequently made on intuitive and qualitative grounds. Cost benefit analysis (CBA) provides an analytical framework that seeks to compare the consequences of alternative policy actions on a quantitative rather than qualitative basis. Indeed, the approach forces quantitative thinking, for its very essence is that costs and benefits must be expressed in a common monetary unit that provides the basis for the tradeoffs. The basic principles are well understood and straight forward: for an action to be justified, the costs of the action should be less than the benefits derived therefrom¹. If there are several alternatives, then one ought to pick that option whose benefits most exceed the costs².

The objective of this Chapter is to examine how and under what circumstances can CBA make a contribution to the resolution of the central questions now facing decision-makers about global climate change: (1) by *how much* should emissions of greenhouse gases (GHGs) be reduced? (2) *when* should emissions be reduced? (3) *how* should emissions be reduced? and (4) *who* should reduce emissions? CBA can at least theoretically and conceptually answer the first three questions. The fourth question is one of equity, and not amenable to resolution by CBA even in simple, traditional applications not complicated by the complexities of the climate change problem³.

Section 2 defines more carefully what is meant by CBA: in fact the term has come to encompass a wide variety of specific techniques. We also review the basic concepts. In section 3 we examine the unique features of global warming and climate change as they pertain to decision-making. Section 4 presents a discussion of the application of CBA to the climate change problem in light of these unique features. In section 5 we discuss the key issues: risk uncertainty, irreversibility, valuation, discounting, equity, and multiple criteria.

¹ Indeed, that cost-benefit analysis is appropriate to the analysis of policy options to address global climate change is not universally accepted. A major report recently issued by the US Office of Technology Assessment (OTA, 1993) contains an extensive discussion of how adaptation strategies should be chosen, yet manages to avoid all mention of cost-benefit analysis *per se*. It talks about how one might minimize vulnerability to climate change and about insurance strategies, but avoids the central question of how one might determine the amount of insurance one wishes to buy. Similarly, priorities may be set on non-economic grounds, and CBA could be used in a secondary role (see e.g. Turner, 1991).

² Although this needs a little bit of modification in the presence of capital constraints, which may limit selection of the "best" single project.

³ However, as we shall see later, extensions of CBA can help in identifying the *trade-offs* between economic efficiency and equity.

2. Cost-benefit analysis

Cost-benefit analysis (CBA) is a generic term that subsumes a wide body of specific techniques. Developed originally as a means to evaluate projects, the original techniques have been extended to cover applications of increasing complexity.

Traditional project level CBA

CBA evolved as a technique to evaluate and compare project alternatives. In the early years of its application, there was little concern with externalities, and the analysis took into account just the direct costs of projects, and the direct benefits. Developed in the west, market prices provided appropriate guidance on how to evaluate benefits. But even as the World Bank began to apply the technique to non-market economies, or where prices were subject to significant distortions, shadow pricing techniques provided simple corrections.⁴

One of the central concepts in CBA is that of discounting, which addresses the fact that costs and benefits may not occur at the same point in time. Thus, while costly actions to avoid future global warming must be taken now, the benefits of such actions may arise very far in the future. Discounting enables one to take into account the time value of money. In the case of evaluating simple investment alternatives over shorter time horizons (e.g., < 15 years), the use of the opportunity cost of capital as the discount rate to be applied to both costs and benefits, is well established and uncontroversial. However, in the case of complex public policy applications, particularly those whose time horizons are very great, and involving environmental impacts or the depletion of natural resources – essential characteristics of the global climate change issue – there is sharp disagreement as to what discount rate is appropriate. This issue is dealt with in Section 5.

Cost-effectiveness analysis

As CBA began to be applied to much broader contexts, and particularly to the comparison of alternative *portfolios* of projects and to broad policy choices, the increasing complexity made it desirable to keep the level of benefits constant, and to analyze the problem simply in terms of finding the most effective, or "least-cost" option to meet the desired level of benefits. This has the additional advantage that benefits in some cases do not need to be explicitly valued. For example, in power sector planning, models are applied to identify the capacity expansion plan whose present value of system costs are minimized, given some exogenously specified time path of electricity demand, and some exogenously specified level of reliability. As we shall see below, this is the variant of CBA that has seen the most widespread application to the climate change problem, in which one seeks to identify the least-cost option to achieve given levels of GHG emission reductions, without any explicit attempt to specify what the *benefits* of that level of emission reduction may be.

The Framework Convention on Climate Change emphasizes that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost." Being a global matter, most of the actions that will be taken to mitigate climate change will be equally efficient independent of where in the world the action takes place. Strictly speaking, therefore, cost effective measures are those that minimize total world cost, given a target for the world as a whole.

⁴ For example, if an oil-importing country kept the domestic price of oil at artificially low levels, CBA requires the use of the border price, not the domestic price, as a basis for costing oil inputs.

The importance of CBA in relation to cost effective mitigation of climate change depends partly on the kind of measure that is considered. Analysis of general measures, such as carbon taxes) is straight forward, assuming that market behavior leads to cost minimization based on the prices of the taxed goods and services. Cost effectiveness is then a question of a proper tax. A global marketable permit system would result in permit prices equivalent to the proper tax – if countries could agree on the target level and how to share the initial distribution of permits. Responses based on the efficient functioning of markets would similarly lead to cost minimization. For a closer examination, see Hoel (1992).

For the evaluation of investments in GHG emissions abatement, CBA will play a more central role. Cost effective measures should be evaluated on the basis of global models in which economic interdependencies between world regions are taken care of. However, such models have to be quite aggregate, and will generally not allow the evaluation of measures for which a rather detailed description of national economies is required. Measures that aim at sectoral substitution within energy intensive industries may be such an example. To evaluate such measures, national macro-economic models might be applied. These will have to take certain conditions on the world market as given – conditions that might change if many countries initiated climate measures.

Many of the potential climate change mitigation measure require a rather detailed technical description to be evaluated. In these cases CBA would normally assume all the prices to be fixed at observed market prices. If introduced on a large scale, however, these kinds of measures might affect market prices at the world level. Thus, a fully consistent evaluation of cost effective measures may require analysis at several levels of aggregation.

In order to evaluate cost effectiveness it is crucial to clarify in what terms the target is set, because there are several options in the global climate change context. Most of the recent analyses of the cost of mitigation have focused on targets of future emission levels⁵, such as stabilization of the emission of certain greenhouse gases by a given year. However, it might be more relevant to express the targets in terms of concentrations of atmospheric greenhouse gases.

To change the target for climate policy from emissions to atmospheric concentrations indicates a radically different cost effectiveness strategy. A stabilization of CO₂ emissions at present levels is not sufficient to stabilize the atmospheric concentrations. Richels and Edmonds (1993) have compared the costs of reaching the same concentration level by year 2100 from alternative strategies. They show that the same concentration level can be met at a considerably lower cost than the cost of stabilizing emissions immediately. The reason being that the economic shock following a sudden stabilization of emissions is avoided, future advanced technologies could be utilized to a larger extent, and sizable abatement costs are postponed.

A third possible target, also affecting the cost effectiveness of alternative measures, could refer to the physical consequences of climate change. Apart from the fact that predictions of these consequences are far more difficult to make than predictions of emissions and atmospheric concentrations of greenhouse gases, the effects of regional differences would have to be included if targets were set on the consequences. For instance, whether global warming contributes to sea level rise or to an increase in the frequency of rain storms will be of quite different importance to people in Nepal and Netherlands. In this context, an additional problem

⁵ The degree of emission abatement is reported in such studies in two rather different ways. The first is as reductions from some baseline, defined as the trajectory of GHG emissions for some postulated business-as-usual scenario. The second is in terms of reductions from some reference year (e.g. "reduce greenhouse emissions to 80% of their 1990 levels by 2010")

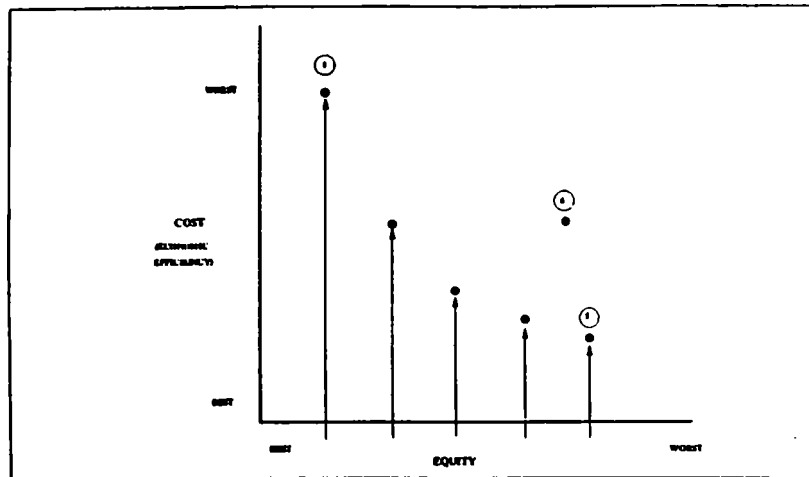


Figure 2.1: Multi-criteria analysis

arises as to how to assess benefits from abatement of different consequences for different countries.

Multi-criteria analysis

The most basic requirement for the application of CBA is that both costs and benefits can be given economic value. This is typically a two step process: first the costs and benefits must be quantified in terms of the physical measures that apply; and then those physical impacts must be valued in economic terms.

Some applications of valuation techniques are likely to be controversial. Putting a value on human health and illness has been a major problem in the practical application of cost-benefit analysis in the past, even in those situations where one can agree upon the levels of increased morbidity and mortality that might be caused by some policy or project. Efforts to place economic value on the loss of biodiversity have been equally difficult. Recognizing this problem has led to the development of so-called multicriteria analysis (MCA) techniques, which are expressly designed to deal with multiple objectives – of which economic efficiency is indeed only one of several that may be employed.

Even if one can place economic value on certain impacts – such as human life – not everyone agrees that it is *appropriate*. Indeed, cost-benefit analysis presupposes that costs and benefits are those perceived by humans – an endangered species might view the trade-off between threatened habitat and GHG emissions in an entirely different way, and use a different numeraire than money⁶. Such views give further support for MCA-based approaches to

⁶ A recent survey of economists and scientists knowledgeable about the climate change problem elicited typical views at the extreme of this spectrum. One respondent argued "...the existence value of species is irrelevant – I don't care about ants except for drugs", while another cautioned that "loss of genetic potential might lower the income of the tropical regions substantially". In Section 5 we address the different types of value – use, option, existence – in more detail. (W. Nordhaus, Expert Opinion on Climatic Change, *American Scientist*, 82, 45-51, 1994).

decision-making. Similarly, there are concerns that monetized values themselves may be inaccurately estimated, and in any case such values might not reflect welfare.

As noted earlier, conventional CBA cannot provide answers about the optimum level of equity in the same way that it provides answers about the optimum level of economic efficiency. But MCA can identify the *trade-offs* between equity objectives and economic efficiency, as suggested by Figure 2.1. Thus, the best equity result (indicated by option 1, say an equal per capita sharing of the burden of GHG emission reduction) may have the highest cost; while the worst equity result (indicated by option 5, say based on the present distribution of GHG emissions), may have the lowest economic cost⁷. Nevertheless, even MCA requires a quantification or at least an ordinal ranking of the non economic efficiency criteria, as suggested in the figure. However, even such a non-cardinal ranking may prove problematic when a global issue like climate change requires comparisons across countries and cultures.⁸

Decision analysis

While MCA addresses certain shortcomings of conventional CBA (like valuation problems), it does not necessarily deal more effectively with uncertainty. Thus has developed a further extension of CBA that goes under the general term decision analysis. Here the focus is expressly on how one makes decisions under conditions of uncertainty. These techniques find application in a wide variety of situations, from decision-making in the high risk field of wildcat oil drilling to analysis of financial options. As we shall see below, these techniques provide a rational approach to deal with irreversibility, one of the more important characteristics of the climate change problem.

Basic concepts

An economically efficient policy for emissions reduction is one that maximizes the net benefits, i.e. maximizes the benefits of reduced global warming less the associated costs of emissions reductions⁹. Economic theory provides that emission reduction efforts should be pursued up to the level where the marginal environmental benefits of an additional unit of reduced warming is equal to the marginal cost of emissions reduction. Figure 2.2 illustrates the concepts of total and marginal costs in simplified form – the marginal costs at any level of emission reduction is equal to the slope of the total cost curve at the same level.

The shape of the total cost and benefit curves reflects the idea of diminishing returns. Each additional unit of emissions reduction will have a higher unit cost: the first 10% reduction can be done cheaply, but the next 10% will cost considerably more, and so on.¹⁰ Thus the

⁷ But see below for a discussion of the difficulties of making cross-country comparisons of costs.

⁸ There may also be some outcomes that are inefficient, i.e. those that lie inside the frontier of efficient points shown on Figure 2.1. Such an inefficient point is represented by option 6. This is discussed further in the presentation of multi-criteria analysis, below.

⁹ It should be noted that the algebra of cost-benefit analysis can be expressed in many different ways: the cost-benefit ratio, net present value, or the internal rate of return are all different ways of doing the arithmetic. However, particularly in situations involving portfolios of potential actions, and where shortages of capital may constrain the choice, great care must be paid to rigorous application of principles, else different methods can yield different decisions. Maximizing net present value subject to applicable resource constraints is the most useful approach for climate change analysis.

¹⁰ Perhaps the simplest and most intuitive example as to why the marginal cost of emissions reduction increases with increasing levels of reduction is the removal of pollutants from wastewater. The first 60% can be easily removed by a settling basin, that require just a structure. large particles

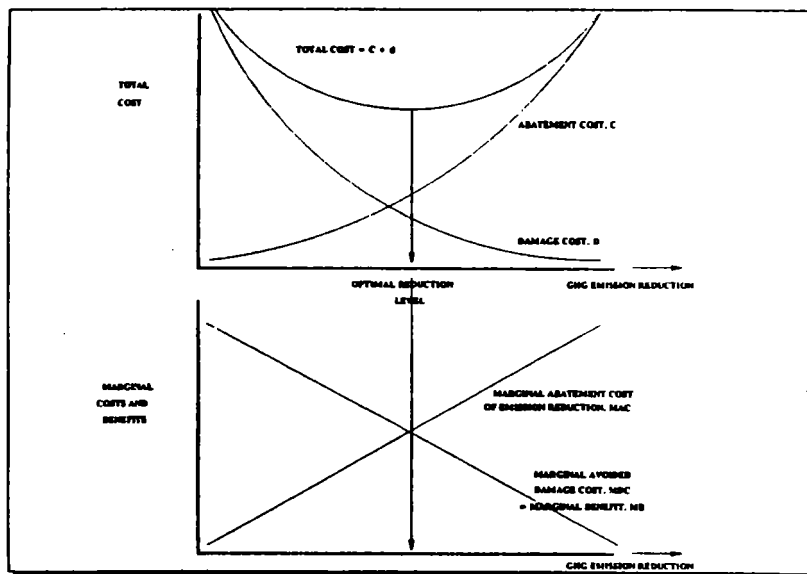


Figure 2.2: Total and marginal costs and emissions reductions.

abatement cost curve is upward sloping (with increasing slope) as shown on Figure 2.2A. Similarly, the marginal benefit (or avoided cost of GHG damages) falls as emission levels are reduced. The consequences of the foregoing is that the total cost (TC) has a minimum at the point where the slope of the abatement cost curve equals the negative slope of the damage cost curve (or avoided costs).

The foregoing analysis ignores many complications. For example, the emission of a unit of CO_2 may give rise to a varying stream of environmental costs which must be discounted to yield a present value aggregate. The environmental damage function may be discontinuous and non-convex. Abatement costs may change over time, depending on when the technologies are applied – because of technological progress. Similarly, abatement costs may exhibit economies of scale (e.g. mass production of solar photovoltaic cells), resulting in a marginal cost curve that actually declines beyond a certain point. Finally, the abatement costs are net costs, to the extent that certain technologies (e.g. renewables) may produce other (non-climate related) benefits and costs – the so-called joint products complication.

simply settle by gravity. The next 30%, to reach, say 90% removal, requires biological treatment: this requires not just a physical structure, but pumps to aerate the water to promote aerobic bacteria. The next 5-6% requires chemical treatment, with high operating costs of chemical agents. 100% removal, theoretically possible, would require complete distillation, which is extremely expensive.

3. Unique features of global warming

There are several important characteristics that define the conventional context in which CBA is applied. First is that costs and benefits arise within a time span typically no more than 15-25 years, corresponding roughly to the physical life of most projects over which benefits are derived. Second is that the elements of uncertainty are relatively tractable, and can often be characterized by probability distributions.

Most of these characteristics are very different in the context of global warming. The relevant time spans extend to a century or more. The uncertainties are extremely large, and few elements of uncertainty are amenable to characterization as probability distributions.

Figure 3.1 shows the chain of causality. It begins with emissions of greenhouse gases. While the most important of these is CO_2 , it should be noted that there are many other gases that contribute to the global warming phenomenon, including methane, and CFCs. While estimates of CO_2 emissions from fossil fuel combustion are fairly straight forward, emissions from other sources are subject to much higher uncertainty.

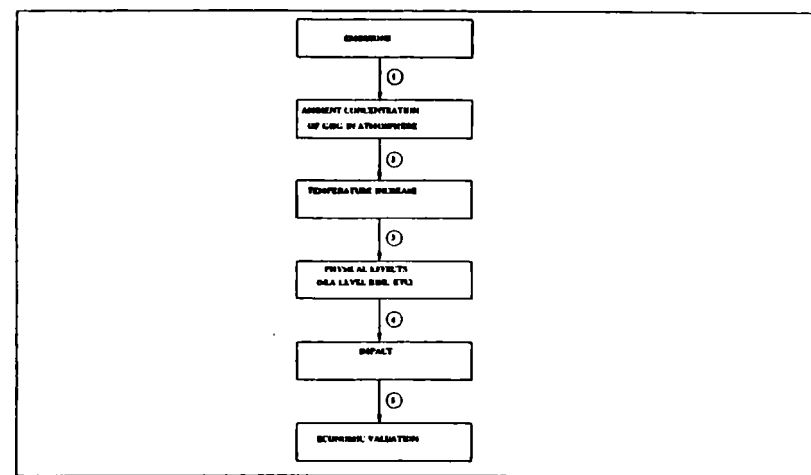


Figure 3.1: The chain of causality

The first link (1) is between emissions and the resultant ambient concentration of CO_2 in the atmosphere. Unlike other pollutants that are subject to complex chemical transformations in the atmosphere,¹¹ the calculation of the ambient concentration increase that follows from a given increment of emissions of CO_2 is relatively simple. However, because of the role of natural sources and sinks (particularly the ocean), even this calculation is subject to a considerable degree of complexity and uncertainty.¹²

¹¹ The acidity of precipitation is influenced by complex interactions between sulfur oxides, related oxidation products, and NO_x .

¹² For example, the presence of CFCs could affect global warming not only directly through its greenhouse warming potential, but also indirectly by its impact on biota like nanoplankton – which in turn influence oceanic CO_2 uptake. Similarly, the degree of reliance on fossil fuels would affect CO_2 directly, and CO_2 absorption indirectly – via the effects of acid rain on forests and biomass.

The next link (2), between atmospheric concentration and temperature, is subject to much greater scientific uncertainty. The greenhouse effect itself, i.e. the trapping of incoming solar radiation, is subject to all kinds of additional factors that are highly complex. For example, if temperatures rise, and cloud cover increases, feedback effects involving increased reflection of incoming radiation will complicate the calculation of equilibrium temperatures.

The next linkage (#3) involves many different components. Some are relatively straight forward: for example, calculating the rise in sea level may be quite simple given assumptions about increases in mean sea temperature. Much more complicated are estimates of how precipitation patterns might change, especially the spatial and temporal distribution of rainfall. Perhaps of even greater concern in the developing countries will be the changes in the patterns of extreme weather events, to which they are particularly vulnerable.

If these physical effects are understood in general terms, quantifying the impacts on the flora and fauna is much more difficult (link #4). Suppose it were possible to predict the change in precipitation and temperature regime for some given region. What can be said about the shifts in vegetation patterns? While general northward shifts of vegetation and agricultural production zones can be predicted in general terms, quantifying the effect is quite difficult. What is the impact on biodiversity? On wetlands? On the water table? Clearly these are very difficult assessments to make.

Finally, in order to estimate the damage costs, one needs to be able to value these effects (link #5). Some valuation tasks will be relatively straight forward: for example, the cost of engineering structures to protect against sea level rise are relatively easy to establish, given the existing experience in this field (in such countries as the Netherlands). Other calculations will be more complex, but at least tractable: as for example, the calculation of increased cooling and decreased heating costs on the energy system, or the impact of increased irrigation pumping requirements associated with drier climates in some regions upon electricity demand. But a very large number of potentially important impacts are very difficult to value such as the impacts on forests, wetlands, and biodiversity.

Unique features

Beyond the degree of uncertainty, what makes the analysis of the climate change problem so different to other environmental analysis problems? The main reasons can be summarized as follows:

GHGs are stock, not flow pollutants:

Many pollution phenomena are relatively short-lived, such that the damages are closely related to the current rate of emissions. This is because the rate at which most pollutants are removed from the atmosphere is relatively rapid (say in the case of particulates by dry or wet deposition). Reducing emissions at major sources will likely have a relatively immediate impact. In the case of GHGs, however, the damages occur as a result of the total atmospheric concentrations at any one time, in other words, are related to the stock of the pollutant, not to the current rate of emissions.¹³

Therefore, in the context of the climate problem, the global climate is a lagged function of the various greenhouse gases. At any point of time, these atmospheric concentrations (which are stock concepts) depend on the whole time path of emission of the greenhouse gases up till

¹³ There are of course some exceptions, notably for radioactive wastes, which also have an extremely long life; thus the total environmental risk, and the scale of the disposal problem at any one time, is not so much dependent on current rates of production of nuclear wastes, as on the total stock.

the point of time under consideration. Similarly, an increase in current emissions of a greenhouse gas at any point of time will affect the atmospheric concentrations of this gas, and thus the climate, in all future periods.

To calculate the marginal environmental cost of increased current emissions of a greenhouse gas, one must first calculate the physical impact of such an emission increase on the future development of the atmospheric concentration of the gas. This will depend on physical characteristic of the gas, which affect how rapidly an increased atmospheric concentration depreciates. There are large differences between different greenhouse gases, with atmospheric lifetimes varying from e.g. 11 years for methane to more than 100 years for CO₂, N₂O and some CFCs.

Once the impact of current emissions of a greenhouse gas on future atmospheric concentrations has been calculated, one can in principle calculate the effect of the increase in current emissions on the future climate development. If one has specified a function which measures the monetary cost of climate change, one may thus calculate the incremental costs, and thus obtain a present value measure of the marginal cost of increased current emissions of a greenhouse gas.

It is clear from the description above that the marginal monetary cost of greenhouse gas emissions is a complex concept. Several assumptions of an economic nature must be made, such as the appropriate discount rate and the monetary costs of climate change for the whole future. In particular, the relative importance of different greenhouse gases is much more complex than some simple physical conversion into a common index. In the context of the climate problem, a reasonable definition of the importance of a greenhouse gas relative to, say, CO₂, is the marginal environmental cost of current emissions of this gas relative to the corresponding marginal cost of CO₂. It follows from the discussion above that the relative importance of GHGs depends on a number of economic assumptions which must be made.¹⁴

Inertia and irreversibility:

Since the emissions of GHGs in any one year represent a relatively small fraction of the total global stock, the system has great inertia. This means that even if all emissions went to zero, it would be decades, if not centuries, before the stock of GHGs become reduced significantly. Therefore, in effect, decisions about emissions reduction become effectively irreversible, at least over the 100-200 year timespan of interest. In other words, failure to reduce emissions in the short to medium term may be irreversible in the sense that once the effects of global warming become apparent, it will then be too late to do anything about it.

Global characteristics:

Most environmental pollution problems are local in scale.¹⁵ The benefits of emissions reductions generally accrue to the same geographic areas as would otherwise bear the costs. The damage associated with GHGs, however, are dependent upon the total global GHG concentration.

¹⁴ See e.g. Hoel and Isaksen (1993, 1994) for a further discussion and numerical calculations.

¹⁵ There are exceptions here as well, most notably the phenomenon of acid rain, which is largely a long-range phenomenon typically involving emissions in one country, and acid rain damage in another (e.g. emissions in the U.K. affect Scandinavia, emissions in the U.S. affect Canada, emissions in China affect Japan). However, to the extent that lake acidification completely destroys aquatic ecosystems, one could argue that at least some of the impacts are irreversible, although even here the impacts are generally of a fairly local nature. Long time periods may also elapse between the onset of acid rainfall, and to actual visible damage.

Therefore the distribution of benefits of emissions reduction is global, not local. Per contra, even a country that emits no GHGs would incur the damages of emissions by other countries.

Geographical distribution of impacts.

Unlike some other trans-national pollution problems, the impacts of global warming are likely to be highly concentrated among poorer nations, who lack the resources to protect themselves against sea level rise, extreme weather events, or desertification. By contrast, the impacts of acid rain tend to be concentrated in richer countries from emissions in poorer countries or regions (Japan from China¹⁶, Germany from E. Europe, the wealthy northeastern states of the US from Appalachia). These richer areas therefore have powerful incentives to promote emissions reductions programs in the source areas, including the provision of financial assistance.¹⁷ By contrast, except upon the basis of humanitarian solidarity and equity, it is unclear why countries like the US have any motivation to provide assistance to those who will bear the brunt of the expected cost of global warming.

Absence of actual impact data:

Unlike almost all other environmental externalities, there are no directly relevant data. All predictions of physical impacts are based entirely upon the predictions, judgments, and models of scientists.¹⁸ And there will be only one chance at collecting a data point – once (or if) global warming does occur, then of course the impacts will be known.

Non-linearity:

Global climate change is determined by complicated interactions involving a chain of non-linear linkages (i.e. GHG emissions - atmospheric concentration - temperature change - physical impact). Therefore, climate change phenomena and risks are likely to be much more non-linear than the relationship between conventional emissions and more local pollution.

¹⁶ For new data on emissions and acid deposition rates in Asia, see *Interim Report, International Collaborative Project on Acid Rain and Emissions Reduction in Asia*, World Bank, Asia Technical Department, September 1993.

¹⁷ For a discussion of the relationship between economic assistance for restructuring in Eastern Europe and assistance to guarantee desired environmental standards, see e.g. M. Amman *et al.*, *Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies*, *Energy Policy*, p.1187-1198, Dec. 1992.

¹⁸ In some cases laboratory experiments – such as growing plants in CO₂-enriched atmospheres – do of course provide some actual data for predictions.

4. Cost-Benefit Analysis in the context of global warming

In light of these unique characteristics of the global warming problem, what can we say about the suitability of CBA? How and under what circumstances can CBA make a contribution to the central questions now facing decision-makers: (1) by *how much* should emissions be reduced? (2) *when* should emissions be reduced? and (3) *how* should emissions be reduced?

The fundamental problem in applying CBA to the climate change problem follows directly from the chain of causality discussed above: while estimating the costs of emissions reduction involves the beginning of the chain, estimating the benefits (or the avoided damage costs) involves the very end of the chain. Since there is some level of uncertainty associated with each of the links, estimates at the last stage of the chain are subject to compound uncertainties which may be very large indeed.

Estimates of the marginal cost curve

A number of studies confirm the shape of the marginal abatement cost (MAC) curve shown on Figure 4.1 for the specific case of GHG emission reductions. London Economics (1992) reviewed eleven studies, and determined the "average" MAC curve as shown on Figure 4.1.¹⁹

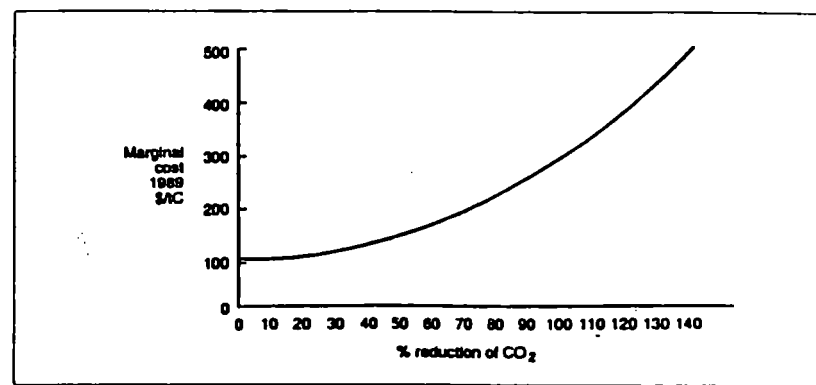


Figure 4.1: Marginal cost of CO₂ reduction (from GEF, 1992, p.31)

Such MAC curves have been derived for many industrialized countries, but for only few developing countries.²⁰ On Figure 4.2 we show the cost for the U.K., as estimated by Jackson (1991). The curve is derived by a rank ordering of the individual measures considered by cost per ton of CO₂ saved (the height of each block), with the width of each block representing the

¹⁹ The most comprehensive review of cost studies is that by UNEP, *Greenhouse Gas Abatement Costing Studies*, UNEP Collaborating Center on Energy and Environment, Riso National Laboratory, Denmark, August 1992.

²⁰ A recent UNEP review on GHG abatement costing studies concluded "...the state of abatement costing studies in developing countries is wholly inadequate even to draw preliminary conclusions concerning possible costs and the impact of different abatement options. It is a body of analysis which is only just beginning, and which may take many years to mature towards consensus even on very rough estimates and understanding of the key issues (UNEP, *op.cit.*, p. 66).

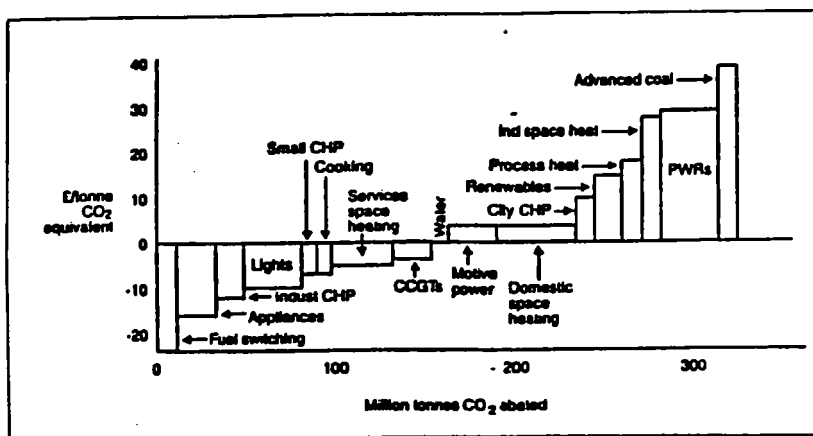


Figure 4.2: The marginal cost curve for the U.K.

tons of CO₂ so saved. The shape of the MAC curve, when smoothed, is indeed of the type indicated on Figure 4.1. Generally, these studies rely on known or near-term technical options, and ignore effects due to joint products, economies of scale, and capacity building, that might reduce the upward slope of the cost curve.

What is interesting in these (and other studies²¹) is the significance of "below the line" options (i.e. MAC is negative but still upward sloping). These are measures that appear to have negative costs associated with them -- in other words, when these options are implemented, both costs and emissions go down, relative to the reference case.²² Compact fluorescent lighting, other energy efficient devices, and demand side management measures typically fall into this category, and in developing countries, measures such as reducing T&D losses, or instituting vehicle maintenance programs, also appear here. These, then, are measures that should be implemented in a least cost energy development strategy, even in the absence of any desire to reduce GHG emissions. The fact that they are not implemented reflects either market failures, or other factors, such as high transaction cost (which might exceed the potential benefits)²³

²¹ See e.g. J. Moreira et al., 1992 for Brazil; S. Sitnicki et al., Opportunities for Carbon Emissions Control in Poland, *Energy Policy*, 19,10, p.995-1002, 1992; or P. Meier, M. Munasinghe and T. Siyambalapitua, *Energy Sector Policy and the Environment*, World Bank Environment Department, 1993, for Sri Lanka.

²² Unfortunately there is some confusion in terminology here. Some (e.g. London Economics, *Economic Costs of Carbon Dioxide Reduction Strategies*, Global Environment Facility Working Paper Series 3, Washington, DC, 1992), use the term "no regrets" to describe policies for which $MB > MAC$, i.e. for which the marginal benefits exceed the marginal costs. Others use the term only where $MAC < 0$, i.e. to those options that are "below the line" in the empirical cost curves of the type shown on Figure 4.2. However, since on both the cost and the benefit side there will be some netting out (e.g., to account for joint costs and benefits), the criterion $MAC < 0$ is arbitrary, whereas $MAC < MB$ is well defined.

²³ The fact that such "no-regrets options" are in fact observed is much debated. What may be calculated as monetary benefits need not necessarily be regarded as benefits to decision-makers -- there may be other, non-monetary costs involved. The huge subsidies given to European agriculture illustrate the point that more than monetary benefits might be involved. In the case of developing

This issue highlights a practical problem for the Global Environment Facility (GEF). The GEF has been set up as the funding mechanism, on an interim basis, to provide financial resources needed by developing countries to meet the "full incremental costs incurred" in complying with their obligations under the Convention on Global Climate Change.²⁴ If the GEF is to fund the "incremental costs" of GHG reduction measures, this presupposes that a baseline can be unambiguously defined, against which such incremental costs are to be measured.²⁵ But under such a definition, should demand side management programs which have negative incremental costs-- such as energy efficient lighting -- be funded by GEF?²⁶

The marginal benefits curve

It follows from the discussion of the previous section that the level of uncertainty in benefits is much greater than the level of uncertainty in the cost curve. The practical implication of this, depicted in Figure 4.3, is that the optimum point of emissions reduction is also subject to significant uncertainty (indicated by points A, B, and C): whether the marginal benefits curve is MB1, or MB2 or MB3 has a much greater impact on the location of the optimum point of emissions reduction than the much smaller uncertainties in the marginal cost curve. Therefore, with such wide uncertainty about the economic optimum, CBA may not be very helpful. On the other hand, a "precautionary" level of emissions reduction, at P, has a very high probability of at least meeting the criterion that $MB > MC$.

In fact, there exist few if any estimates of the benefits curve, and most of the estimates that do exist are not much more than single point estimates for some presumed level of GHGs in the atmosphere. Well known for the US is the work of Nordhaus, who begins by classifying the

countries, the unavailability of finance may constrain the ability to implement some of these options. For example, until recently, obtaining finance through export credits for power generation expansion has been much easier than financing energy efficiency measures.

²⁴ These methodological problems have been recognized by GEF, who has initiated a research program to find an operational approach for measuring and agreeing upon full incremental costs within the context of the Climate Change Convention: the so-called PRINCE study (Program for Measuring Incremental Costs for the Environment). See K. King, *Issues to be Addressed by the Program for Measuring Incremental Costs for the Environment*, Global Environment Facility, Working Paper 8, Washington, DC 1993.

²⁵ Moreover, another problem here is that the concept of "least cost" as well as the integrated planning process to achieve it, may be quite complex (see e.g. M. Munasinghe, *Energy Analysis and Policy*, Butterworths Press, London, UK, 1990; P. Meier, *Power Sector Innovation in Developing Countries: Implementing Investment Planning under Capital and Environmental Constraints*, *Annual Review of Energy*, 15, pp.277-306, 1990; or E. Crousillat, *Incorporating Risk and Uncertainty in Power Sector Planning*, Industry and Energy Department Working Paper, Energy Series Paper 17, World Bank, Washington, DC, 1989). Such a solution, typically obtained by fairly sophisticated optimization models, may be "least cost" only for a very narrow band of input assumptions; and if these assumptions prove to be different, then an investment program predicated upon the "least cost" plan may ultimately be distinctly non-optimal.

²⁶ In the words of King, *op.cit.*, "...How can the adoption of apparent win-win solutions be stimulated? Such solutions are sometimes referred to as negative incremental cost projects because they are economically viable in their own right. The dilemma arises because these projects are often not being funded. On the one hand, if the GEF restricts itself to those projects that have positive incremental cost while the bulk of negative incremental cost options remains unfunded, it risks becoming irrelevant to the main solution to the global environmental problem. On the other hand, providing grant finance for economically viable projects effectively makes a net transfer to the country, which is not the purpose of new and additional funding; worse, it provides a perverse incentive to potential recipient countries to delay economic reform. (p.17)"

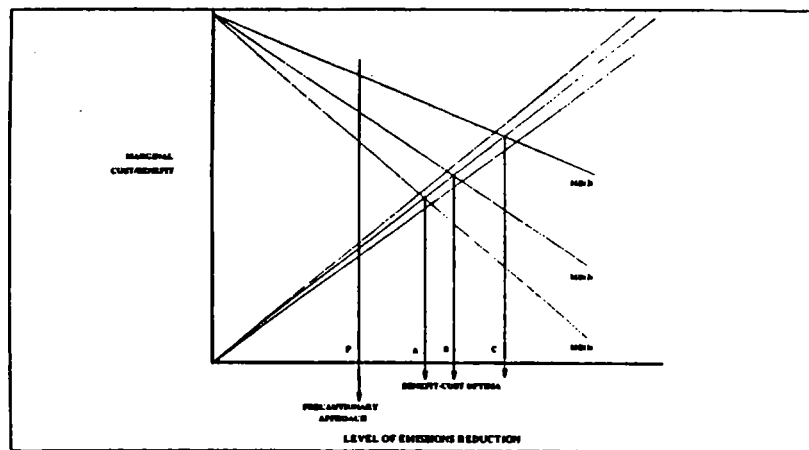


Figure 4.3: Uncertainty in the benefits curve.

components of economic activity (national income) into three groups: (1) those potentially seriously impacted; (2) those with moderate potential impact; and (3) those having negligible effect.

For the sensitive sectors, Nordhaus then goes on to estimate the impacts associated with a doubling of CO_2 in the atmosphere (Table 4.1). He concludes that in fact damage from sea level rise is the most certain major impact, since estimates on the most sensitive sector, agriculture, range from a significant net cost to a significant net benefit. Overall, the central point estimate of impact is 0.26% of national income.

The implication is that countries in which manufacturing and services are the dominant activities are not likely to be greatly affected in overall macro-economic terms (e.g. in the U.S., only some 3% of GDP is in the farm and forestry sector).

Whether this type of approach in fact captures all the relevant costs is of course subject to debate, since a whole range of costs like damage due to extreme weather events and potential non-market impacts, such as loss of biodiversity, is ignored. Moreover, it is entirely unclear whether some of the areas that have been included in Nordhaus' analysis have been given adequate attention.²⁷ For example, municipal water supply, which presently accounts for a very small part of national GDP, may be potentially extremely sensitive to small changes in climate in the western US — where even under present conditions costs are growing very fast.²⁸ However, as shown on Table 4.2, other estimates of the impact of global warming, including those which attribute much larger impacts to wetlands, species loss etc, do not result in significantly larger losses of output.

²⁷ For a critique of Nordhaus' estimates, see e.g. Williams (1993).

²⁸ A study of the impacts of global warming in California points to the severe problems that might be encountered in that state. Because of changes in the distribution of rainfall, resulting in winter runoff and lower spring runoff, water supply from reservoirs in the Central Valley Basin would significantly decrease. See EPA, *The Potential Effects of Global Climate Change on the United States*, Report to Congress, Office of Policy, Planning and Evaluation, Washington, DC, 1989.

Table 4.1: Estimates of the impact of global warming on the US GDP

	% of GDP	% of total	cost billion 1981 \$
Total national income			
Potentially severely impacted		3.1	
farms	2.8		10.6 to -9.7
forestry, fisheries, other	0.3		small
Moderate potential impact		10.1	
construction	4.5		negative
water transportation	0.3		?
energy (electric, gas, oil)	1.9		
electricity demand			1.65
non-electric space heat			-1.16
water and sanitary	0.2		positive?
real estate (land rent)	2.1		
loss of land			1.5
protection of sheltered areas			0.9
protection of open coasts			2.8
hotels, lodging, recreation	1.1		?
Negligible effect		86.8	
mining	1.9		
manufacturing	24.1		
other transport & communications	5.5		
finance, insurance	11.4		
trade	14.5		
other services	13.5		
government services	14		
rest of world	2.1		
Total impact			6.2

Source: W. Nordhaus, *Economic approaches to greenhouse warming*, in Dornbusch and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA, 1991.

Table 4.2: Estimates of the impact of global warming

	U. S.			Global	
	Nordhaus	Cline	Fankhauser	Other	Fankhauser
Heavily affected sectors					
agriculture	1	15.2	7.4	1.2	39.1
coastal areas	10.7	2.5	2.3		12.3
energy	0.5	9			
Other sectors					
wetlands and species loss		7.1	14.8		
health and amenities		8.4	30.3		
other	38.1	11.2	12.1		
total	50.3	53.4	66.9		
total as % of output (GDP)	1	1.1	1.3	1.5	2.8(a)

Blanks denote not available. (a) from Nordhaus's survey of experts. Sources: Nordhaus (1991), Cline (1992), Fankhauser (1992); for agriculture under "other" Reilly and Hohmann, 1993.

Source: Nordhaus (1994), p. 369.

Despite the suggestion that the economic impact of global warming on the industrialized countries is quite small, Nordhaus, as well as others, are quick to concede that such results may not apply to developing countries, where typically much larger shares of national income

are in agriculture, and much of it in subsistence farming in marginal areas where even small changes in climate may have devastating effects, and where the ability of the farming population to adapt may be very small indeed.²⁹ The types of human settlement most vulnerable to climate change are concentrated in developing countries, including low-income communities, residents of coastal lowlands and tropical islands (such as coastal Bangladesh, or the Maldives), populations in areas already significantly affected by desertification, and the urban poor in squatter settlements³⁰.

Unfortunately, to date, most of the discussions of impacts of global warming on the developing countries have been qualitative in nature,³¹ and there is an urgent need for more quantitative estimates for developing countries. According to a recent GEF survey of country studies³², there are now almost as many studies underway on effects as on mitigation, but it is difficult to ascertain how many of these studies, most of them now underway, will result in the sort of quantitative information necessary to construct an impact cost curve. Certainly none of the studies and papers published to date for developing countries contain quantitative estimates of the type derived by Nordhaus for the US.³³

Measuring costs and benefits

Nordhaus' work on the benefit (avoided cost) side, and much of the work on the cost side, assumes that the relevant measure by which to evaluate options is loss of GDP. This raises a separate set of questions about the extent to which GDP, (or loss of GDP growth) is the appropriate measure.³⁴ It is well established (Weitzman, 1976, Brekke, 1994) that GDP is not

²⁹ This is likely to be true even though higher CO₂ concentration itself may promote plant growth.

³⁰ For further discussion, see e.g. J. T. Houghton *et al.* (Eds). *Climate change—The IPCC Scientific Assessment*, World Meteorological Organization and the United Nations Environment Program, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 1990, or L. B. Lave and K. Vickland, *Adjusting to Greenhouse effects: the Demise of Traditional Cultures and the Cost to the USA*, *Risk Analysis* 9, 283-291, 1989. However, as also noted by Nordhaus (1994), the fertilizing effect of atmospheric CO₂ is a particularly strong mitigating factor for Agricultural nations, particularly where water is a limiting factor: while the extent and quantitative importance of CO₂ as a fertilization agent are controversial, the balance of the evidence is positive (Nordhaus, 1994, p.369).

³¹ see e.g. the discussions of P. Glick, *Climate Change and International Policies: Problems Facing Developing Countries*, *Ambio* 18, 6, p.333-339, 1989; or R. K. Pachauri, *Global Warming: Impacts and Implications for South Asia*, Tata Energy Research Institute, New Delhi., 1991).

³² J. Fuglestad *et al.*, *A Review of Country Case Studies on Climate Change*, Global Environment Facility, Working Paper 7, Washington, DC, 1994. This report identifies 39 studies (or elements of studies) focused on inventories of GHGs, 48 studies of effects, and 46 studies on mitigation.

³³ For example, in a report prepared by the Tata Energy Research Institute for the India Ministry of Environment and Forests, the Chapter on Adaptive Strategies for India in the Perspective of Climate Change, which elaborated the impacts associated with given levels of sea level rise and mean temperature, was entirely qualitative in nature, and no cost estimates were attempted. (TERI, *Report on Global Warming and Associated Impacts*, Report to the Ministry of Environments and Forests, January 1991). Similarly, neither Volume on Global warming published by the Asian Energy Institute (Pachauri and Behl, (Eds), 1991), nor the country studies conducted by UNEP (Reported in UNEP, 1992) contain any country specific estimate of costs associated with specific levels of GHG accumulation in the atmosphere. ADB is currently sponsoring a multi-country project in Asia that is attempting to establish costs of potential effects.

³⁴ There are several related issues. For example, should one use nominal exchange rates,

a welfare measure per se, but rather a convenient way to aggregate goods and services which clearly contribute to welfare.

Thus it is well recognized that GDP is an imperfect proxy for social welfare. One recent Norwegian study (Alfsen, Brendemoen and Glomsrod, 1992) showed significant differences in cost-effectiveness of different policy options for GHG emissions reduction policy when consumer surplus effects were also included in the analysis³⁵. These effects have found to be significant in developing countries as well, as shown by Meier *et al.* (1993) in the case of Sri Lanka (see Table 4.3).

Table 4.3: Impact of welfare losses of GHG abatement options in Sri Lanka
(in \$/ton of avoided carbon)

	no coal	wind	CFL
supply cost impact	16	67	-472
consumer impact	10	66	-66
total	26	131	-538

source: Meier, Munasinghe, and Siyambalapitiya, *op. cit.*, 1993.

notes: negative numbers indicate a benefit
CFL= compact fluorescent lighting

Of course, the magnitude of such impacts is a function of how much of the technology is adopted, how soon, and what discount rate is used. The effect of a single 25Mw wind plant will obviously be much less than if a 300 Mw wind farm displaces an imported coal plant in the near-term. Generally, what these results do underscore is the need for great caution when interpreting the so-called costs of GHG-emission reductions attributable to specific technologies.

Equally important are the concerns over the extent to which conventional measurements of GDP growth take into account the depletion of natural resources ("Green Accounting"). For many developing countries this is a particularly important issue, and there is a growing literature suggesting that conventional accounting substantially overstates GDP growth: the corollary is that estimates of GDP impacts of climate change that fail to take into account changes in the rate at which natural resources are depleted, or in environmental impacts, may be understating the true effect.³⁶

Some of these problems are evident from the numerical estimates. On Figure 4.4 we display the results of recent studies of the impact of emissions reduction strategies on loss of GDP³⁷. As is evident, these impact estimates show considerable variation: even so, none of

trade-weighted rates, or purchasing power parity rates in making cross-country comparisons of costs or impacts?

³⁵ Consumer surplus impacts have been vigorously debated in the United States in terms of how to evaluate the costs and benefits of demand side management (DSM) programs. For example, Hobbs(1991) shows that some programs may have positive benefits under a simple "least cost" criterion from the utility perspective (avoided supply costs exceed program costs to the utility), but have negative benefits when changes in consumer surplus are taken into account.

³⁶ The question of "green accounting" is one of valuing and aggregating marketable and non-marketable goods. The many different proposals for "green accounting" reflect the difficulties involved. Rather than speculate about valuation, or poorly founded proxies for non-marketable goods, MCA provides an alternative approach.

³⁷ These results are for studies that estimate both emissions reductions and GDP impacts relative to some baseline, i.e., relative to the trajectory of emissions in the absence of the policies followed. For many countries, particularly the developing nations, even significant reductions from such baselines

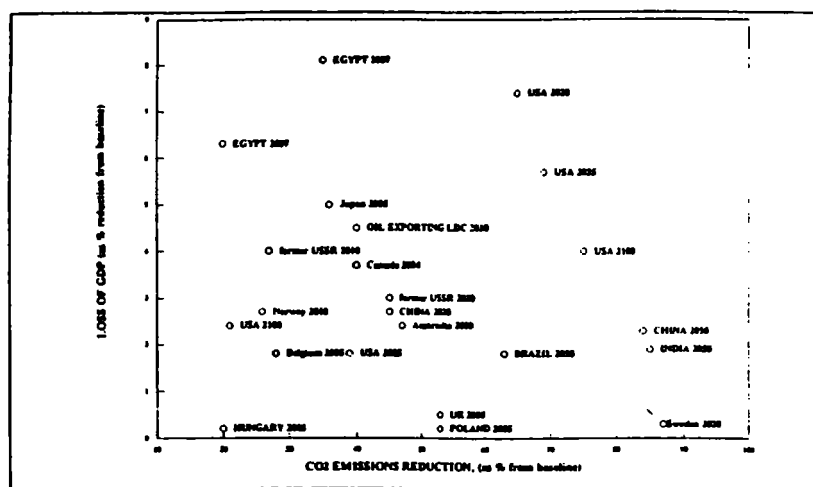


Figure 4.4: Impact of GHG emissions reductions on GDP

these estimates reflect "green accounting", and only one takes into account joint products.³⁸ Most of these studies are national studies. Many researchers argue that unilateral action by the US or by OECD countries are likely to be less effective than global action, and that unilateral actions are likely to exaggerate the impact on GDP.³⁹ However, these studies also neglect the benefits of the development of advanced technologies in the market economies, which could then be more quickly adapted in the developing world.

The joint products problem

A related question concerns the joint benefits and costs of emissions reduction. Options that reduce GHG emissions may also provide significant changes in other pollutants whose impacts are of a quite different scale. For example, the substitution of renewable energy technologies for coal will reduce not just CO₂ emissions – a *global* benefit – but also SO₂ and particulate emissions that bring a reduction in *local* environmental damages. On the other hand, the increased use of renewable energy technologies (such as hydroelectric generation), which also reduce CO₂ emissions, may also impose new and different local environmental costs (such as loss of biodiversity associated with reservoir inundation).

Estimates of the importance of joint benefits and costs vary widely (in part because valuing the costs and benefits of other environmental impacts may be subject to similar

may still imply increases in the absolute quantity of GHGs emitted. Other studies report results in terms of GHG emissions in some future target year, relative to emissions in some prior year (e.g. 2010 emissions 10% less than 1990 emissions).

³⁸ S. Glomsrød, H. Vennemo, and T. Johnson, *Stabilization of Emissions of CO₂: a Computable General Equilibrium Assessment*, Central Bureau of Statistics, Discussion Paper 48, Oslo, Norway, 1990.

³⁹ For further discussion see UNEP, *op.cit.*, p.72. Studies that have examined the question of unilateral v. multilateral approaches include Proost and van Regemorter (1990) for Belgium, and Edmonds and Reilly (1983) and Rutherford (1992).

Box 1: Valuation of joint products in the U.S.

The importance of joint products can be gauged at least in part from the practices of some regulatory commissions in the United States. A growing number of these now require that electric utilities take into account the value of air emissions in their cost-benefit analysis of alternative supply and demand side resources. The table below shows the current monetary values for some States.

Externality values for air emissions, in \$/ton

	CO ₂	NOx	SO ₂	particulates
New York	1.1	1,832	832	333
Massachusetts	22	720	1,700	4,400
Nevada	22	6,800	1,560	4,180
California (PG&E)	26	7,105	4,060	2,380

That the values assumed for CO₂ vary by an order of magnitude is to be expected, given the uncertainties on the benefits side of a unit reduction in emissions. But the wide differences in values for other emissions do reflect strong locational differences. Unlike for GHG, for most other air pollutants it *does* matter *where* they are emitted – indeed, values for the Los Angeles area for NOx emissions are even larger than those shown on the table, reflecting the seriousness of the smog problem in that air basin. The point is that when joint products of GHG emission options are also included in the analysis, then *location* does play a role. Phrased differently, if one is going to reduce GHG emissions, it should be done in those places where the joint benefits of reducing related emissions is highest.

It should be noted, however, that while the CO₂ values are based on avoided costs (e.g. in Massachusetts and Nevada based on the cost of planting trees on otherwise unforested land), the externality values for the other pollutants are based on control costs, the conceptual basis for which is very weak. It is obvious from Figure 2.2 that using the abatement cost function as a proxy for the damage cost function, even in the vicinity of some health-based standard, is likely to involve substantial error. The use of damage control costs as a proxy is justified by these regulatory commissions solely on the basis that damage cost estimates are highly uncertain.

However, in one or two cases we do have consistently estimated damage cost-based externality values. On the table below we show that using estimates derived by the California Energy Commission, for every dollar in benefits resulting from the reduction of CO₂ emissions, there is another \$3 resulting from the reduction of conjoint pollutants. Whatever the uncertainties that may surround the actual values used, it is certainly a reasonable conclusion that joint benefits will significantly affect the overall cost-benefit assessment of GHG.

Estimated benefits of reducing electricity demand by 1 Mwh

	\$/ton	emission rate (lbs/mwh)	total benefit \$
CO ₂	26	1,820	23
joint products			
NOx	14,483	6	43
SO ₂	7,425	6	22
TSP	57,620	0.3	9
total joint products			74

Emission rates based on a notional, new coal-fired plant meeting new source performance standards (NSPS). Externality values for NOx, SO₂, and particulates based on 1992 California Energy Commission Report (Hsieh, Barakat and Chamberlain, California State Summary, EPRINET Environmental Externalities Clearinghouse)

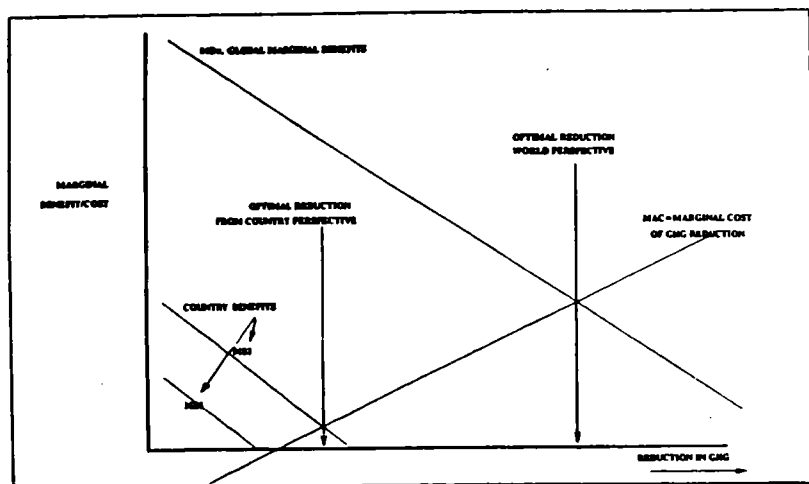


Figure 4.5: The marginal cost and benefits curve for an industrial country

difficulties of valuation and scientific uncertainty as for GHG emissions), but most lie in the range of 1 to 10\$ of additional benefits for every dollar of benefit from GHG emission reduction. (see Box 1). A recent Norwegian study (Alfsen, Brendemoen and Glomsrød, 1992) indicated that when the joint products of carbon reduction were taken into account (reduction in environmental damages to forests and lakes, health damages, reduced traffic congestion, road damage etc.), then such benefits go a long way toward compensating the economic loss measured as reduction in GDP.⁴⁰

Adding the benefits of reductions in conjoint pollutants to the MB measure is one possibility. The other is to subtract these benefits from the MC measure. Since most of such benefits go to the country that bears the costs of abating the CO₂ emissions, while the benefits of less CO₂ emissions go to all countries, it follows that the preferred approach is to adjust the marginal cost curves.

The aggregation problem

We now turn to the matter of implementing policy. Consider first Figure 4.5, which depicts the situation faced by some country. Its marginal cost curve is upward sloping, in the manner discussed above; it begins with negative values (the "no regrets" or "win-win" options) again in the manner indicated earlier.

Suppose Figure 4.5 depicts the situation for an industrialized country, say the US. Suppose that indeed Nordhaus is correct in his estimates that the benefits to the US are rather small. If MB₁ were true, then the optimal policy would be only to implement the win-win policies -- demand side management, more efficient end-use devices, economically efficient pricing, and the like. If MB₂ were true, for the US perspective, then perhaps only small

⁴⁰ For example, in one alternative (the "Treaty Alternative"), loss in GDP was estimated at 3.1 billion Kroner, and the loss of private consumption at 2.6 billion; however joint product benefits were estimated at 2.4 billion (with a range of 1.0-3.8 billion). (Alfsen, Brendemoen and Glomsrød, 1992, p.28).

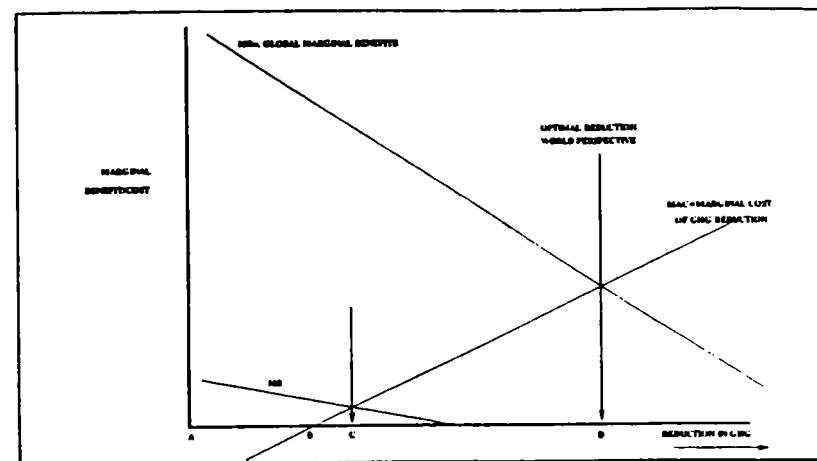


Figure 4.6: The marginal cost and benefits curve for a developing country

emissions reductions are warranted. We assume, of course, an appropriate adjustment for the valuation of the benefits of the reduction of joint costs.

However, the benefits to the rest of the world of emissions reductions are likely to be much higher: and hence the curve MB₂ lies as shown, far above the MB₁ and MB₃ curves. Therefore, when global benefits of emission cost reductions are taken into account, the optimum level of emissions reduction shifts to the right, as shown. How one persuades decision-makers in the US (and in other industrialized countries) to take a global perspective is the main question.⁴¹

Consider now the situation for a developing country (Figure 4.6). Again the global benefits curve lies far above the curve for an individual country. Evidence from empirical studies suggests that a far larger portion of the MC curve is in the no-regrets zone. Several multi-country studies point to the same result.⁴²

⁴¹ In Figure 4.5 we have drawn, for clarity, only a single marginal cost curve (MAC). It is quite possible, however, that different countries will also have different marginal cost curves (although the differences in costs are likely to be smaller than the differences in benefits).

⁴² For example, studies by Burgess (1990) and by Larsen (1993) address the impact of eliminating price subsidies: they estimate the level of reduction in GHG emissions by application of assumed price elasticities to the difference between the subsidized and unsubsidized price. Burgess uses the difference between actual average cost of electricity and the estimated long run marginal cost (LRMC), applies an assumed long run price elasticity of -1, and estimates the reduction in GHG emissions for eleven countries, including the USA, China, India, and some small developing countries such as Tanzania and Peru. Not surprisingly, the bulk of the total carbon emission savings of 124 million tons/year (mtpy) come from coal fuel savings, of which India accounts for 11.9 mtpy, China 26.6 mtpy, and the USA 85.4 mtpy. Larsen does the same analysis but from the perspective of fuel prices, applies estimated own- and cross-price elasticities for the different fossil fuels to the difference between an appropriately adjusted border price and the domestic subsidized fuel price, and, more significantly, includes the countries of the former USSR and Eastern Europe. In this analysis, the former USSR (917 mtpy) and Poland (105.2 mtpy) dominate the results; indeed, the combined estimated impact in India (54 mtpy), and China (45.4 mtpy) together is less than that for Poland.

In the case of developing countries, it is the GEF mechanism that provides the means for shifting the level of emissions reduction undertaken by any specific country to the right. But in what range does the GEF mechanism operate? Conceptually, it should operate in the range CD, i.e. provide funding only beyond the optimal level from the country perspective. But since the MB curve is so difficult to determine, operationally, an easier definition is for GEF to operate in the range BD, i.e., from the conventional "least cost" point that would normally apply, and in which any benefits, even locally, from GHG reductions are simply taken as zero. For example, wind plants would not normally lie in the least cost expansion path for an electric utility (if environmental externalities are valued at zero); GEF provides the mechanism to fund such technologies. Yet in fact, GEF has also funded projects in the range AB – such as the energy efficient lighting project in Mexico.⁴³

The difference between optimal level of reduction from the national perspective, and that from the global perspective, lies at the heart of the practical problem of implementation. A related but different issue – related to equity – concerns one of the premises of CBA, namely that sunk costs and past actions are not relevant. Yet developing countries argue that in the case of the climate change problem, past emissions are relevant, because it is the industrial countries, not the developing countries, that have accounted for the bulk of the man-made GHGs present in the atmosphere.⁴⁴

Systemic evaluation. The above results for Sri Lanka also points to the importance of systemic evaluations: the cost per ton of avoided emission for both wind and the no coal option are much lower than those estimated by others, for the exact same technology (see Table 4.4). The answer, of course, lies in the fact that the incremental cost of, say, wind power, depends upon what technology is being substituted: and these will be very different from case to case. For example in Sri Lanka, imported coal baseload plants largely determine the future system expansion cost. This is much more expensive than in India, which has available relatively large quantities of low cost domestic coal. Similarly in the generic cost estimates made by GEF for no coal options, the presumed substituting fuel is domestic oil or gas, not imported oil (as is the case for Sri Lanka). The point is that there likely exist very large, country-specific variations in the estimates of the cost of GHG emissions abatement through given technologies. Joint costs and benefits that are local in nature will very likely vary even more from place to place.

⁴³ GEF has recently introduced the term "Type I project" for those in which operate in the range AC (i.e. for which national economic benefits are greater than national costs), and "type II project" for those in the range CD, (i.e. for which national economic benefits are less than national economic costs, but the global benefits are such that the project is justified under GEF criteria). For further discussion, and arguments for why GEF should give priority to type II projects, see e.g. D. Anderson and R. H. Williams, *The Cost-Effectiveness of GEF Projects*, Global Environment Facility, Working Paper 6, Washington, DC., 1993.

⁴⁴ See, e.g., M. Munasinghe, Sustainable Energy Options for Developing Countries, *World Energy Council Journal*, 1, Dec. 1991, p.69-87.

Table 4.4: Comparisons of cost estimates for CO₂ abatement.

	study type	wind	no coal
Sri Lanka	systemic, single 300Mw windfarm	67-131	16-26
GEF	generic	116-223	45-89
India	supply cost	150-600	

Sources: For Sri Lanka, Meier, Munasinghe and Siyambalapitiya, *op. cit.* for India J. Hossain and C. Sinha, *Limiting CO₂ emissions in the power sector of India* *Energy Policy*, Oct. 1993, p.1028. Generic estimate from London Economics, *Economic costs of carbon dioxide reduction strategies*, GEF Working Paper Series 3, Washington, DC, 1993.

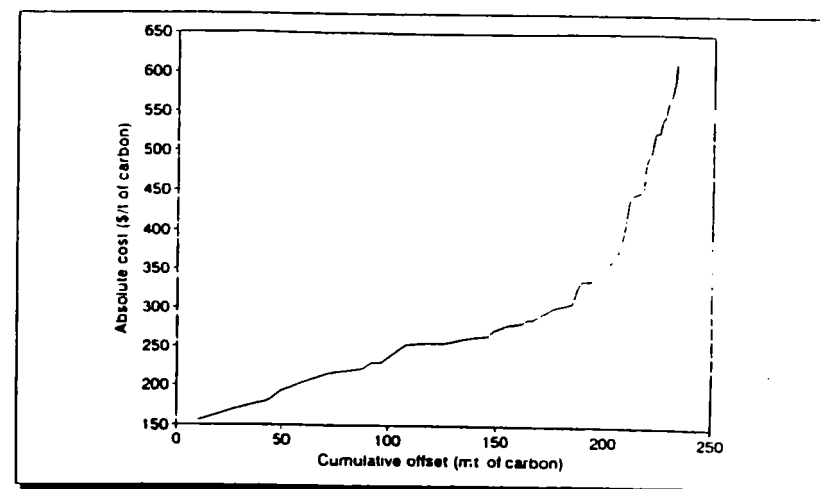


Figure 4.8: supply cost curve for windfarms in India

source: J. Hossain and C. Sinha, *Limiting CO₂ emissions in the power sector of India* *Energy Policy*, Oct. 1993, p.1028.

another way of making the same point is by noting that single point cost estimates for many technologies can be quite meaningless, because the supply curve for even an individual technologies is not flat. For example, in the previously presented GHG emission cost curve of Figure 4.1 (for the UK), "renewables" is shown as a single block, with a single marginal cost. Yet as shown in a recent study of wind and hydro for India⁴⁵, the supply curves have the expected classical upward sloping shape as illustrated on Figure 4.8 for the supply cost of windfarms in India. Such static cost curves neglect the counter-argument that in a more dynamic analysis, cost may decline due to economies of scale and technological advances.

⁴⁵ J. Hossain and C. Sinha, *Limiting CO₂ emissions in the power sector of India* *Energy Policy*, Oct. 1993, p.1028

5. Issues

Risk, uncertainty and irreversibility

Our knowledge about how anthropogenic emissions of greenhouse gases affect global temperature, what kind of effects a change in global temperature may have, and how efforts to mitigate climate change may work is clearly restricted. How different greenhouse gases react in the atmosphere are not fully understood, and exact predictions of the average increase in global temperature will have different regional effects which are exceedingly difficult to foresee, even if the effect on the average temperature were taken as given. There is also considerable uncertainty about the economic and social effects of abatement measures, which are decisive for the costs and benefits of the measures.

One cannot, therefore, evaluate climate measures without taking these uncertainties into account. On the other hand, acknowledgment of vast uncertainties should not lead to an inert attitude, but rather to develop rational strategies for how to act under uncertainty. Economic analysis under uncertainty aims at developing strategies for decision makers that face uncertainties in their future costs and benefits. The uncertainty in the outcome of a variable is often described by a probability attached to each possible outcome. In some cases the probability distribution is objectively presented, in which cases one normally talks about risk. More often, subjective probability distributions are assumed, in which cases one talks about uncertainty.

The attitude towards risky outcomes is often expressed in terms of a risk premium, which is the minimum compensation required to accept a lottery with expected return x to a certain return of x . Such a premium may be required because the decision maker prefers certain to uncertain outcomes, but may also occur if the net benefit of his investment is non-proportionate in quantity. For instance, suppose a country commits itself to reduce emissions by 100 tons, and considers two alternative measures. One alternative reduces emissions by 100 tons with certainty. The other measure has a 50 percent chance of reducing them by 100 tons. Even if the expected reductions are equal, it is evident that a decision maker will prefer the certain alternative unless the uncertain alternative is considerably less costly, as there is a chance of having to impose additional measures if unlucky. Assessments of the uncertainty involved in the analysis of climate change may therefore be of great importance to decision making.

However, given the uncertainty it is also important to emphasize that some actions will be less attractive than others. The mirror of the above argument is that some actions may be acceptable even with negative net expected benefit if they reduce the uncertainty. One way to do so is to spread the risk among several measures. Then, if one fails to meet its expected target, another may satisfy the achievements that were expected. The total risk would thus be lower than if all efforts were concentrated on one single measure.

One is scarcely able to account for all the uncertainties involved when analyzing climate change. In some cases it may be equally difficult to assess a probability distribution of a variable as a single expected estimate. Ignorance about certain effects of a measure indicate that they should be left out of the analysis. However, CBA may be of great help to decision making even when limited to effects on which reasonably well-founded value-estimates can be provided.

One issue that has attained a lot of interest in the literature of environmental economics is the problem of irreversible decisions under uncertainty. The reason is that environmental effects, such as climate change are regarded as irreversible. If the effects turn out to be worse

than expected, the world is stuck with a permanent, perhaps unwanted, climatic change, which clearly is worse than if the climate could be reestablished after such a change.

Provided that the CBA is worked out correctly, however, the cost of irreversible effects would be included. This requires a vast amount of information, such as how the uncertainty evolves over time. Such information, is rarely available, but we may assume that increased knowledge about climate change will narrow the range of uncertainties in the future. If so, it has been shown that measures causing irreversible effects have an extra cost, called quasi option value. This value can be interpreted as the value of keeping future options open, and suggest that decision makers follow flexible strategies when faced with uncertainty.

The strategy that leaves most future options open is, however, difficult to determine. Investing in abatement of climate change opens possibilities for increasing emissions at a later stage if the effects turn out to be less serious than expected. On the other hand, it reduces the potential use of adaptation. In addition, it is difficult to predict the effect of increased knowledge, especially whether the outcomes become more certain. When dealing with many of the effects of climate change, ignorance is perhaps a more appropriate concept than uncertainty. Increased knowledge may change ignorance to uncertainty, but the range of possibilities will not necessarily narrow for that reason.

In applying CBA to the global climate change problem, and in particular to the evaluation of alternative policies to optimize net benefits, there are six major sources of uncertainty that need to be considered:

1. Uncertainty over the actual rates of emission. All of the many studies cited earlier make assumptions about current and future rates of emissions in some "business-as-usual" case as a starting point. Current projections of CO₂ emissions from fossil fuel use may be reasonably well known, but the level of uncertainty increases as one moves to levels of possible fossil fuel use in the more distant future, the impact of deforestation, or to other GHGs such as methane.⁴⁶
2. Uncertainty over the costs of emissions reduction. Again there are significant differences between estimating the costs in electric utility systems (relatively well known for conventional technologies) and those elsewhere, particularly for reforestation.
3. Uncertainty about scientific linkages. As already noted in section 3, there exists a chain of scientific uncertainty (see Figure 3.1). The extent to which these uncertainties can be resolved by further research is itself subject to uncertainty (especially in light of the previously noted fact that by its very nature, *ex ante* verification of models by actual data is impossible). Thus it is unclear that similar arguments invoked in the context of other environmental problems have validity for global climate change. For example, the argument that further research was necessary on an understanding of atmospheric chemistry, or of the chemistry of lake acidification, or of the exact nature of the damage mechanisms on forests, before very costly efforts are undertaken to control SO₂ and NO_x emissions, did at least have the merit that data on the actual damage of acid rain could be found.
4. Uncertainty in valuing the costs and benefits of the physical impacts. Here there may exist quite large variations in the level of uncertainty: for example, evaluating the cost of protective dikes to protect against sea level rise, or of estimating the opportunity cost of inundated land is subject to significantly less uncertainty than estimating the impact

⁴⁶ For a full discussion of uncertainty in emissions, see e.g. Ebert and Karmali (1992).

Box 2: Applications of decision analysis

Option analysis: In conventional CBA analysis, the usual decision rule is to take some action if the expected benefits exceed the expected costs. Depending on the degree of irreversibility present, a more appropriate rule is to take the action when benefits exceed costs by an amount at least equal to the value of the forgone option. Suppose some investment depends upon some assumptions that are subject to great uncertainty – such as future world oil prices. If one makes some investment decision that is largely irreversible – such as building a large hydroelectric power project – then one loses the flexibility associated with waiting to learn more about the factors that affect oil prices. Preserving that flexibility has some economic value, namely the so-called option value. In financial and commodity markets such options to buy (and sell) are traded, with option prices determined by the market itself. But option value theory is now being applied to other fields involving capital intensive investments – such as power generation.¹ In applying these concepts to the climate change problem, there are of course many key differences. First, in one sense the problem is exactly opposite to that faced, say, by the power sector: in climate change, one loses flexibility if one does *not* make short-term investments to reduce GHG emissions. Second, unlike in the financial and commodity context, there is no marketplace to set the value of the option.²

Decision analysis and hedging strategies: Among the foremost exponents of applying decision analysis to the global warming problem are Manne and Richels,³ who have developed an approach for determining the optimal hedging strategy. The paradigm they use is that of a portfolio of insurance options:⁴ what combination of insurance should be bought, if indeed any at all? "...what portion goes to R&D to resolve scientific uncertainties? What portion goes to the development of new supply and conservation technologies to reduce abatement costs? And what portion goes to immediate abatement of emissions? Particularly they focus on the value of information⁵ how much accuracy is needed in climate modeling and impact assessment? Clearly, with perfect information, the best course of action can be charted immediately, and there is no need to hedge bets. Manne and Richels conclude that the need for precautionary near-term emissions reductions is inversely related to the sustained commitment to R&D to develop better climate information (which reduces the need to hedge against an uncertain and potentially hostile future).

¹ See e.g. E. Crousillat and S. Martzoukos, *Decision-making under uncertainty: An option valuation approach to power planning*, Industry and Energy Department Working Paper, Energy Series Paper 39, World Bank, Washington, DC, 1991. This study reviewed power sector investment decisions in Costa Rica, Hungary and West Africa.

² A marketplace might of course emerge if a tradable emissions permit system were to be instituted. Chao and Wilson (1993) outline a means of using option values to quantify the flexibility associated with the purchase of a tradable emissions permit instead of fixed capital investment in control technology.

³ See e.g. A. S. Manne and R. Richels, *Buying greenhouse insurance: the economic costs of carbon dioxide emission limits*, MIT Press, Cambridge, MA, 1992.

⁴ L. Lave (*Are economists relevant? The efficiency of a carbon tax*, in Dorabusch and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA, 1991) notes that the concern about global climate change is not merely concentrated in the rich nations, but in the upper income groups in those nations, these are the same groups that voluntarily purchase insurance to protect themselves against other losses: health, flood, earthquake. Persuading poor people to buy flood or earthquake insurance is exceptionally difficult even in the developed countries.

⁵ The value of information under uncertain conditions is a concept much used in the private sector. For example, in oil exploration, before drilling a wildcat well – a very expensive proposition – the question arises as to how much ought to be spent in much less expensive prior survey work: general magnetic surveys, or more expensive seismic surveys? Neither yields perfect information. For details of how such decision-theory models are applied in this field, see e.g. Newendorp (1976).

on agriculture, or on biodiversity.

5. **Uncertainty about the assumptions underlying policy options:** For example, a number of studies have estimated the impact on GHG emissions of eliminating subsidies on coal, or on electricity, using assumed values of price elasticity.⁶⁷ General equilibrium models require all kinds of assumptions about the elasticities of substitution, whose actual values used in the numerical simulations are either based on historically estimated elasticities, or upon the judgment of the modeler. In either case there is uncertainty about the extent to which such values match actual behavior.
6. **Uncertainty over the effectiveness of policies:** For example, the proposition that a certain level of carbon tax will in fact result in the hypothesized fuel substitution makes a number of assumptions about the functioning of markets. As noted earlier, the very fact that many apparently "no regret" options are not being implemented suggests a higher level of market imperfection than economists like to admit, and/or substantially higher transaction costs or discount rates.
7. **Uncertainty about joint benefits and costs:** As noted earlier (see Box 1), joint benefits and costs may be a very significant factor in evaluating options for greenhouse gas abatement. However, these joint benefits and costs are also subject to significant uncertainties (and also measurement problems).

The application of valuation techniques is difficult even where the impacts themselves can be quantified with relative confidence. But in the case of global climate change, however, uncertainties in economic valuation techniques may be significantly smaller than the *scientific* uncertainties that surround the impacts of increasing concentrations of greenhouse gases. Advocates of immediate mitigation action to reduce emissions argue that even if the probability of some of the important impacts are unknown, and subject to great uncertainty, they are not zero. Low probability, high impact events are especially complex to model, and may also elicit counter-intuitive public reaction due to extreme risk-averse behavior (e.g. nuclear accident). Further, the process of global warming, once underway, will be irreversible (at least during a period measured in centuries), and the damages which may result are so catastrophic, that action may be warranted even in the absence of more precise scientific knowledge about the impacts.

A good analogy is a nuclear power plant accident. The Chernobyl incident notwithstanding, the risk of catastrophic accident is extremely small. But the cost of a major accident is undoubtedly very large. Both the probabilities⁶⁸, as well as the cost of the impacts, are very difficult to estimate. But even if one could agree on appropriate values to use, and one were able to calculate an expected value, decision-making on the basis of the expected value may still not reflect the preferences either of the public or of decision-makers. The consequences of even an extremely unlikely event may be perceived as so undesirable (especially in the case of extreme risk aversion), that "normal" decision rules may simply not be viewed as appropriate. In other words, cost-benefit analysis must deal not just with expected values, but also with risk preferences of the decision-makers, and those they represent.

⁶⁷ see note 42, *supra*.

⁶⁸ The US Nuclear Regulatory Commission has made repeated attempts to establish probabilities for specific kinds of accidents through a technique known as fault tree analysis. Despite the appearance of scientific rigor, the resultant probability estimates remain highly controversial. For examples of the use of cost-benefit analysis by the US NRC, see e.g. Mubayi *et al.* (1991) or Abrahamson *et al.* (1989).

The traditional and simple way of incorporating uncertainty considerations in CBA has been through sensitivity analysis. Using optimistic and pessimistic values for different variables can indicate which variables will have the most pronounced effects on benefits and costs. While sensitivity analysis need not reflect the probability of occurrence of the upper or lower values, it is useful for determining which variables are most important to the success or failure of a project (Dixon *et al.* 1988). Indeed decision-makers often assign (even if only implicitly) probabilities to the various outcomes. Admittedly, the sheer magnitude of the costs of catastrophic climate change will make the sensitivity analysis problematic.

One might note that for certain types of uncertainty, something akin to risk insurance is available in the form of futures and options markets. For example, one can hedge against uncertainty in the future price of oil by transactions in the oil futures markets, but their efficient functioning depends upon there being some balance between those who are buyers of oil (who are primarily interested in protecting themselves against a rise in the price), and sellers of oil (who are interested in protecting themselves against a fall in the price of oil). (See Box 1)⁹.

Finally, extreme uncertainty might also influence the nature of the economic instruments employed for policy purposes. For example, a price-oriented mechanism (such as a carbon tax) which limits economic dislocation might be preferred over a quantity-based mechanism (such as tradable permits) in a situation where there are both uncertain control costs and an uncertain environmental response (see Lave and Gruenspecht, 1991).

Valuation

The robustness of a cost-benefit analysis depends critically on how reliable the values attached to each item are. The prices of marketable goods and services express social values as long as the goods in question are not rationed and there are no externalities. For non-marketable goods and services, such as many environmental services, values have to be estimated in order to aggregate costs and benefits and obtain an overall evaluation of choice of policy. "Synthetic" prices will depend on the methodology chosen to create them, and one should therefore interpret results which include such prices with caution.

One reason why avoiding climate change may have a value is that climate change will cause a change in economic activities. Sea level rise will force people to move, more turbulent weather conditions may increase the need for rebuilding of damaged materials etc. A second reason is that people attach subjective values to the climate where they live, to some extent reflected in the notions of "good" and "bad" weather.

However it is difficult to assess these values. To simplify somewhat, one may base an estimate on the anticipated costs of achieving a certain target at observed market prices, for instance the minimum abatement cost of attaining the same level of greenhouse gases emissions as a previous year. Alternatively, one may estimate the willingness to pay for reaching such a target. In neither of the cases, however, would one be able to assess the equilibrium price, or the value. The choice of approach might therefore be strictly decisive for the conclusion, for instance if pollution that causes severe damage (high willingness to pay) could be avoided by low costs.

Valuation of environmental effects in CBA may be helpful in attaining cost-effective decisions. However, the valuation should be based on a reasonably well founded methodology. Speculative assumptions will not contribute to decision making. A measure which yields negative net benefits according to an analysis may be worthwhile to accept if effects that are

⁹ Precautionary expenditures may also be influenced by aversion to catastrophic risks. A recent example is the hundreds of billions of dollars per year spent in the U.S. to avert soviet nuclear attack.

assumed to be positive but not explicitly valued in the calculation are well documented. Decision makers will normally manage to consider more than one measure simultaneously. CBA usually simplifies the decision by aggregating several effects, but there is no necessity for all effects to be aggregated into one single measure.

There are several fundamentally different types of costs and benefits that must be addressed, each of which requires somewhat different approaches to quantification and valuation:

1. Mitigation actions taken before the actual impacts are observed. These are primarily a matter of emissions reductions, or of removing GHGs through reforestation. The vast majority of the applications of cost-benefit analysis have addressed the question of how best to achieve given levels of emission reduction reductions. Valuation issues generally do not arise in this category.
2. Costs of mitigation actions taken after impacts become apparent. These will necessarily occur in the future, and would be undertaken only if (1) global warming actually does occur, and (2) that global warming does in indeed result in specific impacts. The cost of dikes to prevent inundation of coastal areas is a typical example in this category: based on actual experience (such as in the Netherlands) the cost of such mitigation actions are relatively easy to establish. Climatic engineering options also fall in this category, such as painting roads and roofs white, or putting particles into the stratosphere. Again there are few valuation issues here.
3. Costs (and benefits) of Adaptation. Society will adapt with varying degrees of pain to many of the impacts of global warming. For example, climate change will affect crop yields, and result in Northward shifts in cultivated land. Some areas will gain, and some will lose, which becomes an equity issue (between regions and countries) as much as a cost issue. Estimates of net losses for U.S. agriculture, for example, suggest a tolerable impact for the U.S. as a whole, but significant regional variations.³⁰ Some of the costs of adaptation will vary, depending on ex-ante actions (e.g. more agricultural R&D expenditure to develop drought or saline resistant crops).
4. Costs (and benefits) of non-adaptation. In some cases, adaptation may not be possible, and/or the cost of mitigation may be higher than the loss incurred in its absence. For example, in some areas, the cost of construction of dykes may be far higher than the value of the land lost to coastal flooding, in which case the relevant cost to be estimated for purposes of CBA is the value of the land lost.

It is thus in the third and fourth of these categories that valuation issues arise. Table 5.1 lists the specific categories of impacts that may be encountered as a result of global climate change, together with an indication of the degree of valuation difficulties likely to be encountered.

Conceptually, the total economic value (TEV) of a resource consists of its use value (UV) and non-use value (NUV).³¹ Use values may be broken down further into the direct use value (DUV), the indirect use value (IUV) and the option value (OV) (potential use value). One needs to be careful not to double-count both the value of indirect supporting functions and the value of the resulting direct use. One major category of non-use value is existence value (EV). Thus

³⁰ "Preliminary results suggest that although US crop production could decline, supplies would be adequate to meet domestic needs" (EPA, *op.cit.*, 1989, p.93).

³¹ For further details, see Munasinghe (1993).

Table 5.1: Potential impacts to be valued¹

Systems	Potential Impacts
forests/terrestrial vegetation	migration of vegetation reduction in inhabited range altered ecosystem composition
species diversity	loss of diversity migration of species invasion of new species
coastal wetlands	inundation of wetlands migration of wetlands
aquatic ecosystems	loss of habitat migration to new habitat invasion of new species
coastal resources	inundation of coastal development increased risk of flooding
water resources	changes in supplies changes in drought and floods changes in water quality+hydropower production
agriculture	changes in crop yields shifts in relative productivity and production
human health	shifts in range of infectious disease changes in heat-stress and cold-weather afflictions changes in fertility due to stress
energy	increase in cooling demand decrease in heating demand changes in hydropower output
transportation	fewer disruptions in winter transportation increased risk for summer inland transportation risks to coastal roads
also considered in EPA study	
air quality	
other impacts not considered in OTA or EPA studies	
weather-related damages	damages related to changes in the frequency and severity of extreme weather events like storms.
amenity value	
construction	
industry	

¹ Systems and potential impacts as listed in OTA, *op.cit.*, p.15.

$$TEV = UV + NUV$$

or

$$TEV = [DUV + IUV + OV] + [NUV]$$

Figure 5.1 shows this disaggregation of TEV in schematic form. Below each valuation concept, a short description of its meaning and a few typical examples (based on a tropical rainforest) of the environmental resources underlying the perceived value, are provided. Option values and non-use values and existence values are shaded, to caution the analyst concerning some of the ambiguities associated with defining these concepts — as shown in the examples, they can spring from similar or identical resources, while their estimation could be interlinked also. However, these concepts of value are generally quite distinct. Option value is based on how much individuals are willing to pay today for the option of preserving the asset for future (personal) direct and indirect use. Existence value is the perceived value of the environmental asset unrelated either to current or optional use, i.e., simply because it exists.

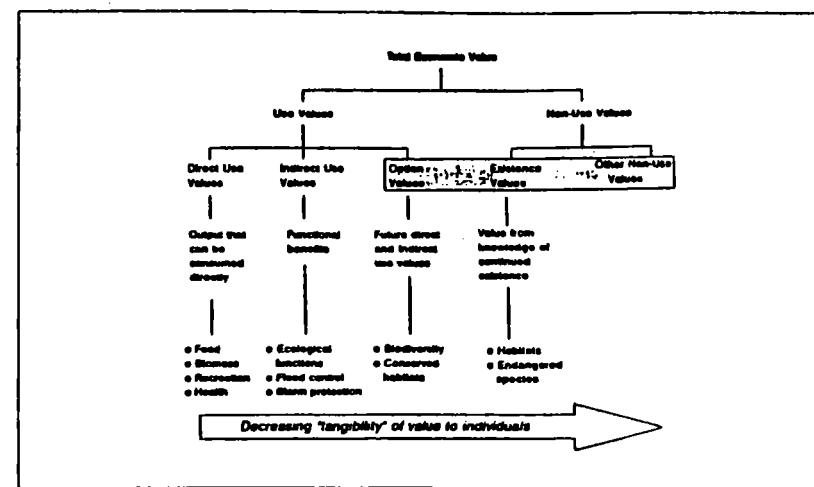


Figure 5.1: Categories of economic values attributed to environmental assets

A variety of valuation techniques may be used to quantify the above concepts of value.³² The basic concept of economic valuation underlying all these techniques is the willingness to pay (WTP) of individuals for an environmental service or resource, i.e., the area under the compensated or Hicksian demand curve. As shown in Table 5.2, valuation methods can be categorized according to which type of market they rely on, and by considering how they make use of actual or potential behavior.

Table 5.2: Taxonomy of relevant valuation techniques

	conventional market	implicit market	constructed market
based on actual behavior	change of productivity loss of earnings defensive or preventative cost	travel cost wage differences property values proxy marketed goods	artificial market
based on potential behavior	replacement cost shadow project		contingent valuation

source: Munasinghe (1993)

We note that these valuation techniques have been developed for more conventional environmental impact analysis, and would require significant modification and/or careful interpretation when applied to global climate change (e.g. long-term intergenerational impacts, biodiversity loss, welfare comparisons across cultures, or where there are wide gaps between gainers and losers, etc.).

³² For a recent overview of techniques suitable for valuing environmental costs and benefits, see M. Munasinghe, *Environmental Economics and Sustainable Development*, World Bank Environment Paper 3, Washington, DC, 1993

Discount rate

We noted in the introduction that CBA requires a very specific and explicit way of dealing with time. The first principle is that past (or "sunk") costs are ignored, based on the premise that since past decisions cannot be changed, they have no bearing over decisions regarding the efficiency of resource use that are to be made in the present or in the future.³³

The second principle is that a discount rate is applied to future costs and benefits to yield their present values. The issue of choosing an appropriate discount rate has been discussed in the context of general CBA for many years (Dasgupta et al. 1972, Harberger 1976, Little and Mirrlees 1974, Sen 1967). The long term perspective required for sustainable development suggests that the discount rate might play a critical role in intertemporal decisions concerning the use of environmental resources (Lind and Arrow 1982).

Compared with most other economic investment decisions, the time perspective of measures aiming at mitigation of climate change is considerably longer. Cline (1992) suggests a 200 - 300 years time horizon for climate policy decisions, while investments in economic activities seldom need more than a 25 years horizon. This makes assumptions about how the economic and the environmental systems will develop, and the discounting of values that occurs in the future critical to the evaluation of measures.

The discount rate denotes the social opportunity cost of capital. It reflects total social benefits if one unit of present output is withdrawn from consumption and rather is invested for instance in production or abatement. The criteria for optimal social and economic development is that the marginal total benefits from the investments should be equal regardless of what the investment is aiming at. In other words, the social discount rate should be equal for all investments. If not, it would be possible to reallocate resources and attain a higher social benefit without any cost. Thus, the discount rate expresses a condition for dynamic (or intertemporal) efficiency.

The discount rate provides a signal to decision makers who evaluate single projects or measures to take decisions in accordance with dynamic efficiency. Although the requirement to apply an equal discount rate for marginal projects is inevitable, there are many potential optimal levels of the discount rate. This level depends, *inter alia*, on the social preferences about present versus future consumption which may be reflected by an intertemporal welfare function. The formulation of this function has been the subject of an extended debate in which questions about intertemporal comparisons as well as current welfare contributors have been raised.

Two concepts mainly help to shape the discount (or interest) rate in a market economy. First, there is the personal rate of time preference of individuals which determines how they compare present-day with future consumption. Second, there is the rate of return on (or opportunity cost of) capital, which determines how an investment (made by foregoing today's consumption) would yield a stream of future consumption (net of capital depreciation or replacement). In an ideally functioning market, the interest rate which equilibrates savings and investment, also equals both the marginal rates of time preference and return on capital. In practice, government policy distortions and market failures lead to divergences between the rates of time preference and return on capital. Furthermore, the social rate of time preference may be less than the individual time preference rate, because long-lasting societies are likely to have a bigger stake in the more distant future than relatively short-lived individuals.

³³ One needs to take note of the fact that this principle is also not universally accepted, particularly by political leaders: the principle that "past sacrifices ought not to be in vain" is frequently invoked as relevant to present decisions.

Box 3: Discount rate and inter-temporal choice

In order to illustrate some important intertemporal choices when deciding about the social welfare function, however, it suffices to apply the additive one, which indeed represents the standard choice.

$$W(c(t), \dots, c(T)) = \sum_{s=t}^T U(c(s)) / (1+\delta)$$

$W(c_t, \dots, c_T)$ is total utility from t to T , which is the sum of the utilities at each time s from t to T , as evaluated at t . $U(c(s))$ is the utility of consumption at s , evaluated at s . δ is the rate of impatience. For simplicity we do not distinguish between total consumption and consumption per capita in this illustration.

The marginal utility of consumption, which is the quality gain from a given increase in consumption, is assumed to be decreasing. In an intertemporal context, this means that an increasing consumption path yields less utility per unit consumption as time passes. How much, depends on the elasticity of marginal consumption, denoted ω . This expresses the attitude towards the distribution of consumption among generations (formally $\omega = -cU''/U'$, where accents denote partial derivatives). The more weight the society gives to inter-generational equity, the higher the value of ω .

The other intertemporal implication of the choice of a welfare function is the choice of δ . Impatience means that preferences over given consumption levels to be consumed in each future year implies the highest level the first year, the second highest next year and so forth till the lowest level the last year. There is empirical evidence that δ is positive, meaning that people seem to be impatient with respect to their own consumption. However, the climate change issue is a genuine intergenerational problem, and one may ask whether individual impatience ("from me to me") is of relevance in such a context ("from me to my descendants"). It should be emphasized, though, that impatience does not imply decreasing consumption. This is because output withdrawn from consumption can be invested and yield a social return next year, thus making the consumption potential higher. The problem is to balance these respects. Optimal economic development requires the following relation between the social rate of return, denoted $\gamma(t)$, and the rate of consumption growth $\dot{c}/c$ to be fulfilled.

$$\gamma(t) = \delta + \omega \dot{c}/c$$

Assuming that we know the parameters δ and ω , we can assess the social rate of discount if the optimal rate of consumption growth is known, or vice versa. This means that a high discount rate reflects a high rate of growth in consumption. Accordingly, a rapid decline in consumption due to an "environmental disaster" in the far future would, if optimal, result in a low, perhaps negative, discount rate. This would make decision makers take such effects into account, even in present day decisions. Note that in general, there are no reasons why the discount rate should be constant over time even if δ and ω are constants, since $\dot{c}/c$ need not be constant. In fact, if we assume a gloomy scenario where future output and consumption decline, then $\dot{c}$ may be negative and $\gamma(t)$ could decline over time (Munasinghe, 1993, Siemer, 1994).

By observing the variables of the above equation, one will normally find that the left hand side differs from the right hand side. There may be several explanations to this, and there is a broad literature discussing how to assess the "correct" social discount rate (see Lind (1982) for a survey). Applying the return on private investments, for instance, one has to take into account that the observations will be affected by the existing tax system, which normally is not "perfect" in the sense that it reflects all the social consequences of a private investment, such as the consequences of climate change.

The rate of capital productivity is very high in many developing countries, because of capital scarcity, and the rate of time preference also is elevated because of the urgency of satisfying immediate food needs rather than ensuring long term food security (Pearce and Turner 1990). Projects with social costs occurring in the long term and net social benefits occurring in the near term will be favored by higher discount rates. Conversely, projects with benefits accruing in the long run will be less likely to be undertaken under high discount rates. Thus, some environmentalists have argued that discount rates should be lowered to facilitate environmentally sound projects meeting the CBA criteria. However, this would lead to more investment projects of all types, thereby possibly threatening fragile environmental resource bases. Norgaard (1991) argues that lowering discount rates can in fact worsen environmental degradation – by lowering the cost of capital and thereby lowering the cost of production, more is consumed in the near-term relative to the case where discount rates were higher. Further, using a very low discount rate to protect future generations is inequitable, since it would penalize the present generation and increase inequalities across time periods – especially when the present contained widespread poverty (Pearce 1991).

In order to facilitate such intergenerational transfers, one option is to impose a sustainability constraint, whereby current well-being is maximized without reducing the welfare of future generations below that of the current generation. In practice, this would entail monitoring and measurement of capital stocks (man-made, human and natural), and a broad investment policy which sought to ensure that compensating investments offset depreciation of existing assets (Pearce 1991). Theoretically, the aim would be to ensure that the overall stock of assets is preserved or enhanced for future generations, but practical application of this principle would be difficult.

It is worth emphasizing that although externalities related to climate change will affect the social rate of discount, it is not sufficient to merely adjust this discount rate in order to take full account of climate change in a CBA. One must include also the "price" of the environment, which may increase substantially over time. As a consequence, future impacts from climate change may be quite important to present day decisions, even in "discounted terms": A five per cent increase in the price of the environment will fully counteract the effect of a five per cent discount rate.

To conclude, discounting is necessary to attain a socially optimal development. Attempts to avoid discounting or to apply a different discount rate for climate measures than other investments will inevitably result in an inefficient policy. However, it is difficult to pick out the correct level of the optimal social rate, as there are no observations of such a rate. Furthermore, discount rates may depend on the future scenario that is assumed, and could vary over time – in particular very long term discount rates may be lower as growth rates saturate (see Box 3)

CBA and Equity

CBA can provide answers on who should engage in how much abatement based solely on the criterion of maximizing economic efficiency. It must however be recognized that some deviation from the global least-cost solution as obtained by CBA may have to be accepted in order to get international agreement. As indicated earlier on Figure 2.1, there will likely be a trade-off between equity objectives and economic efficiency.³⁴ CBA can help define the trade-off curve, but it cannot provide an answer to what combination of economic efficiency and equity is necessary to get international agreement. However, whether there is a trade-off between equity and efficiency (and the properties of this trade-off) depend upon what policy

³⁴ Equity Issues are dealt with in detail by Writing Team 4

instruments are available. For example, if one permits side-payments (of some kind) between countries, the efficient allocation of emissions across countries is independent of the equity issue.

Several concerns shape equity perceptions and the ability to obtain international agreements. Effective action to control global warming is dependent on a degree of international agreement. Therefore a first obstacle to whatever mechanism might be agreed upon is national sovereignty – to what extent will sovereign nations subject themselves to enforcement actions by others? Even simple agreements for joint implementation of projects involving two countries have run into difficulties (see below).

The second obstacle is the heterogeneous nature of the effects of greenhouse warming. Although the most widely cited measure of global warming is the average increase in global temperature, global warming affects different countries differently. In addition, the costs or response measures and their economic implications vary greatly among countries, particularly as a function of the level of development. Therefore the perceptions of benefits of global cooperation will differ greatly.

A third obstacle is posed by strategic incentives. If some countries take the lead and set up a greenhouse gas agreement, others have an incentive to free-ride and abstain from joining, as they cannot be excluded from the benefits such an agreement creates. If countries act selfishly in this way, few will become party to an agreement. Most countries will therefore not cooperate and no general agreement will be reached even if all countries were to benefit from it. (This is the well known prisoner's dilemma from game theory).³⁵ Some argue that the overwhelming historical contribution to the build-up of GHGs from developed countries constitutes an "environmental debt", that cannot be conveniently ignored using the traditional "sunk cost" approach. If past contributions to GHG emissions are considered from an equity viewpoint, establishment of appropriate side-payment mechanisms from developed to developing countries, including financial assistance and technology transfer, could facilitate the more enthusiastic cooperation of developing countries in global warming mitigation efforts.

The question of joint implementation illustrates the limits of CBA in this regard. The motivation for joint implementation is a straight forward result of CBA. If a country – say the U.S. – decides to make an effort to reduce GHG emissions, and if reductions can be obtained at lower costs abroad, then the US should initiate projects in other countries in order to minimize overall costs (Aaheim, 1993). The receiving country has nothing to lose if the additional cost of such a joint implementation project is covered by the investing nation. Yet many countries and organizations have reacted with skepticism, for reasons that are political, and based on equity concerns, rather than on economic efficiency. The reasons include the mistrust of the true willingness of the industrial countries to mitigate climate change; the belief that the ultimate reduction in GHGs under such a regime would be negligible; and the suspicion that joint implementation gives industrial countries an opportunity to "buy themselves out of their problems" at the expense of the developing countries.³⁶ Indeed, some developing countries fear that joint implementation investment might partly substitute for traditional forms of financial and donor assistance, and that such agreements might preclude the right of future generations to emit GHGs.

³⁵ However, for a criticism of this argument, see e.g. Brown (1992), who points out that some European countries have already taken unilateral action to reduce greenhouse gases, in hopes that others will follow.

³⁶ For a discussion of these issues, and a discussion of how CBA can make a contribution to the evaluation of such projects, see Aaheim (1993). Concerns about "market justice" and related considerations are outlined in Rose (1990).

Multicriteria analysis

Even the staunchest advocates of cost-benefit analysis would concede that economic efficiency (or economic value) is not the sole criterion in setting public policy, and that policy-makers rightfully need to consider a broader set of objectives. Unfortunately there is much confusion about what constitutes a coherent set of objectives. Table 5.3, taken from a major EPA study, lists the criteria suggested there as constituting the basis for selecting public policy. Economic efficiency is one of fifteen so listed.

Simple applications of CBA tend to focus only on economic efficiency. However, in more recent extensions, traditional CBA concepts are embedded in MCA, that expressly allows more than one objective, and expressly addresses risk and uncertainty – thereby providing an integrating mechanism for most of the criteria listed. Multicriteria analysis techniques first gained prominence in the 1970s, when the intangible environmental externalities lying outside conventional cost-benefit analysis (CBA) methodologies were increasingly recognized. It also met one objective of modern decisionmakers, who preferred to be presented with a range of feasible alternatives – as opposed to one “best” solution. MCA also allows for the appraisal of alternatives with differing objective values and varied costs and benefits, which are often assessed in differing units of measurement.

Table 5.3: Criteria for choosing a strategy

1. Flexibility
2. Urgency
3. Low cost
4. Irreversibility
5. Consistency
6. Economic Efficiency
7. Profitability
8. Political feasibility
9. Health and Safety
10. Legal and administrative feasibility
11. Equity
12. Environmental quality
13. Private v. Public sector
14. Unique or critical resources

Source: EPA, *The Potential effects of global climate change on the United States*, EPA-230-05-89-050, Washington, DC, December 1989, p.390.

Thus, upon closer examination of the criteria listed on Table 5.3, criteria 1, 2, 3, 4, 5, 6 can all be treated by modern decision-analysis: indeed, questions of timing (urgency), flexibility (or robustness), capital constraints (“low cost”) are all central elements of the approach. Criterion 13 is really part of 6 (in the text the authors of the EPA report amplify the criterion as follows: “Does the strategy minimize governmental interference with decisions best made by the private sector” 7). Furthermore, modern valuation techniques permit substantial parts of Criteria 9 and 12 to be included in the economic analysis as well. As conceded by the EPA report (p.393), “if the principal costs and benefits can be quantified in monetary terms, economic theory provides a rigorous procedure for making trade-offs between present and future costs, and for considering uncertainty, profitability, and most of the other criteria”.

There is also a need to separate the basic goals of public policy – such as economic efficiency and equity – which surely have primacy, from implementation issues such as legal and administrative feasibility, which are generally secondary. The premise of CBA analysis is

that one looks first at the primary objectives, and then asks how much of the primary objectives one may have to sacrifice to achieve practical implementation. This principle has become accepted in many areas of policy-making. For example, the starting point for setting electric utility rates is to calculate the economically efficient tariff (based on marginal costs), and then make adjustments to protect low income groups (through lifeline rates, special provisions for disconnection in the event of non-payment, etc.). The essence of the approach is not that non-economic issues are ignored, but that the trade-offs between economic efficiency and equity (or indeed other objectives not readily monetized) are explicitly quantified and displayed in such a manner that decision-makers are made aware of how much of one objective is traded off in the interests of the other.

The application of MCA methods involves the following steps:

1. Selection and definition of attributes, say A_i , $i=1, \dots, N$, selected to reflect important planning objectives. While the two major relevant attributes in the context of the global climate change problem are cost and GHG emission reductions, we have already noted that strategies to control GHG emissions may have other side-effects, some positive, and some negative, which may also be difficult to value, and which might therefore require additional attributes (such as, for example, for biodiversity).
2. Quantification of the levels A_{ij} of the i attributes estimated for each of the j alternatives. In this quantification, full consideration must be given to discounting issues, for non-economic and economic attributes alike. At this stage of the analysis, trade-off curves are powerful tools to communicate with decision-makers: they are particularly relevant in a situation, such as the climate change problem, where the quantification of benefits may be difficult, and where decision-makers must act largely on the basis of trading-off short-term costs against certain levels of GHG emission reduction.
3. Determination and application of a decision rule, which amalgamates the information into a single overall value or ranking of the available options, or which reduces the number of options for further consideration to a smaller number of candidate plans. Where amalgamation is contemplated, attribute levels are first translated into a measure of value, $v_i(A_{ij})$ (also known as the attribute value function).⁷⁷ This is sometimes combined with a normalization procedure usually on a scale of zero to one (in which the lowest value of the attribute value function is assigned zero, the highest one). Subsequently weights w_i for each attribute must be determined to arrive at the overall amalgamation.

Trade-off curves are a particularly useful tool for analysis of energy-environmental policy options. Figure 5.2, taken from a recent study of options for greenhouse gas (GHG) emission reductions in Sri Lanka (Meier, Munasinghe and Siyambalapitiya, 1993), illustrates the essential concepts. The figure is a plot of two attributes – GHG emissions and total system costs – for the technology options identified on Table 5.4. Each point represents a perturbation of the reference case, defined as the official 1993 basecase capacity expansion plan of the CEB.

The *trade-off curve* is the set of options that are not dominated by others (sometimes referred to as the “non-inferior set”). These are the options that are “closest” to the origin, and therefore represent the “best” set of options that merit further attention.⁷⁸

Several useful concepts arise here. First is the concept of *dominance*.⁷⁹ PFBC (a clean coal technology) is said to dominate the options in the sector shown, namely FGD, wind and

⁷⁷ MCA deals with attitudes toward risk and uncertainty at this stage by the use of multi-attribute utility functions, which explicitly capture attitudes toward risk (see Keeney and Raiffa, 1976; Keeney and Wood (1977) for an application in water resource planning; or Keeney and von Winterfeldt (1987) for application to electric utility planning).

⁷⁸ We note also that the trade-off analysis and surfaces will be much more complex as the number of attributes increases.

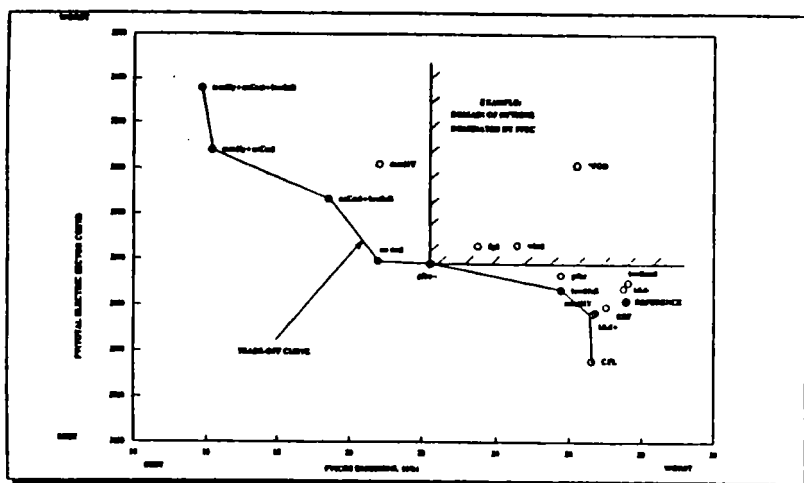


Figure 5.2: Trade-off curve

source: Meier, Munasinghe and Siyambalapitiya (1993)

*FGD. PFBC has better costs and better (lower) GHG emissions, and is thus preferred over these options under both criteria. If only these two attributes mattered, then there would be no reason to select any of the dominated options in place of PFBC.

Another perspective is gained by dividing the solution space into quadrants with respect to the reference case (Figure 5.3). The options that fall into quadrant III are the "win-win" options, which are better than the reference case in *both* attributes. In this case, mini-hydro, energy efficient refrigerators, T&D system loss reduction and compact fluorescents all fall into this quadrant, providing both cost and emission gains. Such win-win solutions were mentioned earlier, in Section 4, in connection with the empirical estimates of the MAC curves (e.g. Figure 4.2): these "below-the-line" options in the MAC curves are equivalent to the options in quadrant III of a multi-attribute analysis.⁶⁰

⁶⁰ Decision analysis distinguishes among several types of dominance – such as strict dominance and significant dominance – see e.g. Meier and Munasinghe (1994) for an application of these concepts to environmental decision-making.

⁶¹ In general, of course, the trade-off curve may extend into quadrant II; and quadrant III may contain fewer, or need not contain any solutions at all.

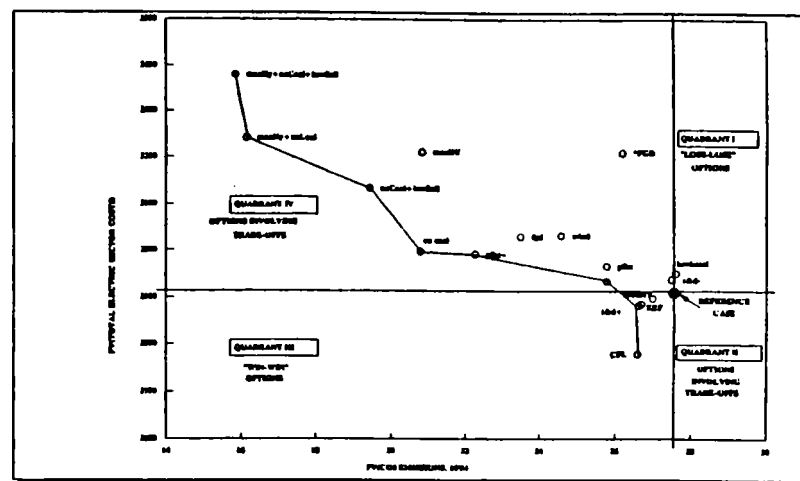


Figure 5.3: "Win-win" options

source: Meier, Munasinghe and Siyambalapitiya (1993)

Table 5.4: Technology interventions for GHG emission reductions

option	comments	symbol
wind energy	305 Mw total	wind
mini-hydro		minihy
DSM: energy efficient refrigerators		EEF
DSM: compact fluorescents		CFL
T&D loss reduction	10% T&D loss goal (in place of 12%) by 2000. 12% goal delayed to 2003	TD+
max hydro	builds both reservoirs in the Upper Kotmale project, 144Mw high dam version of Kukule.	maxHy
clean coal technology	pressurized fluidized bed combustion-combined cycle units; assumed for all coal units after 2000:	PFBC
clean fuels	with pessimistic capital cost assumptions use imported low-sulfur residual oil for diesels (0.5% S by weight rather than 2.5% S).	low S oil
FGD systems	use low sulfur (0.5%) coal (rather than 1% S coal) model free to choose optimal generation mix; coal plants must have FGD systems.	low S coal
	FGD systems forced onto basecase solution	**FGD
no coal	model free to choose least-cost combination of diesels + hydro	noCoal

Concluding Remarks

Cost-benefit analysis has many advocates but also many detractors. Certainly the rather narrowly defined, traditional approaches to CBA, developed originally for project level decision-making with planning horizons typically no more than 20 years, clearly are dealing with the very long time frames, non-marginal impacts, and high levels of uncertainty, encountered in the appropriate context of climate change.

In the introduction we noted that there were four essential questions facing decision-makers regarding climate change: (1) by how much should emissions of GHGs be reduced?; (2) when should emissions be reduced?; (3) by what methods should emissions be reduced?; and (4) who should reduce emissions?

The first question is answerable in principle, using CBA — the measures whose marginal costs are less than the marginal damage costs should be implemented. Clearly, it matters what perspective is taken, since the result will be different if restricted to a consideration of national costs and benefits than if the perspective is global. It is a fundamental result of CBA that the global perspective is the proper one, in the sense that it maximizes net benefits worldwide. The national perspective is relevant when equity issues related to the incidence of costs and benefits are considered (see question 4 below).

The second question is a more complicated one, because it involves judgments about uncertainty. If the marginal damage (benefit) cost were known with certainty, or if future technological advances that might significantly change the marginal cost curve were known with certainty, then the timing of abatement is given by that portfolio of implementation options that maximizes the (deterministic) present value of avoided damage costs (benefits) less abatement costs — a relatively straight forward calculation. But since neither damages nor costs are known with certainty (for example, if fusion technology were to be commercially available at a cost comparable to fossil-fueled technology by 2020 then the optimal timing and structure of abatement actions looks very different than if the date were 2070), extensions of CBA — such as decision analysis — are required. As indicated in Section 4 (see e.g. Box 2), recent developments have begun to deal with the question of timing, particularly with respect to the balance between R&D (on both the cost and benefit side) vis-a-vis immediate commitments to emission abatements.

The third question is closely related to the first. As we have seen (for example in Figure 4.2), most attempts to answer question 1 necessarily require consideration of the specific methods that might be used to reduce emissions. A bottom-up, empirical estimation of the marginal cost curve involves analysis of the broad spectrum of possible abatement options, from which marginal cost curves can be derived. Top-down models, typically using national or regional general equilibrium models (recall the results of Figure 4.4), also necessarily require explicit consideration of specific policy or technology options.

CBA cannot itself resolve the fourth question — which involves equity — but it does provide a framework for understanding the trade-offs to be made between equity and economic efficiency. CBA, when applied globally, can identify in which countries abatement costs are lowest, since the global perspective identifies all measures whose marginal costs are less than the global marginal benefits (recall Figures 4.5 and 4.6). But how such a program can be implemented in practice involves putting in place appropriate transfer payment mechanisms, the amount and structure of which is a matter of equity.

Nevertheless, despite its many imperfections, CBA remains the best guide to policy-making for dealing with the essential questions that must be faced in dealing with climate change. CBA forces decision makers to compare the consequences of alternative actions, including that of no action, on a quantitative rather than intuitive or rhetorical basis — and

can certainly make a contribution to resolution of the first three of these questions. And where impacts on non-monetary objectives (social and environmental) must also be considered, extensions of the traditional CBA approach, such as multi-criteria analysis, permit quantitative expression of the trade-offs to be made. At the same time, issues of risk, uncertainty and discount rate may be addressed through an expanded CBA/decision analysis framework that incorporates recent advances in dealing with such difficulties.

BIBLIOGRAPHY

- Aaheim, A., 1993. Benefits and Costs of Climate Measures under Joint Implementation, CICERO, University of Oslo.
- Abrahamson, S., et al. 1989. Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, NUREG/CR-4214, Sandia National Laboratories, Washington, DC.
- Alfsen, K. H., A. Brendemoen and S. Glomsrod, 1992. Benefits of Climate Policies: Some Tentative Calculations, Discussion Paper, Central Bureau of Statistics, Oslo.
- Amman, M. et al., 1992. Economic restructuring in Eastern Europe and acid rain abatement strategies, *Energy Policy*, p.1187-1198.
- Anderson, D. and R. H. Williams, 1993, The Cost-Effectiveness of GEF Projects, Global Environment Facility, Working Paper 6, Washington, DC.
- Arrow, K.J., 1966. Discounting and Public Investment Criteria, in Kneese and Smith, Eds., 1966.
- _____, and M. Kurtz, 1970. Public Investment, the Rate of Return and Optimal Fiscal Policy, Johns Hopkins University Press, Baltimore.
- Baron, W. and P. Hills, 1990. Greenhouse Gas Emissions: Issues and Possible Responses in Six Large Lower Income Asian Nations, Working Paper #45, Center for Urban Planning and Environmental Management, University of Hong Kong.
- Bernstein, M., 1992. Costs and Greenhouse Gas Emissions of Energy Supply and Use, Environment Department, Working Paper 1993-40, World Bank, Washington DC.
- Blitzer, C., R. Eckhaus, S. Lahiri, and A. Meeraus, 1993. Growth and Welfare Losses from Carbon Emissions Restrictions: A General Equilibrium Analysis of Egypt, *The Energy Journal*, 14, 1, pp.57-81.
- Bohm-Bawerk, E. von, 1989. Kapital und Kapitalzins: Zweite Abtheilung: Positive Theorie des Kapitals, Wagner, Innsbruck.
- Brekke, K. A., 1994. Net National Product as a Welfare Indicator, *Scandinavian Journal of Economics*, 96, 2, p.241-252.
- Bromley, D., 1986. Natural Resource Economics: Policy Problems and Contemporary Analysis, Kluwer/Nijhoff Publishing, Boston, MA.
- Brown, P. G., 1992. Climate Change and the Planetary Trust, *Energy Policy*, p.208-222.
- Burgess, J., 1990. The Contribution of Efficient Energy Pricing to Reducing Carbon Dioxide Emissions, *Energy Policy*, p.449-455.
- Butlin, R. (ed.), 1981. Economics of the Environmental and Natural Resource Policy, Westview Press, Boulder CO.
- Center for Energy and Environment, University of Pennsylvania, 1992. Costs and Greenhouse Gas Emissions of Energy Supply and Use.
- Chao, H. P. and Wilson, R., 1993. Option Value of Emission Allowances, *Journal of Regulatory Economics*, 5: 233-249.
- Cline, W. R., 1992. The Economics of Global Warming, Institute for International Economics, Washington, DC.
- Coppel, J. 1991. An Analysis of Energy Policy Measures and their Impact on CO₂ Emissions, Proceedings, ESCAP Conference of Greenhouse Research, Bangkok, August 1991, p. 263-286.
- Crousillat, E., 1989. Incorporating Risk and Uncertainty in Power Sector Planning, Industry and Energy Department Working Paper, Energy Series Paper 17, World Bank, Washington, DC)
- _____, and H. Merrill, 1992. The Trade-off/Risk Method: A Strategic Approach to Power Planning, World Bank, Industry and Energy Department, Washington, DC: p. 16-17.
- _____, and S. Martzoukos, 1991. Decision-making under uncertainty: An option valuation approach to power planning, Industry and Energy Department Working Paper, Energy Series Paper 39, World Bank, Washington, DC.
- Dreze, J. H. and A. Sandmo, 1971. Discount Rates for Public Investment in Closed and Open Economies, *Economica*, Vol. 38, (November), pp. 395-412.
- EPA, The Potential effects of global climate change on the United States, EPA-230-05-89-050, Washington, DC, December 1989, p.390.
- Fuglestad et al., 1994. A Review of Country Case Studies on Climate Change, Global Environment Facility, Working Paper 7, Washington, DC.
- Glieck, P., 1989. Climate Change and International Policies: Problems Facing Developing Countries, *Ambio*, 18, 6, p.333-339.
- Glomsrod, S., H. Vennemo, and T. Johnson, 1990. Stabilization of Emissions of CO₂: a Computable General Equilibrium Assessment, Central Bureau of Statistics, Discussion Paper 48, Oslo, Norway.
- Goto, N. and T. Sawa, 1993. An Analysis of the Macro-economic Costs of Various CO₂ Emission Control Policies in Japan, *The Energy Journal*, 14, 1, pp.83-110.
- Gregory, R., S. Lichtenstein and P. Slovic, 1993. Valuing Environmental Resources: A Constructive Approach, *Journal of Risk and Uncertainty*, Vol 6, pp 177-197.
- Heal, G. M. (1981). Economics and Resources, in R. Butlin (1981).
- Hoel, M., 1992. The Role and Design of a Carbon Tax in an International Climate Agreement, in Climate Change. Designing a Practical Tax System, OECD, Paris
- _____, and I. Isaksen, 1993. Efficient Abatement of Different Greenhouse Gases, Memorandum No. 5/93 from Department of Economics, Univ. of Oslo
- _____, and I. Isaksen, 1994. The Environmental Costs of Greenhouse Gas Emissions", Mimeo, Department of Economics, Univ. of Oslo.
- Hogan, W., 1990. Comments on Manne and Richels: CO₂ emission limits: An Economic Cost Analysis for the USA, *Energy Journal*, 11, 2, pp.75-85.
- Hossain, J. and C. Sinha, Limiting CO₂ emissions in the power sector of India, *Energy Policy*, Oct. 1993, p.1028
- Houghton, J. T., et al. (Eds), 1990, Climate Change-- the IPCC Scientific Assessment, World Meteorological Organization and the United Nations Environment Program, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.
- Huetting, R., P. Bosch and B. de Boer, 1992. Methodology for the Calculation of Sustainable National Income, Statistical Essays, M44, Centraal Bureau for de Statistiek, Gravenhaage.
- ICF, Inc., 1990. Preliminary Technology Cost Estimates of Measures Available to reduce U.S. Greenhouse Gas Emissions by 2010, Report by ICF to the U.S. Environmental Protection Agency.
- International Energy Agency, 1988. Emission Controls in Electricity Generation and Industry, Paris.
- Jackson, T., 1991. Least-cost Greenhouse Planning: Supply Curves for Global Warming Abatement, *Energy Policy*, (Jan-Feb).
- Jones, B. and E. Wheeler, Editors, 1992. Greenhouse Research Initiatives in the Escap Region. Proceedings of a Conference, Bangkok, August 1991, ESCAP.
- Keeney, R. L. and H. Raiffa, 1976. Decisions with Multiple Objectives: Preferences and Value Trade-offs, New York: Wiley.
- _____, and D. von Winterfeldt, 1987. Optimal Procedures to Evaluate Decisions with Multiple Objectives, EPRI EA-5433, Electric Power Research Institute, Palo Alto, CA.
- King, K., 1993. Issues to be Addressed by the Program for Measuring Incremental Costs for the Environment, Global Environment Facility, Working Paper 8, Washington, DC.
- _____, and M. Munasinghe, 1992. Global Warming: Key Issues for the Bank, World Bank Environment Department Divisional Working paper 1992-36, Washington, DC.
- Kneese, A., 1984. Measuring the Benefits of Clean Air and Water, Resources for the Future, Washington D.C.
- _____, and S. C. Smith (eds.), 1966. Water Research, 13-32, Johns Hopkins University Press for Resources for the Future, Baltimore, MD.
- Koopmans, T. C., 1960. Stationary Ordinal Utility and Impatience, *Econometrica*, Vol 28 no.2, pp. 287-309.
- Kreps, D. M. and E. L. Porteus, 1979. Temporal von Neumann-Morgenstern and Induced Preferences", *Journal of Economic Theory*, Vol. 20, pp. 81-109.
- Larsen, B., 1993. World Fossil Fuel Subsidies and Global Carbon Emissions in a Model with Inter-fuel Substitution, World Bank, Washington, DC.
- Lave, L., 1991. Are Economists Relevant? The Efficiency of a Carbon Tax, in Dornbusch

- and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA.
- _____, and Grunspacht, H., 1991. Increasing the Efficiency and Effectiveness of Environmental Decisions: Benefit-cost Analysis and Effluent Fees: A Critical Review, *Journal of the Air Waste Management Association*, 41,5, pp.680-693.
- _____, and K. Vickland, 1989. Adjusting to Greenhouse Effects: the Demise of Traditional cultures and the Cost to the USA, *Risk Analysis*, 9, pp.283-291.
- Lind, R. C., 1984a. Discounting for time and Risk in Energy Planning, Johns Hopkins University Press for Resources for the Future, Baltimore, MD.
- _____, 1984b. A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options", in Lind (1984a).
- London Economics, 1992. Economic Costs of Carbon Dioxide Reduction Strategies. Global Environment Facility Working Paper Series 3, Washington, DC.
- Manne, A., 1992. The Rate of Time Preference - Implications for the Greenhouse Gas Debate, mimeo. Stanford University.
- Manne, A. and R. Richels, 1990 CO₂ emission limits: An Economic Cost Analysis for the USA, *Energy Journal*, 11, 2, pp.51-74.
- _____, 1992. Buying Greenhouse Insurance: the Economic Costs of Carbon Dioxide Emission Limits, MIT Press, Cambridge, MA.
- _____, A. Mendelsson and R. Richels, 1992. MERGE - A MODEL for Evaluating Regional and Global Effects of GHG Reduction Policies, mimeo. Stanford, Yale and EPR
- Marglin, A., 1963. The Social Rate of Discount and the Optimal Rate of Investment", *Quarterly Journal of Economics*, Vol. 77, pp. 95-111.
- Markandya, A., 1990., Environmental Costs and Power System Planning. *Utilities Policy*, 1,p.13-27.
- _____, and D. Pearce, 1988. Environmental Considerations and the Choice of the Discount Rate in Developing Countries. Environment Department Working Paper #3, World Bank, Washington, DC.
- Meier, P., 1990. Power Sector Innovation in Developing Countries: Implementing Investment Planning under Capital and Environmental Constraints, *Annual Review of Energy*, 15, pp.277-306.
- _____, and M. Munasinghe, 1994. Incorporating Environmental Concerns into Power Sector Decision-making, World Bank, Washington, DC.
- _____, M. Munasinghe, and T. Siyambalapitiya, 1993. Energy Sector Policy and the Environment: A Case Study of Sri Lanka. Environment Department, World Bank, Washington, DC.
- Mubayi, V., L. Neymotin and V. Sailor, 1991. Cost-benefit Considerations in Backfit Analysis, Brookhaven National Laboratory, Upton, NY.
- Munasinghe, M., 1990. *Energy Analysis and Policy*, Butterworths Press, London, UK.
- _____, 1991. Sustainable Energy Options for Developing Countries, *World Energy Council Journal*, 1, December, p.69-87.
- _____, 1993. Environmental Economics and Sustainable Development, World Bank, Washington, DC.
- Newendorp, P., 1976. Decision Analysis for Petroleum Exploration, Pennwell, Tulsa, OK.
- Nordhaus, W., 1991. Economic approaches to greenhouse warming, in Dornbusch and Poterba (Eds) *Global Warming: Economic Policy Responses*, MIT Press, Cambridge, MA.
- _____, 1991. The Cost of Slowing Climate Change: a Survey, *Energy Journal*, 12, 1, 37-65.
- _____, 1994 Expert Opinion on Climatic Change, *American Scientist*, 82, 45-51.
- _____, 1993. Running the DICE: An Optimal Transition Path for Controlling Greenhouse Gases, *Resources and Energy Economics*, Vol. 15 pp. 27-50.
- _____, 1994. Climate Change and Economic Development: Climates Past and Climate Change Future, Proceedings of the World Bank Annual Conference on Development Economics, Washington, DC.
- Office of Technology Assessment, 1992. Fueling Development: Energy Technologies for Developing Countries, OTA-E-516, Washington, DC.

- _____, 1993. Preparing for an Uncertain Climate, OTA-O-568, Washington, DC.
- Ogawa, Y. and H. Awata, 1991. Simulation Study of Greenhouse Gas Emissions due to Future Energy Consumption, Proceedings, ESCAP conference of Greenhouse Research, Bangkok, August 1991, p. 234-262.
- Pachauri, R. K., 1991. Global warming: impacts and Implications for South Asia, Tata Energy Research Institute, New Delhi.
- _____, and A. Behi, Editors, 1991. *Global Warming: Mitigation Strategies and Perspectives from Asia and Brazil*, Tata McGraw-Hill for Asian Energy Institute, New Delhi, India.
- Page, T., 1977. Conservation and Economic Efficiency, Johns Hopkins University Press, Baltimore.
- Proost, S. and D. Van Regemorter, 1992. Economic Effects of a Carbon Tax: With a General Equilibrium Illustration for Belgium, *Energy Policy*, p. 136-149.
- Putta, S., 1990. Weighing Externalities in New York State, *Electricity Journal*, July 1990.
- Ramsey, F., 1928 A Mathematical Theory of Saving, *The Economic Journal*, Vol. 38 no 152, pp. 543-559.
- Randall, A., 1986. Valuation in a Policy Context, in Bromley, 1986, pp. 163-200.
- Rawls, J., 1972. A Theory of Justice, Oxford University Press. Oxford
- Repetto, R., 1989. Wasting Assets: Natural Resources in National Income Accounts, World Resource Institute. Washington.
- Richels, R., and J. Edmonds, 1993. The Economics of Stabilizing Atmospheric CO₂ concentrations.
- Rose, A., 1990. Reducing Conflict in Global Warming Policy: The Potential of Equity as a Unifying Principle, *Energy Policy*, December, pp. 927-935.
- Ryder, H. and G. Heal, 1973. Optimal Growth with Intertemporally Dependent Preferences, *Review of Economic Studies*, Vol. 40, pp. 1 - 31.
- Sen, A., 1979. Personal Utilities and Public Judgments: Or What's Wrong with Welfare Economics?, *The Economic Journal*, 89, pp.537 - 558.
- _____, 1984. Approaches to the Social Discount Rates for Social Benefit-cost Analysis, in Lind (1984a).
- Sitnicki, S. et al., 1991. Opportunities for carbon emissions control in Poland, *Energy Policy*, 19, 10, p.995-1002
- Steinberg, M. and H. Cheng, 1985. A Systems Study for the Removal, Recovery and Disposal of Carbon Dioxide from Fossil Fuel Power Plants in the U.S., Brookhaven National Laboratory, BNL 35666, July 1985.
- Stern, T., 1994. Discounting in a World of Limited Growth, *Environmental and Natural Resource Economics*, 94, 4.
- Tata Energy Research Institute, 1991. Report on Global Warming and Associated Impacts. Report to the Ministry of Environment and Forests, New Delhi, India.
- Turner, R. K., 1991. Environment, Economics and Ethic, in *Blueprint 2: Greening the World Economy*, D. Pearce, (Ed.), Earthscan Publishing, London.
- United Nations Environment Programme, 1988. Assessment of Multiple Objective Water Resources Projects: Approaches for Developing Countries, New York.
- _____, 1992. UNEP Greenhouse gas abatement costing studies, Riso National Laboratory, Denmark.
- United Nations, 1992. Handbook of National Accounting: Integrated Environmental and Economic Accounting, Draft, Department of Economic and Social development, Statistical Division, New York, NY.
- Weitzman, M., 1976. On the Welfare Significance of National Product in a Dynamic Economy, *Quarterly Journal of Economics*, 90, pp. 156-162.
- Williams, R. H., 1993. Comment on "Climate and Economic Development" by Nordhaus, Proceedings of the World Bank Annual Conference on Development Economics, Washington, DC.
- World Commission on Environmental and Development, 1987. Our Common Future, Oxford University Press, Oxford, UK.
- Yamagi, K. et al. 1993. A Study on economic measures for CO₂ reduction in Japan, *Energy Policy*, February 1993, p.123-1319

Clinton Presidential Records Digital Records Marker

This is not a presidential record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

This marker identifies the place of a tabbed divider. Given our digitization capabilities, we are sometimes unable to adequately scan such dividers. The title from the original document is indicated below.

Chap 3 SOCIAL COSTS

Divider Title: _____

3

The Social Costs of Climate Change:
Greenhouse Damage and The Benefits of Control

D.W. PEARCE, W.R. CLINE, R.K. PACHAURI, P. VELLINGA,
S. FANKHAUSER, AND R.S.J.TOL

Contents

3.1 Conceptual Framework

- 3.1.1 Purpose of the Chapter
- 3.1.2 The Nature of Damage Assessment
- 3.1.3 The Valuation of Market and Non-Market Impacts
- 3.1.4 Transient and Equilibrium Warming
- 3.1.5 Time Horizon and Discounting
- 3.1.6 Technological Change
- 3.1.7 Adaptation
- 3.1.8 Recent Scientific Evidence

3.2 Damage Estimates for Benchmark Warming (2xCO₂)

- 3.2.1 Agriculture
- 3.2.2 Sea Level Rise
- 3.2.3 Forests
- 3.2.4 Water Supply
- 3.2.5 Space Cooling and Heating
- 3.2.6 Insurance
- 3.2.7 Other Market Sectors
- 3.2.8 Health
- 3.2.9 Air Pollution
- 3.2.10 Water Pollution
- 3.2.11 Migration
- 3.2.12 Human Amenity
- 3.2.13 Ecosystem and Biodiversity Loss
- 3.2.14 Extreme Weather Events
- 3.2.15 Damage Estimates: Summary

3.3 Damage Estimates for Longer Term Warming

3.4 Catastrophic Risks

3.5 Regional Implications of Global Warming Damage

- 3.5.1 Regional Damage Estimates
- 3.5.2 Japan
- 3.5.3 Africa
- 3.5.4 Bangladesh
- 3.5.5 India
- 3.5.6 Indonesia
- 3.5.7 Malaysia

- 3.5.8 Thailand
- 3.5.9 Latin America
- 3.5.10 Small Island States
- 3.5.11 Conclusions on Regional Impacts

3.6 From Greenhouse Damages to Abatement Benefits

3.7 The Secondary Benefits of Abatement Strategies

3.8 Comparing Benefits and Costs of Response Strategies

- 3.8.1 Social Efficiency of Abatement
- 3.8.2 Possible Implications

Boxes

- Box 3.1 Estimating the Value of a Statistical Life
- Box 3.2 Damage Aggregation Across Countries and Individuals
- Box 3.3 Relative Damage in Developing and Industrialised Countries

Figures

- Fig 3.1 Global Warming, Cost-Benefit Analysis and Sustainable Development
- Fig 3.2 2xCO₂ Damage vs. Abatement Benefits

Tables

- Tab 3.1 Overview on Climate Change Impacts
- Tab 3.2 The Economic Value of Endangered Species and Prized Habitats
- Tab 3.3 Reported Fatalities due to Weather Events 1989-1992
- Tab 3.4 Economic Damages from Global Warming: US Economy at Present Scale
- Tab 3.5 Quantitative 2xCO₂ Damages in Different World Regions
- Tab 3.6 Monetary 2xCO₂ Damage in Different World Regions
- Tab 3.7 Expert Opinion on Climate Change Damage
- Tab 3.8 Illustrative Damages from Long Term Warming: US Economy at Present Scale
- Tab 3.9 Losses of Rice Output in Coastal Zones of Bangladesh
- Tab 3.10 Vulnerability Index for Different Categories of Countries
- Tab 3.11 The Social Costs of CO₂ Emissions in Different Decades
- Tab 3.12 Reduced Air Emissions due to CO₂ Abatement
- Tab 3.13 The Social Costs of Air Pollution

3.1 Conceptual Framework

3.1.1 Purpose of the Chapter

This chapter is concerned with the nature of the damage from climate change. Damages in the context of this chapter refer not to the physical impacts of climate change, but to the consequences of these effects for individual and social welfare. Addressing the available literature, the chapter assesses the possible aggregate scale, the geographical distribution, and the nature of those damages. While it is not directly concerned with decision-making rules (see Chapter ZZ) it raises some issues relating to those rules since the meaning of damage assessment cannot otherwise be understood. In particular, alternative ethical approaches to harm done to future generations have implications for damage assessment.

3.1.2 The Nature of Damage Assessment

Two perspectives have emerged on ways to analyse decisions the effects of which are so long-term that generations yet to be born may be adversely affected. While they initially appear to be very divergent, they have features in common.

The first perspective is the *benefit-cost framework*. It requires that the future damages be weighed up, integrated into an overall cost assessment, and then compared to the benefits from the decision being made now by the current generation. The benefits of fossil fuel production and use now, for example, would need to be compared to both the resource costs now, the localised and regional pollution impacts now (e.g. acid rain), and the longer term impacts of likely global warming and acidic deposition. In turn, there are two perspectives on the way in which benefits and costs should be compared:

- (i) the *judgemental benefit-cost framework*, in which gains and losses are compared but without reducing benefits and costs to common units. On this approach, the monetary costs of control might be compared with some wide-ranging *environmental impact statement* representing the best state of knowledge about climate change impacts, together with assessments of the *distributional incidence* of those impacts both geographically and across time;

- (ii) the *monetised benefit-cost framework*. On this approach, the common unit of money is used to 'reduce' the benefits of climate control to the same units as costs to permit direct comparison, but only as far as 'monetisation' is credible.

Approach (a) requires that the information on impacts (Working Group II) be combined with information on abatement costs (Chapter XX) and distributional incidence (Chapter YY) be given to policy makers for their own deliberation. It is not therefore the subject of further assessment in this chapter.

Approach (b) is characterised by the following features:

- (a) benefits and costs are defined in terms of human preferences. A benefit is anything that improves an individual's wellbeing; a cost is anything that reduces that wellbeing;
- (b) those preferences are expressed in the market place by willingness to pay (WTP) for a benefit and willingness to accept compensation (WTAC) for a cost;
- (c) where markets do not exist - for example with respect to ecosystem change - WTP and/or WTAC are measured through 'surrogate markets' or 'created markets'. Surrogate markets are real markets in which environmental change has an influence: a house price or land value may be higher because of an environmental amenity for example (the hedonic property price method). Created markets reflect people's responses to questions put to them about their willingness to pay (the contingent valuation method);
- (d) the 'intrinsic' values of other species and ecological systems may be captured at least in part by created markets since people may be expressing their understanding of intrinsic values when they express their willingness to pay for the continued existence of an environmental asset even though they may make no use of it, nor do they intend to use it ('passive use', or 'existence' value - see Carson *et al.* 1994);
- (e) future generations' preferences count at least in so far as they are assumed to want what current generations want. If there is evidence that they will want more of certain assets, especially environmental assets affected by climate change, then this 'rising

relative preference' can be accommodated by benefit-cost approaches by allowing benefits or cost to rise through time, although it often is not in practice;

- (f) future generations' preferences may count equally with current generation preferences if the *pure time preference* component of the *discount rate* is zero. If it is positive, their preferences count less in the benefit cost framework (see Chapter xxx and Section 3.1.5 below), but some judgement is implicitly being made about them. For example, if future damage costs from global warming are discounted at a positive rate, the implicit assumption is that the benefits of burning more fossil fuels now will partly accrue to future generations in the form of higher economic development. However, this approach overlooks the possibility that climate change itself may make future generations worse off by threatening their development potential: the discount rate becomes endogenous - it ceases to be an externally 'given' factor (Markandya and Pearce, 1988);
- (g) since WTP is constrained by income, it is likely to be less (but not necessarily so) for low income groups than for high income groups. This may give rise to apparent biases in that the concerns of developing countries will appear to be less important than those of developed economies. One way of avoiding this problem is to express the valuations as a proportion of income. Another is to give different weights to different income groups in the aggregation process (see Box 3.2). A third way, with less welfare theoretical underpinning, would be to adopt the valuations of the higher income groups and apply them to all countries (e.g. Hohmeyer and Gärtner, see also Box 3.1).
- (h) aggregation of damages is also a hallmark of benefit cost studies. Care has to be taken in interpreting such aggregate figures since they clearly mask (a) substantial regional variations in impact within a country and between countries, and (b) dislocation costs in adapting to changed local impacts. The aggregation of sectoral impacts also tends to imply that losses in one sector are compensated for by gains in other sectors.

The monetary benefit-cost approach has been used by several writers to secure guidelines on the amount of control of greenhouse gas emissions - e.g. Nordhaus (1991, 1993a, b), Peck

and Teisberg (1992); Cline (1992a); Hope *et al.* (1993), Manne *et al.* (1993), Tol (1994b).

The second overall perspective may be termed the *sustainability approach* (e.g. Howarth and Monahan, 1992; Spash, 1994). On this approach, the highest priority is given to the avoidance of 'unacceptable' damage to future generations. Rationales for avoiding this harm vary, but generally focus on the following sequence:

- (a) there is reasonable evidence to suppose that actions now in emitting greenhouse gases will cause significant damage to future generations, including unborn generations;
- (b) future generations are defenceless against actions taken now in the knowledge that those actions may cause harm;
- (c) current generations have obligations to future generations at the very least through a set of links from parents to children, from children to their children, and so on (Howarth, 1992), or, more generally, because future generations have rights even when those generations are not identifiable, and even when their existence is contingent on actions taken now;
- (d) probable improvements in the wellbeing of future generations cannot be treated as 'compensation' for harm knowingly inflicted on future generations by current generations, any more than harming the poor now can be excused by paying them compensation after the event (Spash, 1994);
- (e) hence doing harm is not reversible by doing good. Benefits and costs cannot be 'traded off' in the sense advocated by benefit-cost analysis *regardless of whether the benefit-cost analysis is monetised or not*. There is a *duty* to avoid future harm.

As with the benefit-cost approaches, all the propositions in the sustainability approach are open to dispute. Controversial assumptions include: (i) that harm can accrue to individuals whose existence is contingent on actions now and (ii) that trade-offs can be avoided, since any action now incurs a cost of abatement, and any abatement cost involves losses for others

which in turn implies that other individuals' rights may be impaired.

Within the sustainability approach two views are:

- a) since the obligation to avoid harm is absolute, the cost of avoiding harm is irrelevant. In the benefit-cost framework, the benefits of control are so large that inspection of costs is unhelpful. This is the *absolute standards* approach;
- (b) harm should be avoided subject to a constraint that avoiding harm does not itself impose 'unacceptable cost' now - the *safe minimum standards* approach.

The sustainability approach takes a long-term view and stresses the need to sustain a viable global ecological system. It therefore tends to be characterised by:

- (a) the avoidance of unacceptable risk where risks are known
- (b) the 'precautionary principle' - whereby actions giving rise to *possible* but quantitatively unknown but potentially very large risks are avoided or corrected. The precautionary approach *logically implies* a benefit - cost comparison since it assumes that the (expected) value of damage exceeds the costs of abatement;
- (c) the view that what is unacceptable is only partly measured by reference to individuals' preferences since (i) individuals are not well informed about climatic risks, (ii) experts are similarly not well informed due to uncertainty about climate change and its effects, and (iii) human preferences may not capture other values, e.g. intrinsic values;
- (d) very low discount rates of the order of a few percentage points, and maybe even zero.

Whereas the benefit - cost approach seeks to demonstrate the scale of damage, the sustainability approach assumes that damage will be 'significant', so much so that action is warranted regardless of quantification.

The sustainability approach often tends to have as its objective a concern to avoid exceeding some target rate of temperature rise, usually quoted as 0.1°C per decade, and some absolute overall rise in temperature of 2-3°C. Examples include Krause *et al.* (1989) and Rijsberman and Swart (1990). The costs of achieving these constraints are assumed to be worth incurring in order to avoid the risks to future generations.

Figure 3.1 illustrates the various approaches. Figure 3.1a shows a sustainability constraint set as some limit on the rate of warming (a limit on absolute warming might also be shown). On the absolute standards approach the *only* point of reference is the vertical constraint line. On the safe minimum standards approach (3.1b), the only points of reference are the constraint line and the abatement cost function, ΔA , which is shown as the marginal abatement cost which rises sharply as lower and lower levels of warming rates are sought. Figure 3.1c shows monetised marginal damage (ΔD) and marginal abatement cost functions. Their intersection determines the economically 'optimal' level of control. In practice, (a) benefit - cost approaches have typically used *point estimates* of damage, e.g. the damage that would occur for $2\times\text{CO}_2$ to approximate ΔD , since the informational needs of damage functions are substantially larger (see Section 3.6), and (b) neither the damage nor the abatement cost function is known with any certainty, and the uncertainty will tend to be higher for the damage function. On the judgemental benefit cost approach the abatement cost curve is compared to some judgement about benefits. The presumption in Figure 3.1 is that benefit-cost approaches yield outcomes consistent with higher warming rates than are implied by the sustainability approach.

[Figure 3.1]

It is well known that a time path in which the present value (i.e. the discounted value) of benefits minus costs is maximised need not be a sustainable path, and that a sustainable path could, in turn, be unacceptable in terms of its implied living standards for each generation (Page, 1977; Pearce *et al.*, 1994; Pezzey, 1994). The choice between the two paradigms therefore depends crucially on (a) attitudes to uncertainty, (b) the degree of concern for the wellbeing of future generations, and (c) beliefs about the damage function, i.e. the way in which warming relates to damages.

A consensus viewpoint stresses the following common features of both the sustainability and the benefit-cost approaches:

- (a) the existence of uncertainty cannot justify 'business as usual', i.e. doing nothing. Action on climate change is justified since the damage costs could be very high, the 'coefficient of concern' for the future is not zero, and there are costs of delayed action since greenhouse gas impacts may not be reversible;
- (b) the right benefit-cost perspective is one which investigates the benefits and costs of taking actions. Such actions are likely to yield benefits of a similar order of magnitude as the costs of the actions for some time to come, since avoided climatic damages are not the only benefits of those actions. This underlines the difference between damage estimation and abatement benefits: the latter include the avoided damages estimated by the former concern, but also include other benefits from greenhouse gas abatement (see Section 3.7);
- (c) neither sustainability nor 'maximising net benefits' is an obviously non-controversial objective. Sustainability cannot be an overriding objective independently of the quality of life that is sustained or the costs of achieving it. Maximising net benefits cannot be an overriding objective either since it may be consistent with an approach which discriminates against future generations. This suggests an approach in which the best features of both approaches are taken: a concern for the wellbeing of future generations, the wellbeing of Earth itself, and acknowledgement of the limited resources that all societies have at their disposal to tackle global problems. Such approaches come closest to the 'safe minimum standards' approach: taking a precautionary approach in favour of the environment unless the demonstrated costs of so doing are very high.

3.1.3 The Valuation of Market and Non-Market Impacts

The benefit cost approach requires that the damages from climate change be expressed, as far as is possible, in terms of money units. These money units are measures of preferences as revealed through choice-making actions involving the exchange of money for goods and

services. One obvious problem is that many of the impacts of climate change will not be revealed directly in the market place. It is important therefore to distinguish market and non-market values, although it is equally important to stress that the absence of markets does not mean that non-market impacts are any less important than market impacts. The point of the distinction is to ensure that non-market impacts are adequately accounted for.

As an example of market impacts, damage to crop productivity will be expressible in market terms since the crops in question have market prices. This does not mean that simple multiplications of estimated crop loss and market price will be accurate measures of economic damage. The crop prices, for example, are very likely to reflect policy distortions, such as guaranteed farmgate prices. These are not the correct prices to use since they contain often substantial elements of internal transfer payments from taxpayers to farmers, via the government. The relevant prices are those which measure the true willingness to pay of final users for the crops, or 'shadow prices' as they are known. In the case of agricultural crops, such prices will tend to be the world prices since these measure the true opportunity cost of producing an extra unit of output.

Non-market impacts may take a variety of forms. One important example is the impact of warming on human health. Human health is, to some extent, bought and sold, for example in private health care systems in some countries. But it is generally publicly provided without direct charge. It is not obvious therefore what individuals' willingness to pay for health is. In some cases, there are surrogate markets for risks to life. Occupations are subject to varying degrees of risk and that risk is sometimes compensated for by variations in wages. The 'risk premium' in the wage can then be interpreted as a valuation of the risk (see Box 3.1). Valuation of morbidity is more complex since the strictly correct measure is the WTP of individuals at risk and who suffer illness. Contingent valuation approaches are best suited to such indicators but, as yet, few studies exist outside the USA. In their absence, second best measures such as the costs of treatment may be used.

The general approach in benefit-cost studies is to treat market and non-market impacts on the

same footing. Non-market costs can be high, from about one third to two thirds of the total¹. Cline (1994a) suggests that the way non-market impacts are treated matters, however. The reasons are: (a) they affect human wellbeing directly (through the utility function), rather than through production, (b) they are liable to be less substitutable and (c) their value will rise relative to other (production) damages (see 3.1.1c above).

Market price (in the case of market goods) and WTP (for non-market goods) reflect people's appreciation for the *marginal* (last) unit of a good or service consumed. The utility gained from consuming the first unit of a good is usually much higher than that from consuming the last unit, however. Especially for food and other products with price inelastic demand - where the appreciation of additional units beyond an essential minimum decreases rapidly - the value lost from a cutback in availability will be understated if the quantity loss is evaluated at the original (ex ante) price. Price increases as a consequence of global warming are often important. The correct measure to assess the costs of global warming in such cases is the change in producer and consumer surplus². This consideration also means that it can be misleading to gauge the potential impact of global warming by the present size of a sector in the economy. In industrial countries agriculture is typically on the order of 3 percent of GDP, but reduction of X percent in agricultural output could cause far more than 0.03X percent of GDP economic loss because of the induced price increase and loss of consumer surplus.

The time dimension of damage is also important. Damage at any time, *t*, is not the same thing as the eventual damage caused by emitting greenhouse gases due to atmospheric lag effects. The difference between transient and equilibrium warming thus requires explanation.

¹ In Table 3.4 below, the Cline (1992a) estimates show a share of two-thirds for losses in market sectors (agriculture, sea walls, dryland loss, electricity, nonelectric heating, hurricanes, leisure activities, water supply) and one-third in non-market sectors (forest loss, species loss, wetlands, human life, migration, and air pollution). In contrast, in the Titus estimates, in which forest losses and pollution damages are much larger, non-market effects are more than 80 percent of the total.

² Consumer surplus is the excess of what consumers would be willing to pay if necessary above what they actually pay. Producer surplus is what producers receive in excess of their actual costs of production.

3.1.4 Transient and Equilibrium Warming

Ocean thermal lag causes realized equilibrium warming from a given steady-state increase in greenhouse gas concentrations and their consequential radiative forcing to be delayed by at least two, and perhaps several, decades³. Among economic analyses, Cline (1992a) simply applies a 25 year lag, whereas other models (e.g. Nordhaus, 1993a, b) often explicitly model thermal capacities of, and transfer between the atmosphere, upper ocean and lower ocean. The lag of realized warming introduces an inherent asymmetry into the economics of global warming: advantages associated with emissions (e.g. the benefits of automobile driving or electricity generation) occur immediately, whereas economic damages occur only after a significant lag.

In addition, an even more fundamental asymmetry is that emissions in a given year typically generate a contemporary, one-year flow of advantages, but create a stock of warming that then produces a recurrent annual flow of damages into the indefinite future. There is thus an inherent temporal asymmetry between earlier satisfaction from emissions and later, more persistent damages, even if thermal lag is ignored.

For a specified radiative forcing, the transient warming may not follow a smooth path between present and future equilibrium climate. Transient climate change in a particular region cannot therefore be assumed to be a steadily rising fraction of equilibrium impact; instead, there could be discontinuities and reversals. Damages is likely to be sensitive to such variability. Adjustments of natural systems and social institutions are not instantaneous. A world with continual climate shocks would affect the ability of economic and natural systems to adjust and to recover. The economic implication is that the strategy of relying solely on adaptation rather than abatement could have higher costs than implied under a smooth transient path.

In addition, it is generally agreed that the faster warming occurs - either because of higher

³ Under business-as-usual conditions of steadily rising concentrations, realized warming at a point in time is roughly 60% of equilibrium or committed warming corresponding to radiative forcing already present, for atmospheric models with climate sensitivity parameters of 4°C; and 80%, for 1.5°C (IPCC, 1990a).

climate sensitivity (equilibrium warming for a given radiative forcing) or the shorter the ocean thermal lag - the greater the economic damages will be. That is, damage is a function of absolute warming as well as the rate of warming. Species and forests will have less time for migration; agricultural and other climate-sensitive human activities will have less time for adaptation. In a survey of experts' opinions Nordhaus (1994a) finds that for a hypothesized warming of 6°C, the mean estimate of damage is 6.7% of world product if the arrival date is 2175, but 10.4% if the warming occurs by 2090 (with wide extremes around the mean in both cases, see Table 3.7 below).

3.1.5 Time Horizon and Discounting

The emission of carbon dioxide causes effects likely to persist on a time scale of centuries. IPCC (1990a) estimates that the first half-life of CO₂ is 50 years and the second half-life another 250 years (with the decline to 1/e taking 120 years). In the absence of policy intervention carbon dioxide concentrations could continue to rise for the next 300 years, given current fossil fuel resources. Global warming thus poses unusual problems for economic analysis, which more typically considers issues with time scales of only a few decades.

The discount rate is the analytical tool economists use to compare benefits and costs over time. Rates of 8% - 10% per annum are often used in project analysis. Such rates cause the future to vanish rapidly. Thus, discounting at 8%, damage of \$1 billion 50 years from now is valued at only $\$10^9 \cdot 1.08^{-50} = \$21,300$; and the same damage 200 years from now, at only \$200. This collapse of future values suggests the need to think especially carefully about proper discounting for global warming analysis if the interests of future generations are to be accounted for.

There are two basic schools of thought about discounting. The first holds that the proper discount rate is the rate of return on capital, because this is the opportunity cost of using resources for global warming abatement or any other purpose (Birdsall and Steer, 1993). The second considers the underlying social rate of time preference (SRTTP) to be the appropriate rate. Typically there is a substantial wedge between a (higher) rate of return on capital and a (lower) SRTTP. In this second approach, the entire stream of economic effects is first

converted into consumption-equivalents, in which all capital effects are multiplied by a shadow price that increases capital's weight because of its higher rate of return. The stream of consumption equivalents is then discounted at the SRTTP for consumption. The second approach tends to generate discount rates that are lower than the first approach. A fundamental difference between the two is the recognition that only a fraction of the resources allocated to a given endeavour is likely to come out of alternative capital investment, and that a substantial alternative fraction is instead likely to come out of consumption.

Most analysts of global warming implicitly or explicitly adopt the second approach. They disagree, however, on the specific implementation of this approach. Their most important division concerns the concept of "pure time preference."

There is general agreement that the social rate of time preference equals:

$$SRTTP = \rho + \theta g \quad (3-1)$$

where ρ is the rate of pure time preference, θ is the elasticity of the marginal utility of consumption, and g is the rate of growth of per capita income.

Consider pure time preference first. In a society in which income levels are not expected to rise, impatience may still cause a household to discount the future, that is, to equate a smaller amount of consumption today with a larger amount in the future. Ramsey (1928, p. 543) judged that any allowance for pure time preference ($\rho > 0$) "is ethically indefensible and arises merely from the weakness of the imagination."

Most economists could agree in principle, but many nonetheless use non-zero pure time preference, either because optimization models otherwise tend to explode or because zero pure time preference is "lower than would be consistent with observed real interest rates" (Nordhaus, 1992). This proposition has been questioned by Cline (1992b) who observes that, at least for the USA, the asset return closest to a risk-free intertemporal tradeoff for consumption - the real rate on US Treasury bills - has averaged only 0.3% over the past 60 years.

The second component of the SRTTP is an element that reflects the declining marginal valuation in utility terms from an extra unit of consumption at successively higher levels of income and consumption. This component essentially discounts the future because future generations are expected to be richer, not because of impatience. The term " θg " is comprised of the per capita growth rate (g) multiplied by the parameter showing how quickly marginal utility falls as consumption rises, or the elasticity of marginal utility of consumption⁴. One of the most commonly used utility functions, logarithmic utility (see e.g. Blanchard and Fisher, 1989) has a unitary value for θ , meaning that if income rises by 1% the marginal utility of consumption falls by 1%. Initial attempts to estimate this elasticity (Fellner, 1967; Scott, 1989) both place it somewhat higher, at 1.5. Recent studies estimating the parameter suggest $\theta = 0.8$ (Pearce and Ulph, 1994).

In a benefit-cost analysis of greenhouse abatement, Cline (1992a) adopts a zero rate of pure time preference (ρ), and sets the SRTTP at 1.5% per annum, the result of an assumed consumption growth rate of 1% multiplied by an elasticity of marginal utility of 1.5. After taking account of the share of resources coming out of capital (20% economy-wide, versus 80% out of consumption) and shadow-pricing capital effects (at a price close to two units of consumption equivalent to one unit of capital), Cline's effective discount rate is in the range of 2% per annum. This is in keeping with recent work by Pearce and Ulph (1994).

In contrast, most global warming optimization models (e.g. Nordhaus, 1993a, b; Peck and Teisberg, 1992; Manne *et al.*, 1993) apply a pure rate of time preference of 3%. They typically also use a logarithmic utility function, which, for a per capita growth rate of 1-2%, implicitly adds another 1-2% for utility-based discounting (θg), to give a SRTTP of 4-5%. As discussed below, the divergent discounting methods explain much of the difference in the policy findings of different studies.

Rothenberg (1993) and Schelling (1993) have suggested that, beyond a certain future point, it makes no sense to apply further discounting of consumption for pure time preference. Thus: "as the future recedes ... single generations come to be perceived more and more as

⁴ This elasticity is negative; the absolute value is used here.

homogeneous entities" (Rothenberg). Similarly: "time may serve as a kind of measure of 'distance' ... Beyond certain distances there may be no further depreciation for time, culture, geography, race, or kinship" (Schelling). In this approach, a graph of the fraction of face value accorded to each successive generation (for constant real consumption) is a series of declining, successively shallower steps that eventually reach a horizontal plateau. A deep plateau signifies major discounting for empathetic distance; a horizontal line beginning and remaining at unity is the zero pure time preference rate across generations recommended by Ramsey. Policy based on empathetic distance (a shelf lower than unity) may be more defensible when the action is refraining from conferring a windfall gain (as in penurious aid budgets) than when it involves the imposition of windfall damage (as in global warming's effects on future generations).

Identifying the proper discount rate is probably the single most important analytical step in economic analysis of global warming. It is also the most profound philosophical question, since it inherently confronts present pain of abatement cost against the suffering of future generations if no action is taken.

3.1.6 Technological Change

Even over two or three decades, technological change can profoundly alter the options available for low cost adaptation, on the one hand, or for greenhouse abatement, on the other. Over a time horizon of two or three centuries the technological unknowns become overwhelming. Cline (1992a) suggests that this problem can be obviated if it is assumed that the proportional effects of technological change are the same for abatement costs as for the damage-avoidance benefits of limiting warming. Thus, whereas technological breakthroughs on seed varieties might neutralize damage from increased droughts, thereby reducing the benefit of limiting warming, breakthroughs in non-fossil-fuel (e.g. solar) energy could correspondingly reduce the opportunity cost of reducing carbon emissions. This assumption provides a logical basis for proceeding with the benefit-cost analysis of abatement applying the best expectations of technologies on both sides⁵. However, the powerful influence of

⁵ Some of the energy models already incorporate plausible technical change (e.g. Manne and Richels, 1992); so do some agricultural yield projections (e.g. Rosenzweig *et al.*, 1993). More precisely, then, the assumption is that additional, unanticipated technological changes are distributed

technological change means that there is a wide band of uncertainty around the comparisons from this standpoint, added to that already present from climate uncertainty.

It is important to highlight the interaction between policy and technological change. Most models take technological change as exogenous. However, there are strong reasons to believe that, especially over a time horizon of many decades, new technology would respond to price signals sent by policy. Thus, the future path of carbon-sparing energy technology is likely to hold a wider array of innovations if there is a price signal discouraging carbon emissions than otherwise.

3.1.7 Adaptation

The severity of global warming impacts will depend on people's ability to adapt to a warmer world. Measures will generally be taken to accommodate to global warming, both on an individual level and by society as a whole. The search for more resilient crops will be intensified, vulnerable coastlines will be defended by sea walls, new buildings will be located and designed in a way to better withstand the force of extreme weather events. On an individual level farmers will change crops or adjust planting dates. Households will increase their demand for air conditioning, people may migrate to less affected regions, and so on.

Adaptation can potentially be a very powerful option. In a stylized cost-benefit model of global warming policies, Hope *et al.* (1993) found strongly positive cost-benefit ratios for an "aggressive adaptive policy", mainly in the form of coastal protection. The benefits of adaptation exceed the costs by more than a factor 20. Fankhauser (1994c) calculated optimal coastal protection levels of 50 to 100% for the countries of the OECD. In a series of country studies IPCC (1994) found that through appropriate adaptation measures the number of people at risk from flooding could on average be reduced by about 65%.

Agricultural studies provide a similar picture. In a case study of the Missouri-Iowa-Nebraska-Kansas (MINK) region, Easterling *et al.* (1993) found that low-cost adaptation measures, like earlier planting or increased irrigation, could succeed in reducing agricultural damages to the

evenly on both sides of the benefit-cost calculus.

region by 30% or more (see also section 3.2.1). A comparable range was found by Rosenzweig *et al.* (1993) and (using the same yield data) Reilly *et al.* (1994). In the Rosenzweig *et al.* study a change of -1.2 to -7.6% in worldwide cereal production without adaptation is reduced to 0% to -5% with moderate farm-level adaptation and +1% to -2.5% with a more comprehensive managerial adjustment. As a consequence, the global welfare loss reduces from \$ -0.1 to -61.2 billion without adaptation to \$ +7.0 to -37.6 billion in the case of a moderate response (Reilly *et al.*, 1994).

Adaptation will in general not be costless, and may require extensive planning. The need for an integrated and forward looking coastal zone management has been identified as an essential prerequisite for the future development of coastal zones (IPCC, 1994). The significance of adaptation will also depend on institutional factors. Limited availability of irrigation water or of sufficient capital to finance increased input requirements (e.g. more fertilizer) may limit the scope of agricultural adaptation poorer regions (Rosenzweig *et al.*, 1993). Lack of funds may also be a problem for the implementation of coastal protection schemes in developing countries.

Conceptually, the costs of global warming impacts in the presence of costly adaptation measures consist of two parts: The costs of adaptation (e.g. for coastal protection), plus the costs of the remaining, unmitigated damage (e.g. the loss of unprotected land). In the estimates reviewed in section 3.2, for many categories the damages of global warming also incorporate considerations of adaptation. A prime exception is loss of biodiversity, for which there are little adaptation options. Damage from sea level rise is partly comprised of the cost of building coastal protection structures. Similarly, the impacts on the electricity sector caused by global warming amount to costs required or induced by adaptation (space cooling). Implicitly or explicitly most of the estimates incorporate both effects: costs of plausible adaptation, plus the remaining damages from unmitigated impacts.

The question of the optimal level of adaptation is strongly linked to that of optimal greenhouse gas abatement and other response strategies. The most desirable level of adaptation will depend on the amount of greenhouse gas abatement undertaken, and *vice versa*. Abatement and adaptation policies should thus be carefully coordinated and would

ideally be set simultaneously. For example, if significant abatement can be achieved at reasonably low costs, less action may be needed with respect to adaptation. Conversely, if the consequences of global warming could easily and cheaply be accommodated by adaptation, there would be less need for preventive carbon abatement (Fankhauser and Hope, 1994).

However, as suggested by the hybrid nature of most of the estimates, as *damage-cum-adaptation* cost, assuming a strict dichotomy between abatement and adaptation would be misleading. Indeed, an underlying point is that the greenhouse problem is likely to require both sets of actions. Even with the most aggressive abatement policy, benchmark $2\times\text{CO}_2$ warming seems likely to occur eventually, although the date can be greatly delayed. Conversely, even the most extensive adaptation strategy is unlikely to fully mitigate the adverse impacts of global warming. Adaptation is primarily a complement, rather than an alternative to greenhouse gas abatement.

3.1.8 Recent Scientific Evidence

The literature reviewed below largely takes as its point of departure the scientific appraisal of IPCC (1990a). It is important to consider at the outset whether changes in the scientific assessment since then provide grounds for altering the economic evaluation of the greenhouse effect. In its preparation of the 1995 review, by mid-1994 IPCC Working Group I (scientific assessment) has tentatively identified the following changes in the underlying impact science that might affect the measurement of damage.

First, while the climate sensitivity parameter range remains at $1.5\text{--}4.5^\circ\text{C}$ for equilibrium $2\times\text{CO}_2$, transient realised global mean surface temperature is now expected to rise by a central estimate of roughly $0.25^\circ\text{C}/\text{decade}$, or by 2.5°C by 2090 over the 1990 base. The corresponding central estimate in the 1990 report was $0.3^\circ\text{C}/\text{decade}$, for a cumulative 4.2°C over the preindustrial base by the year 2100. This diminution is attributable to consideration of terrestrial uptake, incorporation of the effect of ozone stripping in the evaluation of radiative forcing from CFCs, and the influence of aerosol sulphates.

Second, there is increasing emphasis on regional differences. These stem importantly from

the differential impact of ocean thermal lag. In the Northern Hemisphere, with greater land mass relative to oceans, realized warming may be $0.5^\circ\text{C}/\text{decade}$, twice the pace of the global mean. Centres of land masses may have warming two to three times the global mean. Of specific interest is the effect of increasing land-ocean temperature differentials.

Third, a central estimate for sea level rise by the year 2100 is now placed at 45 cm, compared to 66 cm in IPCC (1990a).

The broad thrust of these changes is to moderate the expected pace of mean global warming, but to intensify the role of variability and surprises at the regional level. For mid-continental areas in the Northern Hemisphere, the new estimates would seem to leave even the mean pace of warming close to that in the earlier report of IPCC (1990a). Increasing ocean-land differentials suggest greater precipitation changes and higher damages in the category of storms. Importantly, the new incorporation of aerosol sulphates also carries the implication of potential acceleration from baseline warming if there is greater progress than expected in the reduction of urban pollution and thus reduction in these aerosols (Wigley and Raper, 1992).

In view of these considerations, it would seem that increased damage associated with variability and unpredictability, as well as greater attention to the high regional warming coefficients for the Northern Hemisphere and for mid-continental areas, would broadly compensate reduced damages from the standpoint of the timetable of mean warming. For its part, even this time path for mean global warming over the next century has only been reduced by 17% (from $0.3^\circ\text{C}/\text{decade}$ to $0.25^\circ\text{C}/\text{decade}$). On this basis, there would appear to be little reason for altering the broad orders of magnitude of the damage estimates in the economic effects literature reviewed below. At the most, the revised assessment might imply somewhat later damages for Southern Hemisphere (and thus, broadly, developing) countries.

3.2 Damage Estimates for Benchmark Warming ($2\times\text{CO}_2$)

Monetary values for climate change damages have been estimated for a number of sectors in the market economy. In addition, there are non-market damages, which are typically more

difficult to quantify (e.g. species loss), and a mixture of both market and non-market effects in some sectors (e.g. forest loss in lumber and public use value). Table 3.1 provides an overview of the categories of damages that might be caused by climate change and associated sea level rise. The estimated damages are not complete. For some categories, monetary estimates of damages have not been attempted. For other categories, the estimated damages only partially reflect the potential welfare loss. In many cases, the preferred measure of welfare impacts - willingness to pay - had to be approximated with other indicators.

[Table 3.1]

Most estimates are for equilibrium global warming associated with a doubling of pre-industrial carbon dioxide equivalent of all greenhouse gases (referred to here as benchmark warming). Absolute estimates are usually based on the present-day economy, and then expressed as a percentage of GDP. Projections then apply these percentage impacts to future world product (e.g. for 2060 for realized benchmark warming), although some of the effects are likely to grow more than proportionately with GDP and others less than proportionately. Estimates are predominantly for the United States and other OECD countries. Material relating to other countries is sparse. The incomplete nature of climate change damage estimates presented here must be borne in mind when evaluating the full welfare implications of global warming.

3.2.1 Agriculture

Global warming is likely to damage agriculture in many areas but aid it in others. The principal damage will arise from heat stress and decreased soil moisture. Warmer temperatures cause the growing cycle of many plants to accelerate, allowing less time for plant development before maturity. Continental interiors are expected to become drier with global warming. The principal offsets would be longer growing seasons in cold Northern climates, and the fertilization effect of greater atmospheric carbon dioxide.

Rind *et al.* (1990) use GCM results to calculate that for many mid-latitude locations (e.g. the United States), the incidence of severe droughts that currently occur only 5% of the time would rise to a 50% frequency by the 2050s, based on the difference between precipitation

and potential evapotranspiration (E_p). They find that:

E_p increases most where the temperature is highest, at low- to mid-latitudes, while precipitation increases most where the air is cooler and easiest to saturate by the additional moisture, at higher latitudes (p. 9983).

On the favourable side, higher atmospheric carbon concentrations are expected to increase photosynthesis, which combines carbon dioxide and water to produce carbohydrates. Laboratory experiments suggest that doubling of CO_2 from 330 to 660 ppm could raise yields by 34% for C_3 crops (wheat, rice, soybeans, fine grains, legumes, root crops, most trees) and 14% for C_4 crops (maize, sorghum; see Schneider and Rosenberg, 1989b). However, open-field conditions may not necessarily achieve the same yield increases (Parry, 1990; Evans *et al.*, 1991; Körner and Arnone, 1992; Erickson, 1993). Bazzaz and Fajer (1992) note that the laboratory experiments are dependent on availability of fertilizer and water, and conclude that because of "competitive interference and limited nutrients ... we do not expect that agricultural yields will necessarily improve in a CO_2 -rich future." Moreover, the doubling of atmospheric carbon is conceptually the wrong experiment for calculating the effects of benchmark (equilibrium) warming. After taking account of other greenhouse gases, CO_2 concentration would be only 440 ppm at carbon-equivalent doubling (Cline, 1992a, calculated from IPCC, 1990a).

In assessing agricultural damage on a global level changes in trade flows are of crucial importance. Kane *et al.* (1992) apply the US Department of Agriculture's Static World Policy Simulation (SWOPSIM) model of agricultural trade to emphasize the importance of trade effects. Even in a "very adverse" scenario in which yields fall by 5% - 40% in most developed countries, the former Soviet Union and China, and remain unchanged in most other developing countries, net global welfare declines by only 0.47% of GDP. World food prices are expected to increase in the order of 40% or more, with repercussions on both producer and consumer welfare. In a food exporting country like the United States, for example, consumers are expected to lose \$40 billion annually in consumer surplus (at 1986 prices), while US farmers gain \$19 billion annually in producer surplus because price increases more than offset yield reductions. Of course, the implication is that a corresponding loss of consumer surplus occurs for importing nations, associated with terms of trade gains

on US farm exports. The main loser identified in this particular model run is China, with economic losses of more than 5% of GDP. Increased world food prices also heavily affect consumers in the former Soviet Union. In a second, more optimistic scenario, worldwide impacts are practically zero, with negative results in Canada, Japan and Europe being offset by gains in Australia, and now also the former USSR and China. The Kane *et al.* figures, averaged over all scenarios, are reproduced as the agricultural damage in Table 3.5.

In another global study Rosenzweig *et al.* (1993) coordinated research applying crop simulation models in 18 countries to examine the impact of benchmark $2\times\text{CO}_2$ -equivalent warming on yields for wheat, rice, maize, and soybeans by 2060. Linking the results in a world trade model (Basic Linked System), they calculated the impact on production levels, prices, and the number of people at risk from hunger. The study finds that crop yields would decline in the low latitudes, where they are currently grown near their limits of temperature tolerance. However, yields could increase at middle and high latitudes when carbon fertilization is included.

Under their variant with moderate adaptation, output rises in developed countries by 4% - 14% but falls by 9% - 12% in developing countries (which must import). Depending on the GCM used, global output falls by 0% - 5%, prices rise by 10 - 100%, and the number of people at risk from hunger rises from a baseline of 640 million to a range of 680-940 million. Although the results are open to the critique that the climate models used (GISS, GFDL, UKMO) have sensitivity parameters higher than the IPCC's 2.5°C (Reilly and Hohmann, 1993), from another standpoint the results are optimistic. They employ a carbon concentration of 555 ppm, essentially a transient concept for the year 2060 rather than an equilibrium concept for $2\times\text{CO}_2$ -equivalent (440 ppm)⁶.

On a regional level, a study for the European Union predicts that overall agricultural yields in Europe are likely to increase as result of increased temperature and precipitation. Welfare gains of ECU 3.2 billion are predicted for 1°C warming and 12.2 billion for 4°C

⁶ The eventual equilibrium warming consistent with the 2060 greenhouse gas concentrations would be higher than benchmark warming (because of the lag of two decades or more between committed and realized warming, associated with ocean thermal lag).

(CRU/ERL, 1992). Gains would mainly occur in the north, while the outcome for southern Europe would be more mixed.

For the United States, the Environmental Protection Agency (EPA) estimates that combined producer and consumer economic effects of global warming at benchmark carbon dioxide equivalent doubling would range from -\$5.9 billion annually (GISS model) to -\$33.6 billion (GFDL model) at 1982 prices, before taking account of carbon fertilization; and at +\$10.6 billion to -\$9.7 billion, respectively, under 660 ppm carbon concentration (EPA, 1989). Nordhaus (1991) uses the latter concept, and thus estimates zero mean impact. In contrast, Cline (1992a) sets expected damage at \$17.5 billion at 1990 prices, consistent with 440 ppm at $2\times\text{CO}_2$ -equivalent.

A study of the Missouri-Iowa-Nebraska-Kansas (MINK) area introduces the further influence of farmer adaptation (earlier planting, use of longer season varieties, changes in tillage to conserve water; see Easterling *et al.*, 1993; Rosenberg and Crosson, 1991a, b). Using actual climate conditions of the 1930s as an analog for a 2030s climate, the study finds that without carbon fertilization climate change cuts agricultural production in the area by 17.1%, but only 12.1% with on-farm adaptations. Adaptation thus reduces losses by about one third. If 100 ppm carbon fertilization is added as an offsetting factor, output is reduced by only 8.4%. This loss is cut further to 3.3% by adding the influence of adaptation. As regional temperatures were only about 1°C higher than today in the 1930s, and adjusting for commensurate carbon fertilization, the MINK results suggest losses on the order of 10% for benchmark $2\times\text{CO}_2$ warming, even with farmer adaptation.

In another study focusing on the USA, Mendelsohn *et al.* (1992) apply a completely different approach to estimate agricultural impact. They argue that the production function method of crop models inadequately captures induced producer responses. Instead, they suggest that existing cross-section data across different climatic regions can provide a better guide to total effects incorporating these responses. For this purpose, they use county-level US data to regress farmland values on climate and a number of other relevant variables. They then simulate the impact on aggregate US agriculture of global warming causing a rise of 2.8°C (5°F) in mean temperature and 8% in rainfall. Under these assumptions, US agriculture

experiences losses of \$6 billion to \$8 billion annually if county results are weighted by shares in cropland area, but -\$0.7 billion to +\$2 billion if the weights are shares in crop revenue (which gives much more weight to irrigated lands of the West and South).

The study is partial-equilibrium in nature, and does not incorporate the effect of changing relative prices. As a result, it tends to overstate the scope for shifting from temperate to warm, dry-climate products. Applying IPCC (1990a) regional warming coefficients, US warming should amount to 3.9°C (rather 2.8°C) for global mean warming of 2.5°C. In addition, the authors apply a global mean precipitation increase larger than that implied by e.g. the GCMs results summarized in IPCC (1990a). Waggoner *et al.* (1992) further stress that shortages of irrigation water are likely to become a problem for US agriculture even without global warming. For these reasons, the Mendelsohn *et al.* study may understate damage for US agriculture.

3.2.2 Sea Level Rise

IPCC (1990a) estimated that under business as usual, realized global warming above preindustrial levels would amount to 4.2°C by the year 2100 and that the corresponding sea level rise would reach 66 cm. In a model incorporating biosphere feedback (carbon fertilization), stratospheric ozone depletion, and sulphate aerosol screening, Wigley and Raper (1992) used the subsequent 1992 updated emissions projections of the IPCC to calculate that as a best guess, realized warming from a 1990 (not preindustrial) base would amount to 2.5°C (rather than 3.3°C) and sea level rise by 2100 would reach 48 cm (rather than 66 cm).

Both the original and updated IPCC-based estimates understate the equilibrium impact of sea level rise. Unlike other damage categories, for sea level the equilibrium effects are far greater and take much longer to occur than the point estimates corresponding to the first year the equilibrium warming is realized. For a discrete warming shock, the sea level continues to rise for up to 500 years (Titus, 1992; Manabe and Stouffer, 1993). A somewhat clumsy compromise to telescope this growing long-term effect into a point estimate is to use a benchmark of usually 1 metre sea level rise, even though realized increases by 2100 are estimated to be lower.

The costs of sea level rise divide into three types: capital costs of protective constructions, the recurrent annual cost of foregone land services, and the costs associated with increased flood frequencies.

Protection Costs: In its 1989 report to Congress, the US EPA estimated that for the United States, a 1 metre rise in sea level by the year 2100 would require \$73 billion to \$111 billion cumulative capital costs to protect developed areas through the building of bulkheads and levees, pumping sand, and raising barrier islands (EPA, 1989). Assuming that capital costs would be spread over a 100-year period, Cline (1992a) estimated costs in the order of \$1.2 billion for capital construction. Gleick and Maurer (1990) estimate capital construction and maintenance costs for protecting the San Francisco bay from 1 metre rise at \$200 million annually, or a sixth of the US total estimated in Cline (1992a), suggesting the latter may be an underestimate. Fankhauser (1994a) estimated annuitised costs of coastal protection against a 50 cm rise in the order of \$1 billion worldwide, with about half of it occurring in non-OECD countries.

Land Loss: The EPA (1989) report estimated that under a 1 metre rise scenario unprotected dry land amounting to 6,650 square miles would be lost in the US, and 49% of today's 13,000 square miles of wetlands would be lost (Titus *et al.*, 1992). Titus *et al.* (1992) indicate that wetlands preservation programs typically cost up to \$30,000 per acre. Using a more conservative \$10,000 capital cost per acre of wetlands, placing coastal drylands value at \$4,000 per acre, and applying a rental opportunity cost of 10%, Cline (1992a) estimates the annual US losses from a 1 metre rise at \$4.1 billion for wetlands and \$1.7 billion for dryland.

Assuming only a 50cm rise in sea levels, but doubling wetland costs to \$20,000 per acre, at least in developed countries, Fankhauser (1994a) obtains a cost estimate of \$45.6 billion annually for foregone land services worldwide. With over 85% of coastal wetland loss occurring in developing countries, low income regions are by far the most heavily affected areas. For the OECD (excluding Canada, Australia and New Zealand) Rijsberman (1991) estimates a loss of coastal wetlands in the order of 48,000 - 64,000 km² for a 1 metre rise, more than 50% of the remaining habitats. In comparison, Fankhauser (1994a) assumes a 33%

loss under a 50cm rise).

Sea Surges: A 1 metre rise in sea levels could increase the number of people subject to annual flooding by about 20%, according to estimates by IPCC (1994). Particularly at risk would be coastlines along the Indian Ocean, in the South Mediterranean and in Africa, as well as small island states. A number of case studies exist which identify the impact of sea level rise on sea surges in the USA (see Titus, 1987). The annual average damages in Charleston, South Carolina, could double due to an 88 cm sea level rise; the damages of a 100 year storm in Galveston, Texas, could triple (Note that cost-effective protection measures can mitigate this loss). US FEMA-FIA (1991) estimates that the area inundated by a 100-year flood will increase from 19,500 square miles to 23,000 and 27,000 square miles for a 1-foot and 3-foot sea level rise, respectively, by the year 2100. The region most significantly affected would be the Louisiana coast. The expected annual flood damage in the year 2100 increases by 36-58% (\$150 million) for a 1-foot rise and by 102-200% (\$600 million) for a 3-foot rise in sea level. For the European Union, CRU/ERL (1992) calculate that the consideration of periodic flooding would increase the costs of sea level rise by as much as a factor 2.7.

3.2.3 Forests

Global warming is expected to cause a poleward migration of forests, and change in their composition. Sedjo and Solomon (1989) use the Holdridge Life Zone classification system together with GCM projections of changed climate by grid area to calculate that the steady-state effect of $2\times\text{CO}_2$ warming would be to reduce boreal forests by 40% and temperate forests by 1.3% in biomass, but increase tropical forests by 12%. The net change would amount to a decline of 3.7% globally in biomass, and 5.8% in area. Based on these figures, Fankhauser (1994a) has estimated annual forestry damages of \$1.8 billion in OECD countries and \$2 billion worldwide, using forest values of 2,000, 400 and 200 \$/km², respectively, for high, middle and low income countries. Because of the positive impact on tropical forests and the use of higher forest values in developed nations, most forestry damage occurs in OECD countries.

Compared to the equilibrium estimates of Sedjo and Solomon, transient effects over as much

as three centuries would be much more severe. Whereas the latitudinal borders of potential location for given species would migrate poleward by 600 to 1,000 km over the next century, the actual migration pace could be as low as 100 km (EPA, 1989). Dieback along low-latitude boundaries would thus exceed additional growth on the poleward boundaries. Over the next 100 years US forests could lose 23% - 54% of standing biomass in the Great Lakes region and 40% in the West.

On this basis, Cline (1992a) estimates a loss of 40% for US forests. Estimating the value of annual wood extraction at \$10 billion, and allowing for some limitation of losses through reforestation, he estimates net US forest loss from benchmark $2\times\text{CO}_2$ warming at \$3.3 billion annually over the relevant horizon, solely for commercial wood products.

Titus (1992) places US forest damages an order of magnitude higher, at \$44 billion annually (central estimate). He estimates a median percentage biomass loss of 34% in the 30 states he examines. His much higher damage estimates thus stem not from greater biomass loss but from a higher valuation of unit forest area. Using a comprehensive measure that includes recreation and other value, Titus values forested area at \$45 to \$150 per acre per year of forest (above raw land value). The Titus estimates would make US forest loss the largest damage category. At the other extreme, Nordhaus (1991) judges that forest losses would be "small". The range of estimates thus suggests especially large uncertainty for estimates in this category.

3.2.4 Water Supply

Warming is expected to put stress on water supply. A smaller share of precipitation in the form of snow, combined with earlier snow-melt, would mean higher run-off in the winter. Run-off in the spring and summer would correspondingly be reduced. In those areas and/or periods where precipitation declines, the combination of higher evaporation (from warmer temperatures) and lower precipitation would reduce soil moisture and water levels and flows. At the same time, the demand for water would tend to rise with warming, because of increased needs for irrigation and for cooling in electric power production (EPA, 1989).

The IPCC stresses that river basin run-off is very sensitive to small variations in climatic

conditions, because run-off is a residual between precipitation and soil absorption or evaporation; and small changes on any of the underlying variables can cause a much larger proportionate impact on this residual. For the United States, water basin simulation models show that in a warmer, drier climate (+2°C, -10% precipitation), water supply in 18 major water regions covering the bulk of national supply would decline by approximately one-third (calculated from IPCC, 1990b).

For the US, the EPA (1989) predicts that 2xCO₂ warming would reduce annual water deliveries in California's central valley basin by 7% - 16%, even as demand for water rises by about 50% as early as 2010. For the Sacramento basin, Gleick (1987) estimates that a 4°C increase in temperature would decrease summer run-off by 55% even if there were a 10% rise in precipitation. For the Boston area, Kirshen and Fennessey (1992) apply water balance models to GCM projections for benchmark warming and find that reliable water yields of existing water systems could fall by as much as one-third (GISS, GFDL), but could also rise (UKMO, OSU), because some models predict falling precipitation and others rising. If zero change in precipitation is imposed, the mean model estimate is a decline of 18% in reliable water yield.

Cline (1992a) sets 10% as a central estimate for water supply reduction in the United States from benchmark warming. He estimates national annual withdrawals at 0.4 billion acre-feet, and unit price at \$250 per acre foot. The resulting estimate of annual damage is \$7 billion. Titus (1992) uses a larger volume impact, but lower unit prices to reach a central estimate of \$11.4 billion annual losses. For the European Union CRU/ERL (1992) estimate that the costs of reduced water run-off would amount to ECU 5.8 billion for 1°C warming and 18.8 billion for 4°C.

Fankhauser (1994a) uses a somewhat lower percentage volume loss than the US studies, but, at least for OECD countries, a unit price more than twice as high as Cline's. He estimates annual losses at \$34.8 billion for the OECD, and \$46.7 billion worldwide. Again, the high share of OECD damages is due to differences in valuation between regions. In physical units about three quarters of water losses occur in non-OECD countries (see Table 3.5).

In all cases, more efficient water allocation with less low-priced water allocated to agriculture and more to urban use could attenuate losses in water supply, but would aggravate prospective agricultural output losses. At the same time, Gleick (1992) and Homer-Dixon *et al.* (1993) have emphasized another dimension of water supply effects: the potential for political conflict, such as the dispute over the Jordan river basin that contributed to the 1967 war in the Middle East. From this standpoint associated damages might appropriately include higher defense costs, in terms of economic reckoning, or perhaps more appropriately some unquantified social cost of increased probability of regional wars.

3.2.5 Space Cooling and Heating

Global warming would impose higher air conditioning (space cooling) costs, but reduce heating costs. For space cooling costs in Japan, Nishioka *et al.* (1993) report estimates of a 2% increase in electricity demand per °C warming for temperatures between 24-30°C, and 1% increase for temperatures between 17-24°C. No significant change in demand was found for temperatures above 30°C.

On the basis of detailed energy projections, the US EPA (1989) has estimated that with warming of 3.7°C by 2055, there would be a net increase in US electricity demand by about one-fifth above baseline, requiring additional annual operating costs of \$53 billion and cumulative capital cost increases of \$224 billion. Scaling back these estimates for consistency with present-day economic size and for warming of only 2.5°C, Cline (1992a) estimates annualized damages of \$11.2 billion from higher net electricity requirements under benchmark warming. Arguably, this estimate is understated, because with global mean warming of 2.5°C, US warming would amount to 3.9°C, based on IPCC regional warming coefficients. Titus (1992) uses the same underlying study to reach a central estimate of \$5.6 billion.

More informally-based estimates of the corresponding savings on space heating are considerably lower, in the range of \$1 billion annually (Nordhaus, 1991; Cline, 1992a). Detailed work by Loveland and Brown (1992) confirms that prospective global warming is likely to increase energy requirements for air conditioning by more than it reduces energy needed for heating. A major reason is that cooling is by electricity, which is much more

expensive per BTU than oil or gas (the dominant heating fuels; Titus, 1992). Taking into account anticipated baseline building standards by 2040, Loveland and Brown (1992) estimate that 2xCO₂ warming would raise cooling demands by 35 to 75% for most US areas, and increase peak loads by 6% - 12%. Cline (1993e) applies the Loveland-Brown data to estimate that the weighted average of energy requirements amount to 16 Btu per square foot per degree day for cooling and only 2.6 Btu for heating. As a result, net damages would result from global warming even though in an initial phase warming would actually move average US temperatures closer to 65°F and thus could reduce unweighted degree-days of climatization⁷.

Extrapolating the same US EPA data to other geopolitical regions, Fankhauser (1994a) assumed an increase in electricity demand of 3.2% in all regions considered, except for the former Soviet Union, where electricity demand is assumed to decrease by 1%. This resulted in increased space cooling costs of about \$20 billion in the countries of the OECD and \$23 billion worldwide.

Based on estimated changes in heating and cooling degree days, CRU/ERL (1992) calculated significant benefits from reduced heating expenses in the European Union. Gains in Northern Europe are only partly offset by increased costs in Portugal, Spain and Greece. A 1°C rise in temperature would yield net benefits in the order of ECU 13 billion. For 3°C warming the figure would rise to about ECU 32 billion. These rather optimistic results appear to be mainly due to the dominance of heating over cooling degree days in the baseline case without warming.

3.2.6 Insurance

The insurance industry protects other economic sectors from the financial consequences of unexpected or uncertain events, including weather extremes. As such, it is highly exposed to changes in these extremes and thus to climate change.

⁷ Extrapolating from the Loveland-Brown data and weighting by population, there are currently 5,000 degree-days (DD) of heating and only 1,000 DD of cooling; and benchmark warming would reduce heating requirements by 2,000 DD while raising cooling requirements by 1,000 DD (Cline, 1993e).

The basic function of insurance is to transfer financial risk from an individual to a group, i.e. to spread a specific individual loss over everybody potentially affected. In the case of hazards affecting entire regions the risk is spread, through reinsurance, over several regions. In many countries, the risk related to weather hazards is partly transferred to the government. Claims are paid from the central pot, and, if the event is declared a disaster, the excess damage is covered by the government. The insurance contract determines, besides the premium, exclusions of particular events or property and limitations of the amount to be paid. While flood coverage varies from country to country, storm damage is generally covered. Other extremes are often covered through their indirect consequences.

The present capacity of natural hazard insurance is about \$100 billion. For comparison, in 1992 hurricane Andrew alone caused an economic damage of \$30 billion, about half of which was insured (Dlugolecki *et al.*, 1994, 1995).

Since 1987, after a relatively quiet period of about 20 years, the insurance industry has been confronted with a large number of major weather related catastrophes, i.e. events which involved insured losses of over \$1 billion. This increase was caused by a variety of reasons, including population growth, increased standards of living, concentration of people and capital in large conurbations, the development of extremely exposed areas, and environmental changes. Although there is no clear connection to the enhanced greenhouse effect, the reaction of the sector is illustrative of what would happen if climate change were to lead to an increase in the number and intensity of extreme weather events (Berz and Conrad, 1993; Dlugolecki *et al.*, 1994, 1995; Leggett, 1993; Tol *et al.*, 1994).

At a first instance premiums were increased and cover was restricted. In some areas, such as the Caribbean and the Pacific, insurance and reinsurance supply was temporarily withdrawn after a sequence of hurricanes in the late 1980s and early 1990s. As a further reaction, the insurance sector is currently also considering (Dlugolecki *et al.*, 1994, 1995; Tol *et al.*, 1994)

- (a) alterations in the price determination, incorporating more knowledge on the actual risk (so far, prices have primarily been determined by competition and recent claims),

- (b) changing the product, limiting the insurer's exposure
- (c) extending the available funds through further pooling and accumulation. This may require alterations of existing fiscal and institutional regulations.
- (d) risk management, i.e. getting involved in restricting the damage caused by weather events.
- (e) lobbying for, and investing in environmentally sound policies and projects.

While a number of these points help in reducing the overall exposure to weather hazards, many merely affect the exposure of the insurance sector itself. Only limiting the insurers' exposure obviously leads to an expansion of the exposure to others. Little research has been done to assess the consequences of such a policy on households, industry and government.

3.2.7 Other Market Sectors

Construction: Nordhaus (1991) suggests that the construction sector in temperate climates would be "favourably affected" by global warming because of a "longer period of warm weather." However, although construction is adversely affected by frost, it is also inhibited by rainfall, and GCMs typically predict an increase in global mean precipitation by about 8% as the consequence of benchmark 2xCO₂ warming (IPCC, 1990a). Solomou (1990) has examined data on construction and rainfall in the period 1856-1913 and found a close negative correlation between the two. The IPCC similarly notes adverse effect of rainfall on industry more generally, and cites Parry and Read to the effect that "rainfall is responsible for more delays than any other climatic variable" for UK industry (IPCC, 1990b, p. 5-23). However, estimates are not available on the net effects of warming and increased precipitation on construction or industry more generally.

Tourism and Leisure Activities: Studies by the Canadian Climate Program Board suggest that as a consequence of a shortened period of snow cover Quebec could lose 40 to 70% of skiable days. In Ontario, the shorter skiing season may cause a loss of up to \$50 million in revenue (Canadian Climate Program Board, 1988a, b). Losses would presumably be larger

in relative terms in US ski areas, where the temperature base is already higher. Annual US ski activity amounts to an estimated \$5.6 billion and 53 million skier visits (Waters, 1990). Assuming a 60% reduction from benchmark warming, and allowing for released productive labour and capital, Cline (1992a) estimates ski industry losses at \$1.7 billion annually.

The tourist industry will also be affected by beach washing and the inundation of beaches (Baan *et al.* 1993), as well as likely coral reef death and other ecosystems loss (EPA, 1989)^a. These impacts could be particularly significant for small island states, where tourism often accounts for more than a third of GDP (see Turner *et al.*, 1994).

On the other hand, there could be gains from global warming in other leisure sectors such as camping, boating and sunbathing. The Ontario case study, for example, predicts and increase in the camping season of up to 40 days in some areas (Canadian Climate Program Board, 1988b). In many regions, however, an increase in summer activities could be hampered by increased rainfall. CRU/ERL (1992) have developed a "comfort index", using temperature, sunshine and rainfall as indicators of the suitability of climates for leisure activities. Using this index and figures on current European tourist revenues they estimate that 1°C warming could benefit tourism in the EU by about ECU 4.7 billion. As temperature rises, the impact value at least in Southern Europe soon becomes negative, though.

Urban Infrastructure: The EPA (1989) has examined the impact of global warming on urban infrastructure costs. For coastal cities, sea level rise or more frequent droughts would increase the salinity of coastal aquifers and tidal surface waters, requiring a response where these are the sources of metropolitan water supply. In addition, more frequent and intense storms would likely overload existing storm sewer systems. On a basis of EPA studies for New Orleans, New York, Philadelphia, and Miami, Cline (1992a) suggests that annualized damages of benchmark warming for US urban infrastructure could amount to \$100 million yearly.

^a Some of these impacts may, as forgone use value, be included in estimates for ecosystems loss (see section 3.2.13).

3.2.8 Health

There is a U-shaped relationship between mortality and outdoor air temperature. Death rates increase as a consequence of both heat waves and very cold weather. The lowest mortality rates are found at temperature levels of about 16-25°C (Kunst *et al.*, 1993; Haines and Parry, 1993). Global warming could lead to an increase of heat related deaths from coronary disease and stroke which is likely to more than offset the reduction in winter mortality. Air pollution increases the occurrence of respiratory diseases (emphysema and asthma), and longer, warmer summers are expected to increase the severity of air pollution.

In addition to directly heat related health effects, there could be indirect losses from increased vector-borne diseases (e.g. carried by ticks and mosquitoes). The risk areas of diseases like malaria or yellow fever may shift as their vectors adjust to new climate conditions (Haines and Parry, 1993). WHO (1990), for example, suggests that the so far disease-free highlands of Ethiopia, Indonesia and Kenya might be invaded by vectors. There would be a general migration of the carriers. Vector-borne diseases may therefore also spread into developed countries. Hohmeyer and Gärtner (1992) estimate that under 2xCO₂ an extra 200 million people could be exposed to malaria. Simulations for the United States on a possible increase of malaria are however inconclusive (EPA, 1989).

Kunst *et al.* (1993) have analysed the statistical relationship between mortality and air temperature in the Netherlands. They found that a 30 days increase in air temperature of 1°C above its ideal level would lead to a rise in mortality of 1.1 - 1.9%. A 1°C drop from the optimum would cause a slightly lower rise of about 0.8 - 1.3%. For the UK Langford and Bentham (1993) estimate that the higher temperatures predicted for 2050 (about 2.5°C) could result in some 9000 fewer winter deaths per year. Kalkstein has used statistical methods to analyse the mortality impact of changed weather conditions under 2xCO₂ for 15 major US cities (EPA, 1989; Kalkstein, 1989). Even after accounting for induced acclimatization (based on mortality statistics for control cities with comparable present climate conditions), he finds that increased summer deaths substantially exceed decreased winter deaths. Cline (1992a) and Fankhauser (1994a) weight these results by population and extrapolate that benchmark warming would increase mortality by about 27-40 persons per million population, depending on the warming scenario. Without acclimatization this figure would be about six times

higher. For the United States the more conservative figure including acclimatization translates into 6,600 to 9,800 additional deaths annually at present US population scale.

On a global scale, mortality effects could be particularly damaging in the more vulnerable countries of the developing world. In Shanghai, for example, death rates from heat stress are currently over twice those in New York City (Haines and Parry, 1993). Health problems associated with hot spells are also significant in Bangladesh (Asaduzzaman, personal communication, 1994). Using uniform mortality rates, Fankhauser estimates that about 115,000 casualties will occur in non-OECD countries, compared to some 23,000 in the OECD (for 2.5°C warming, see Table 3.5). Tol (1994b), using the same estimates but without scaling to 2.5°C warming, arrives at a figure of 215,000 casualties worldwide.

Expressing the value of this loss in monetary terms is controversial (see Box 3.1). Cline (1992a) uses lifetime earnings to place life valuation at a conservative \$595,000 and reaches a corresponding estimate of \$5.8 billion in annual US losses from benchmark warming. Titus (1992) applies the same underlying Kalkstein estimates, but uses different values of a "statistical life". For his central scenario he obtains annual damages of \$9.4 billion for the US. Fankhauser uses value-of-life estimates of \$0.1 to 1.5 million, depending on regional income levels, and obtains mortality damages of \$10 billion in the US, \$34 billion for the OECD and \$49 billion worldwide. If an identical value of \$1 million were used worldwide this latter figure would explode to almost \$140 billion. Tol (1994b) uses a still higher value of \$3.4 million for the US, but again differentiates between regions⁹. With worldwide mortality costs of \$188 billion health damages account for more than half of his total estimate.

[Box 3.1]

3.2.9 Air Pollution

A warmer climate would aggravate urban pollution. In the United States, tropospheric ozone is the most severe problem in terms of the number of persons living in areas with air quality

⁹ He assesses a statistical life at \$250,000 + 175*(income per capita).

indexes that violate national standards (75 million persons in 1986). Total suspended particulates (TSP) and carbon monoxide are also important (41 million each). Ozone has proven the most difficult to reduce. Its concentrations declined only 13% from 1979 to 1986, compared with reductions of 23% for TSP and 37% for SO₂ (EPA, 1989).

Numerous studies confirm that ozone concentrations rise with temperature (see e.g. IPCC, 1990b). The US EPA has summarized various US estimates with the conclusion that a 4°C rise in temperature (about what could be expected for the United States under 2.5°C global mean warming) could cause an increase in peak ozone concentrations by 10%. The result would be to double the number of cities in violation of the air quality standards from 68 to 136, causing most midsize and some small cities in the Midwest, South, and East to be added to the list of those presently in violation.

The EPA has applied its past models relating ozone concentrations to emissions of volatile organic compounds (VOC) to estimate that, to offset benchmark 2xCO₂ warming, it would be necessary to reduce VOC in the United States by 700,000 tons from a year-2000 expected base of 6 million tons. At an estimated cost of \$5,000 per ton, the agency calculates that the resulting costs would amount to \$3.5 billion annually (EPA, 1989). Cline (1992a) uses this figure as an estimate of US air pollution damage to be expected from benchmark warming, and compares it to an estimate of \$60 billion for existing annual spending on air pollution abatement¹⁰.

Titus (1992) estimates US tropospheric ozone damage from benchmark warming at \$27.2 billion annually. This is almost an order of magnitude higher, although he too bases his estimate on the EPA analysis. The difference appears to be that Titus projects a high baseline of VOC (volatile organic compound) emissions, at 3% growth and reaching an implied 70 million tons by 2060, whereas the EPA estimate is based on the present scale of emissions. Although some allowance for growth in the base is appropriate, it seems unlikely that the

¹⁰ Warming could also increase the incidence of acid rain, because of consequential increases in concentrations of the precursor hydrogen peroxide and because of increased power generation to meet air conditioning demands. A 10% rise in electric power demand would mean a 30% rise in SO₂ emissions (IPCC, 1990b).

pollution baseline would grow faster than GDP and energy output.

Instead of calculating the additional expenditures needed to maintain present air quality standards, Fankhauser (1994a) estimates the extra damage occurring if air quality standards were allowed to deteriorate. Assuming increases in NO_x and SO₂ emissions of 5.5% and 2%, respectively he estimated additional air pollution damages of \$12 billion in the OECD, and \$15 billion worldwide (see also the cost of air pollution estimates provided in Table 3.13).

3.2.10 Water Pollution

Titus (1992) and Nishioka *et al.* (1993) have identified water pollution as a category with potentially large damages from global warming. They predict a likely decline in river flow under global warming because of lesser water run-off. Because rivers serve to carry away waste, lesser river flow leaves more waste to be removed by emissions controls. Nishioka *et al.* also discuss a possible decrease in the water quality of lakes through increased algae growth.

In assessing the impact of water pollution on the US Titus assumes that the discharge of pollutants would change by the same proportion as river flow. He cites EPA estimates to establish a base of \$64 billion for US water pollution control costs in the year 2000 (at constant 1990 prices). Based on estimates by Waggoner and Revelle, he calculates that run-off declines by 2% - 4% if either precipitation decreases 1% or temperature increases by 0.4°C. Setting the elasticity of control costs (percent change for a one percent change river flow) at 1 to 1.7, Titus calculates that water pollution control costs imposed on the United States by benchmark global warming would be in a range of \$15 billion to \$67 billion annually, with a central estimate of \$34 billion. Like Titus' estimate for forest damage, this estimate dwarfs typical damage calculations for most other individual categories. Yet water pollution is one of the most under-researched aspects of economic damage.

3.2.11 Migration

Global warming could increase the displacement of people because of coastal inundation from sea level rise, increased droughts (e.g. from Mexico to the United States), and possibly increased tropical cyclones (e.g. from the Caribbean to the United States). Schelling (1983)

views migration as an efficient adaptive response to global warming. However, presumably a cost should be imputed to the utility loss by families compelled to migrate (Jansen, 1993). Indeed, historically peoples have often fought wars to avoid being forced to leave their homelands. Tol (1994b) arbitrarily puts this loss at three times the average income per capita in the region of departure, this is reflected in Table 3.6. There is also a cost to the recipient host country. In many countries, e.g. in Europe and the United States, the costs of incorporating immigrants into the social welfare infrastructure are already a politically sensitive source of social and budgetary pressure.

Cline (1992a) reports estimates of 640,000 legal immigrants into the United States annually in recent years, in addition to perhaps 130,000 illegal immigrants (Goering, 1990). He hypothesizes an increase of 25% in illegal immigration and 10% in legal immigration as a consequence of benchmark warming. Based on total per capita spending by state and local governments, and assuming 18 months before an immigrant's tax payments cover the family's social infrastructure costs, Cline estimates costs at \$4,500 per immigrant; Ayres and Walter (1991) similarly cite a figure of \$4,000 per refugee accepted by the United States. Cline (1992a) estimates annual immigration costs to the United States from $2xCO_2$ warming at \$450 million. The hardship and stress suffered by refugees remains uncounted, though.

Fankhauser (1994a) has extended the Cline estimates to the world as a whole, assuming that current migration patterns will hold (see Table 3.5).

3.2.12 Human Amenity

Mearns *et al.* (1984) use statistical distributions of current temperatures to explore the impact of global warming on extreme temperature events for the United States. In their base case, they increase mean temperature by 3°F (1.7°C) and hold the variance and autocorrelation of daily temperatures constant. Under these assumptions, they calculate that the frequency of heat waves (defined as 5 consecutive days with maximum temperature at least 95°F) would multiply three-fold (estimated for Des Moines, Iowa). There is reason to believe that people would be willing to pay something to avoid a threefold increase in the incidence of heat waves. At the same time, global warming would reduce disamenity of severe winters in colder areas. The net balance under benchmark warming is unclear. As suggested below,

however, for much higher warming over the very-long term, the amenity damages would be more likely to dominate.

Cline (1992a) provides an order of magnitude estimate of the value of the disamenity caused by a sharp increase in the number of hot spells in the USA; assuming that people are willing to pay 0.25% of their income to avoid this and other disamenities, a \$10 billion loss per year results¹¹.

Leary (1994) has surveyed the available empirical evidence on the implicit valuation of local climatic variation in the USA. The results of this study are:

- (a) that individuals value changes in climate and are willing to accept lower wages, or pay more for property, in return for an improved local climate. Some migratory patterns are explained by climate differences.
- (b) in the USA these values appear to be substantial, ranging from hundreds to thousands of US dollars.
- (c) households prefer sunny, mild climates. Increases in winter temperature and the number of sunny days are favoured, while higher summer temperatures deter migrants, so that hot summers appear to be a disamenity.

While these findings are intuitively appealing, characterisation of "climate preferences" is not, however, robust across the studies evaluated and it is not possible therefore to say whether climate change will, on balance, increase or decrease climate amenity. As with other aspects of the economics of climate change, these results are relevant only to the USA and, perhaps, other industrialised temperate zones where housing and labour markets respond to differentials in housing and work characteristics.

Amenity effects would vary by region, tending toward damages in presently warm areas and

¹¹ As the estimate is purely speculative, it is excluded in the central estimates of that study, and from Table 3.4 below.

gains in presently cold areas. Potentially amenity valuations could be large in absolute terms, because they apply to the entire income base of the population. However, the tendency toward neutralization of differential effects among geographic regions and between seasons would tend to reduce the overall magnitude of amenity effects.

3.2.13 Ecosystems and Biodiversity Loss

Perhaps the category in which losses from global warming could be among the largest, yet where past research has been the most limited, is that of species loss. There is a serious need for conceptual and quantitative work in this area.

The EPA (1989) has noted in general terms the risk of increased species extinction from global warming, because of changes in habitat, predator/prey relationships, and physiological changes. It cites the poleward migration of forests as a major reason to expect stress on species, especially in view of natural and manmade barriers to animal migration. Another category of likely species loss is that of coral reefs, as suggested by recent instances of coral death from El Niño warming (Glynn and de Weerd, 1991).

Economists identify three types of species value: direct and indirect use value (e.g. plant inputs into medicine and the role of forests in protecting watersheds, respectively); option value (preserving a species to retain the possibility that it may be of economic use in the future); and existence value (like the value society places on a rare work of art). Table 3.2 (based on Pearce, 1993) summarises the results of "contingent valuation" sample survey estimates of what the public would be willing to pay to preserve an endangered *animal species*. Average values range from \$1 - \$18 per person per year for preservation of an individual species, with a maximum of \$40 to \$64 obtained for humpback whales. The willingness to pay figure for the preservation of entire *habitats* is somewhat higher, with a range of \$9 - \$107 per person and year.

[Table 3.2]

The economic value of *plants* is dominated by their potential significance for medicinal purposes. Pearce (1993) notes that in the United States about 40 plant species accounted for

plant-based prescription sales of some \$15 - 20 billion/year during the 1980s (at 1990 prices). This would imply an economic value of at least \$300 million per successful species and year. The figure could rise up to several billion dollars if values were calculated on the basis of deaths avoided using statistical life valuation. These are averages and some species are clearly more valuable than others. Nevertheless, the figures can provide some indication of the lost pharmaceutical value from disappearing species. Some 60,000 plant species are expected to become extinct over the next 50 years. Given that the probability of a plant species yielding a successful drug is between 1:10,000 and 1:1,000, between 6 and 60 plant species with potential drug value could thereby be lost. With a mean loss of 30 such species, and applying the price range just noted, Pearce (1993) calculates that the annual losses for the United States could amount to between \$8.8 billion and \$180 billion (assuming there are no synthetic substitutes). By implication, if global warming were to increase these expected losses by just 10%, plant species alone could cause annual US losses from global warming on the order of \$1 billion to \$18 billion.

Fankhauser (1994a) cites the Pearce (1993) survey (see Table 3.2) to arrive at a willingness to pay estimate of \$30 per person per year to avoid species and habitat loss from global warming. This amounts to a total of \$40 billion annually, with about one third occurring in developing countries (Fankhauser again uses lower value estimates for low-income regions). As \$30 per person is about the median value for one habitat or a prominent endangered species, implicitly Fankhauser places the probability of extinction attributable to global warming at $1/n$, where "n" is the number of such habitats. A statistic by World Resources Institute (WRI, 1990) gives a rough indication about the size of this implicit probability. It reports a total of about 5000 protected parks and wildlife areas worldwide. Assuming that each person has a positive willingness to pay for one hundredth of these areas¹², the probability of climate induced habitat loss would be about 2%, probably a rather conservative value.

Using a totally different methodology, Cline (1992a) arrives at an estimate of about \$4 billion annually as a notional value of species loss from benchmark global warming for the US, and

¹² It is unreasonable to assume that all people have a positive willingness to pay for all habitats. They will have a preference for unique sites or those in their neighbourhood.

suggests that the figure could as easily be an order of magnitude higher (\$40 billion). The estimate is based on an extrapolation of observed US public expenditures for the preservation of one particular species (the spotted owl).

3.2.14 Extreme Weather Events

Along with changes in the mean climate, changes in the extremes can be expected. Changes in the extreme values of meteorological variables are not necessarily proportional to changes in the mean; if, for instance, mean precipitation shifts upwards while at the same time the variability increases, the number of droughts might remain roughly the same whereas the number of floods rises drastically (Graßl *et al.*, 1995). Also, extremes are of more importance in studying the socio-economic impacts of climate change. Most societies, in accommodating to the environment they live in, have developed strategies to cope with only a limited range of climatic events. Within this range, the 'normal' variability is regarded as a resource while the extremes constitute hazards (Heathcote, 1985). All kinds of adaptation mechanisms, such as insurance, exist to deal with these extremes. However, adaptation is costly, and therefore limited. Prevention is only to a certain extent better than cure.

Measures to adapt to natural hazards comprise a mix of physical, economics, and societal features. At the physical level, there is the design of buildings and protection constructs, such as dikes. At the economics level, there are personal savings and insurance to cover the damage. At the societal level, there are social safety nets, charity, and the government. Different adaptation mechanisms exhibit different degrees of flexibility; an insurance policy is valid for one year, an average Dutch dike has a lifetime of about two centuries. Flexibility is enhanced as adaptation measures are under constant pressure of changes in population and industrialisation, and their densities, and the legal, economic, financial and social systems (Berz and Conrad, 1993). On top of that, climate constantly changes. The main difference between 'natural' changes and the enhanced greenhouse effect, however, is that the latter involves a prolonged tendency in one direction, uncertain in its magnitude and pace (Tol *et al.*, 1994).

It is clear from the above that the qualification 'extreme event' or 'disaster' is a social construct, which is hard to measure. The continuously changing mechanisms to cope with

natural disasters complicate this matter further. Also, while the direct impacts of natural disasters may be harmful, the event might set in motion a chain of beneficial changes, compensating for the initial losses. Finally, a disaster is not only local in a social and temporal sense but also in a spatial sense. The current generation of GCMs is not capable of reproducing present extremes very well, certainly not without spatial filtering, let alone capable of deriving changes in extremes due to the enhanced greenhouse effect (Graßl *et al.*, 1995).

Little systematic research into the impact of changes in extreme weather events has been performed. Most attention has been paid to tropical cyclones, the consequences on which appear to be one of the most controversial questions of climate change impact research.

Tropical Cyclones: On the basis of $2\times\text{CO}_2$ simulations with the GISS GCM, Hansen *et al.* (1989) conclude that global warming would bring "increased intensity" of "both ordinary thunderstorms and mesoscale tropical storms". Wendland (1977) has provided empirical support for the relationship of hurricanes to ocean surface temperatures. From monthly data for 1971-81, the frequency of hurricanes is closely related to the size of ocean area with temperature over 26.8°C , and the relationship is exponential. Similarly, Emanuel (1987) argues that tropical cyclones are "particularly sensitive to sea surface temperature".

Higher sea surface temperature causes a larger drop in barometric pressure. Applying a 2.3°C to 4.8°C range of GCM estimates for increased August temperatures in the tropics under $2\times\text{CO}_2$, Emanuel estimates that the destructive potential of hurricanes could rise by 40% - 50%. Houghton (1994) expects an increase in both the frequency and severity of tropical and other storms. Haarsma *et al.* (1993) report a 50% increase in the number of tropical disturbances under $2\times\text{CO}_2$. The maximum windspeed would increase by 20%. The Australian CSIRO 9 GCM also points at an increased cyclone activity, and shows that a threefold increase is not impossible (Ryan *et al.*, 1992). Other results, on the other hand, give a less clear cut picture (see e.g. Broccoli and Manabe, 1990; Mauder, 1994; Raper, 1993). Idso *et al.* (1990), for example, argue that tropical sea surface temperatures would increase very little with global warming while the tropical tropopause could become more stable, leading to less intense cyclones. IPCC (1990a) judges that the impact of global

warming on storm intensity is "ambiguous". Clearly, the controversy is not yet resolved.

The existing economic estimates tend to include increased hurricane damage as part of the damage to be expected from global warming (see Tables 3.4 to 3.6). Thus, Cline (1992a) reviews past hurricane damage for the United States, and applies the 50% increase implied by Emanuel to estimate that benchmark warming would impose average annual damages of \$750 million. Considering that the IPCC did not indicate any likelihood that tropical cyclones might decrease, the expected direction is an increase. Because the most recent hurricanes have imposed even larger damages than most of those surveyed below, a lower implicit probability to account for uncertainty, applied to a higher damage base, could still yield central damage estimates comparable to those reported here.

Worldwide, in an average year about 70 to 80 tropical cyclones are recorded, causing damages of about \$ 1.5 billion, with a death toll of 15,000 to 23,000 lives (Smith, 1992; Bryant, 1991). The occurrence of cyclones is distributed unevenly over the globe. Northern regions like the former Soviet Union and Europe, for example, are only marginally affected. Based on the natural hazard map of Berz (1990), Fankhauser (1994a) has estimated that the United States is affected by 6.6% of all cyclones, while some 7.2% occur in China and 28.9% in OECD nations (Australia, Japan, New Zealand and the US). Combining this distributional pattern with the Smith/Bryant figures and the Emanuel estimate, Fankhauser (1994a) arrives at an additional 8,000 cyclone casualties, practically all in developing countries, and \$630 million additional damages due to $2\times\text{CO}_2$. Using the same value-of-life estimates as for health damages total worldwide hurricane damages amount to about \$2.7 billion.

These average figures are overshadowed, however, by the disastrous consequences of individual events, with poorer countries being particularly vulnerable (see Box 3.3). In 1970 a cyclone caused more than 500,000 deaths in what is now Bangladesh. In 1985 a similar disaster in the same region killed another 100,000 people (Bryant, 1991). The \$2.7 billion figure may therefore underestimate the true costs.

Extra-Tropical Storms: Dlugolecki *et al.* (1994, see also Munich Re, 1993) report worldwide

losses due to major windstorm events to have averaged \$2.0, \$2.9, and \$3.4 billion (1990 prices) for the 1960s, 1970s, and 1980s, respectively. For 1990-1992 this figure has risen to \$20.2 billion. The larger part of these damages is due to tropical cyclones, however. The 1990 storms in Europe (Daria, Herta, Vivian and Wiebke) resulted in a total loss of DM 25.3 billion (Munich Re, 1993). However, while storm damages have clearly increased over the last decades, it is not clear how much of this rise is attributable to global warming. The results of Changnon and Changnon (1992) and CATMAP (Clark, 1988; 1991) indicate that most of it is probably due to socio-economic development.

River Floods: Little information is currently available regarding the socio-economic impact of changes in the frequency and intensity of river floods (see Arnell and Dubourg, 1994).

Droughts: The impact of drought on agriculture has already been treated in section 3.2.1 on agriculture. As an alternative way to estimate agricultural damage, Cline (1992a) reports an annual loss imposed on US agriculture by increased drought of \$18 billion/year. Water supply in general is dealt with in Section 3.2.4. The effect of decreased water run-off is partly dealt with in the subsection on water pollution (3.2.10). A further impact of drought is land subsidence. The 1975-1976 drought in England and Wales, for example, led to a cost of £100 million to the insurance industry (Doornkamp, 1993). By 1979 the costs had amounted to £220 million.

Hot and cold spells: The impacts of hot and cold weather spells on human amenity and health were treated in the respective subsections above.

Total Losses: Table 3.3 (after Limbert, 1993) provides total fatalities attributed to weather events between 1989-1992 as reported for the six WMO regions. The average number of lives lost to natural hazards is more than 4,000 per year, with the highest proportion occurring in Asia. This is likely to be an underestimate, because some major events are not included. Again it is unclear which fraction of casualties has to be attributed to global warming, however.

[Table 3.3]

3.2.15 Damage Estimates: Summary

Tables 3.4 to 3.6 summarize the principal existing estimates of global warming damage for major regions of the world. In the United States, losses from benchmark $2\times\text{CO}_2$ equivalent warming reach over 1% of GDP in the Cline, Fankhauser and Tol compilations, and some 2.5% of GDP in the central Titus estimates¹³. Estimates for other OECD countries are mostly within the same order of magnitude of 1-2% of GDP (see Table 3.6).

Less comprehensive estimates by Nordhaus (1991), again for the US, arrive at a direct calculation of only 0.26% of GDP, primarily from sea level rise; but Nordhaus also sets 1% of GDP as a reasonable central estimate. The CRU/ERL (1992) estimates for the European Union, on the other hand, are significantly higher, with costs in the order of 1.6% of national income per degree of warming. The principal reason for this is a very high assessment of sea level rise damages. By augmenting sea level rise costs by a factor 2.7 to account for storm damages, the study may be a bit pessimistic. On the other hand, their assessment of non-sea level rise impacts appears rather optimistic, with an overall beneficial outcome in these categories.

[Table 3.4]

[Table 3.5]

With the possible exception of the Titus calculations and, for some categories, the CRU/ERL estimate, these damage figures seem likely to understate the true impacts, for two reasons. First, several effects were not fully quantified (e.g. non-tropical storms, droughts, morbidity, transport). These are probably predominantly harmful, with the possible exception of climate amenity values for some regions. Second, the figures are far from exact and one should allow for a considerable range of error. Many are deliberately kept conservative. Species loss valuation in particular could be far higher. It should also be emphasized that the estimates in Tables 3.4 to 3.6 refer to central warming expectations. The corresponding damages for upper-bound warming would be higher, and more than linearly so. Finally, when moving

¹³ Note that Titus specifies a lower and upper end of his range of estimates, at 0.8% and 5.4% of GDP, respectively. It should also be noted that the Titus estimates are based on GCMs with average warming parameters of about 4°C, higher than the IPCC's best guess of 2.5°C.

from the question of damage estimation to that of abatement benefits, a number of non-climate change related benefits will have to be taken into account (see Section 3.7).

Regional differences can be substantial, as is exemplified by the estimates for developing regions and the former USSR (see also Section 3.5). For the former Soviet Union damage could be as low as 0.7% of GNP or even negative (ie climate change is beneficial). The negative figure by Tol (1994b) mainly stems from large beneficial impacts in the agricultural sector. In the Fankhauser study, on the other hand, possible beneficial yield impacts are more than offset by the adverse impact of increased world prices on food imports. The region will also suffer from particularly high health and air pollution costs. The extremely high estimate for the Asian regions and Africa, on the other hand, are predominantly due to the severe life/morbidity impacts. As explained above, both the quantitative assessment and the underlying value-of-life estimates are very volatile, however, and the probability range of total damage is particularly wide for these regions.

Damage is likely to be more severe in developing countries, compared to developed countries like the US, as is shown in Table 3.6, and discussed in Box 3.3. Table 3.6 reports damages in non-OECD countries of about 1.6-2.7% of GDP, some 50% higher than the OECD average. The main causes for this high estimate are health impacts and the high portion of natural habitats and wetlands found in developing countries. Although the data for the non-OECD estimates are significantly weaker, they provide a clear indication that global warming will have its worst impacts in the developing world, with a damage of probably *at least* 2% of GNP for $2\times\text{CO}_2$.

[Table 3.6]

In general, the estimates in Tables 3.4 to 3.6 show a relatively narrow band for central damage calculations for the United States, and for developed countries in general. It is important to recognize, however, that this field of estimates is probably biased toward convergence. The reason is that, with the exception of CRU/ERL (1992), the underlying sources of many of the estimates are the same, particularly EPA (1989). The convergence tends to become extrapolated to other regions, too, considering that several of the

international estimates in Fankhauser (1994a) and Tol (1994b) are obtained by parametric extension from the US estimates. The similarity in of the estimates should therefore not necessarily be interpreted as evidence of their robustness. Nevertheless the relative ranking of regions appears to be reasonably robust, with the most severe impacts to be expected in Asia and Africa, and northern and developed regions suffering less.

The worldwide estimates of Table 3.6 are expressed as the total sum of regional damages relative to the global sum of GDP. As set forth in Box 3.2, it can be argued on equity grounds that there should be greater weights placed on impacts for low-income countries than would result from simply applying their shares in the global income base. As shown in the box, under one commonly used utility function (logarithmic), equity weighting would tend to raise the global aggregate damage measure. This would especially be the case for the Tol estimates, where damages are particularly high in developing countries.

[Box 3.2]

[Box 3.3]

It is useful to consider the results of an opinion survey of 19 global warming experts from both physical sciences and economics (Nordhaus, 1994a, see Table 3.7). For a 3°C actual warming by 2090, global damages estimated ranged from zero to 21% of gross world product, with a mean value of 3.6%. For a more rapid and severe warming (scenario B) the mean increases to 10.4% of GDP. Diverging from the estimates of Table 3.4, virtually all of the respondents judged that more than half of the damages would occur in the market sectors (such as agriculture), rather than in sectors outside the standard system of national accounts (biodiversity, amenity)¹⁴. The three natural scientists included in the survey gave the highest damage estimates, whereas the lowest estimates were from eight economists who had not done research on global warming. An important implication of the survey is that the perceived scope of global warming damage tends to be considerably higher among natural scientists than among most economists. Natural scientists also attach a higher probability to the possibility of a calamitous outcome. This pattern suggests another reason why the

¹⁴ Nordhaus (1994a) includes human health in the non-market sectors.

estimates reported in the two tables here may be under- rather than over-statements.

[Table 3.7]

3.3 Damage Estimates for Longer Term Warming

Most analyses of global warming focus on the doubling of atmospheric concentrations of carbon equivalent of all greenhouse gases above preindustrial levels. The first IPCC scientific report (IPCC, 1990a) indicated that concentrations could reach this benchmark as early as 2025 under business as usual policies. Yet there is no reason to believe that greenhouse gas emissions and atmospheric build up would stop at that point.

Sundquist (1990) has estimated that there are sufficient fossil fuel reserves that rising emissions of carbon dioxide could cause its atmospheric concentration to reach 1600 ppm by the year 2200, before the exhaustion of reserves would reduce emissions and allow concentrations to plateau through 2300 and then moderate back to about 1200 ppm over a 400 year period as the consequence of deep-ocean mixing. With pre-industrial concentrations of 280 ppm, this scenario amounts to a potential rise of nearly six-fold in carbon concentrations alone.

On the basis of Sundquist, Cline (1992a) uses a 300 years time horizon to investigate the very-long-term impacts of global warming. On the basis of fossil fuel (primarily coal) reserves estimated by Edmonds and Reilly (1985), he concludes that as much as 14,000 GtC in carbon could be available for use at reasonable economic cost. He applies three leading energy-carbon models (Reilly *et al.*, 1987; Nordhaus and Yohe, 1983; Manne and Richels, 1992) to project carbon emissions through the year 2100, and extrapolates their rates late in the 21st century through 2275. Average emissions rise from 7 GtC today to 20 GtC by 2100 and 56 GtC by 2275.

Under the assumption that atmospheric retention remains at its recent 50% level, Cline estimates carbon concentrations on the order of 2,200 ppm by 2275, or about eight times pre-industrial levels. Applying the standard logarithmic equation, the corresponding increase in

radiative forcing would reach about 13 Wm^{-2} , from carbon alone, or some 19 Wm^{-2} from all greenhouse gases. With the central IPCC climate sensitivity parameter (Λ) of 2.5°C for 4 Wm^{-2} , the resulting mean warming would be almost 12°C . On this basis, Cline (1992a) sets 10°C (the lowest range from the three emissions models) as a tentative benchmark for ultimate warming over a 300 year period. This would take the earth back to the climate of the mid-Cretaceous period 100 million years ago, when mean temperatures were an estimated 6°C to 12°C higher than today (Hoffert and Covey, 1992). If instead the upper-bound climate sensitivity parameter is applied ($\Lambda = 4.5^\circ\text{C}$), very-long-term warming could reach approximately 18°C .

Recent simulations of the GFDL (Geophysical Fluid Dynamics Laboratory) general circulation model at Princeton University tend to confirm this range of $10\text{-}18^\circ\text{C}$ for baseline warming. Manabe and Stouffer (1993) examine the effects of a quadrupling of pre-industrial carbon dioxide equivalent by 140 years from now. They note that this level amounts to a 1% annual increase in CO_2 -equivalent concentration, and is consistent with the IPCC "business-as-usual" scenario. The equilibrium mean surface air temperature increase reaches 7°C , while the actual transient warming is 5°C . This estimate turns out to be slightly more severe than that in Cline (1992a), which estimates 7°C warming commitment only by the somewhat later date of 2150¹⁵.

Manabe and Stouffer do not argue that atmospheric concentrations will in fact stop rising after 140 years. Instead, their interest is in examining the consequences of this specified century-scale scenario. They find that sea-level rise from thermal expansion alone reaches 1.8 meters by the 500th year, and would presumably be much greater if the effect of melting of ice-sheets were taken into account.

After first conducting an economic analysis of global warming using comparative static techniques with carbon doubling as the benchmark (Nordhaus, 1991), Nordhaus (1993a, b) has also adopted a centuries-scale horizon for his dynamic model DICE. However, Nordhaus' baseline involves warming of only 5.5°C by 2275, because of lower emissions (31 GtC by

2275) and lower atmospheric retention¹⁶. Lower emissions stem from lower growth expectations, as Nordhaus' model assumes progressive slow-down in technological change that has the effect of limiting growth. Global product by the year 2275 is a multiple of only 7 times today's output in the DICE baseline, but 26 times in Cline (1992b), suggesting that diverging economic assumptions may be even more important than different assumptions about the scientific parameters for such long-term analysis.

If 10°C is used as a guideline to potential warming over a 300 year horizon (or much sooner if the upper end of the climate sensitivity parameter range proves valid), the corresponding economic damages could be very large. The central reason is that in many categories, damage is likely to rise non-linearly with warming. As one example, water run-off is a residual between precipitation, which rises linearly with global warming (and primarily in the higher latitudes), and evapotranspiration, which rises non-linearly (see e.g. Rind *et al.*, 1990). Similarly, Yohe (1993) finds that at intermediate sea level rise a doubling of the rise causes damages to rise about 2-1/2 fold; and above 60 cm, a doubling of the rise causes a tripling of damage.

It seems likely that the damages of high, very-long-term warming would be especially pronounced in the non-market sectors. Human amenity could face major losses. For example, Cline (1992a) estimates that with 10°C global mean warming, among 66 major US cities the number with average daily temperatures in July exceeding 90°F would rise from 18 presently to 62.

Attempts to quantify long-term damage are rare and highly speculative in nature. Most often, long term damage estimates are simple extrapolations of the $2\times\text{CO}_2$ equilibrium case, using different assumptions about the degree of non-linearity in the damage temperature relationship. Cline (1992a) uses a relatively modest degree of non-linearity for most effects, with an overall damage function exponent of 1.3. Nordhaus (1993a, b) applies a quadratic damage function; and Peck and Teisberg (1992) consider both quadratic and cubic functions. Table 3.8 reports the central estimates in Cline (1992a) for US damage from 10°C warming.

¹⁶ In contrast, note that the first IPCC report identified a commitment to 5.7°C already by 2100 (IPCC, 1990a).

¹⁵ Note that the GFDL GCM has $\Lambda = 3.5^\circ\text{C}$; Cline (1992a) uses $\Lambda = 2.5^\circ\text{C}$.

Against present economic scale, they amount to \$335 billion annually, or 6% of GDP. The figure is only illustrative, though. Assuming a quadratic temperature-damage relationship, US damage from 10°C warming would amount to over 17% of GDP. If more allowance is made for such categories as species loss the central range could rise to 2% of GDP for 2xCO₂ at 2.5°C and 12% of GDP at 10°C. With upper-bound warming, the very-long-term damage reaches 20% of GDP. In the long term scenario in the Nordhaus (1994a) poll of experts, respondents predicted a mean damage of 6.7% of GDP for 6°C warming by 2175. Answers ranged from negligible damages to 35% of GDP (see Table 3.7).

[Table 3.8]

In addition, warming on this scale could trigger some of the catastrophic results sometimes mentioned. Thus, Manabe and Stouffer (1993) find that the 7°C warming scenario is sufficient to cause the shutdown of the ocean conveyor belt (thermohaline circulation) that causes the present Gulf Stream. Similarly, although disintegration of the West Antarctic ice sheet is not considered likely under 2xCO₂ (IPCC, 1990a), it could be much more likely under 10°C. If this disintegration occurred, it would raise sea levels by 5 to 6 metres (Revelle, 1983), inundating 30% of the land area of Florida and Louisiana and causing other large land losses (Schneider and Chen, 1980). Another catastrophe scenario is one of large and "sudden" temperature change. Thus, Dansgaard *et al.* (1989) indicate that Greenland ice cores show a rise of temperature by some 7°C in as short a period as 50 years some 12,000 years ago (Younger Dryas period). Climate catastrophes and surprises are further treated in the following section.

3.4 Climate Catastrophes and Surprises

The chapter has so far focused on the impact of the best-guess climate change and some reasonable upper and lower bounds in the next century (section 3.2) and on the longer term (section 3.3). This section makes some statements on the impact if all climatic dice roll the wrong way, i.e., if the enhanced greenhouse effect leads to rather unlikely but possible changes. These changes are here referred to as climate catastrophes, in case some information on the physical mechanisms is available, and surprises otherwise. Most attention

will be paid to the catastrophes as surprises are by definition unknown. Collard (1988) distinguishes between weakly and strongly catastrophic risks. The former category refers to the case in which the product of the likelihood of an event times its consequences tend to zero as events become more and more disastrous, i.e., the probability on the event declines more rapidly than its impact grows. A strongly catastrophic risk describes the converse situation, where the severity of an event rises more rapidly than the probability of its occurrence declines. Which category best applies to climate change risks is still unclear. However, as damage cost functions in the literature are generally low order polynomials, the climatic uncertainties would have to be rather drastic, and probably more so than climatologists currently assume, to render the risks described below strongly catastrophic (see Tol, 1994b).

Three main types of climate catastrophes are identified in the literature, all associated with strongly non-linear responses to changed forcing: (i) the runaway greenhouse effect, (ii) disintegration of the West-Antarctic Ice Sheet, and (iii) structural changes in ocean currents. These three categories have a small but unknown possibility to occur.

The runaway greenhouse effect refers to the scenario in which one or more of the positive feedbacks dominates the negative ones such that the climate changes to a much more and much faster than the common consensus indicates. The main causes are a rapid increase in the natural emissions of greenhouse gases, e.g., through methane and carbon dioxide releases from melting permafrost or methane clathrates, a shutdown of major greenhouse gas sinks, e.g., through reduced plankton activity or the reduction of growth or die-back of forests, and changes in atmospheric chemistry. The runaway greenhouse effect does not only bring much larger and faster climate change, it also considerably enlarges the possibility of other catastrophes and surprises. The disintegration of the West-Antarctic Ice Sheet refers to a rapid melting of this ice-sheet, which could be unstable, leading to an additional sea level rise of about 5 metres within the next century. Changes in ocean currents have more regional impacts. The Gulf Stream transports energy from the tropics to northern Europe thereby being responsible for its moderate climate. This 'conveyor belt' is driven by temperature contrasts and salinity near Iceland. Reconstructions of past climates and model experiments reveal that the energy transport can be weakened, start to fluctuate or even stop completely,

possibly as a result of global warming. This would lead to a sharp drop in European mean temperatures. Another important ocean current is the Humboldt Stream (IPCC, 1995).

Rapid climate change brings forward the impact of long-term warming (see section 3.3), leaving less time to adapt and thereby increasing the impact enormously. Table 3.8 illustrated the impacts of a 10°C increase in the global mean temperature (4 times the temperature rise associated with $2 \times \text{CO}_2$), and suggested that this might lead to about a sixfold increase in the costs compared to a 2.5°C rise. This figure cannot readily be applied to a 10°C temperature rise at the shorter term, though. The estimates assumed a moderate level of adaptation which lowers the losses considerably (see Section 3.1.6). Adaptation will be much less successful in case of rapid climate change. Subsection 3.1.6 states the power of adaptation, preventing the larger part of the losses due to sea level rise in the OECD, and mitigating agricultural losses at a moderate cost. This adaptation cost is likely to be much higher for fast or sudden changes, and might even be impossible to implement. The long-term figure stated above thus at best represents the lower bound of the actual costs of a catastrophe.

Unfortunately, few attempts exist to quantify catastrophic impacts directly. One exemption is Tol (1994b) who splits the damage costs of climate change *inter alia* into those due to the rate of change and those to the change compared to present temperatures. The damage module of his model *FUND* yields tangible damages of 0.33%, 0.55% and 1.09% of Gross World Product for a 2.5°C warming in 2095, 2057 and 2031, respectively. However, no figures on a more rapid temperature increase are reported there. The *ICAM* model (Dowlatabadi and Granger, 1993) also considers the pace as well as the amount of warming in the damage cost functions, but explicitly adds adaptation. A warming of 8°C at high latitudes and 2.8°C at low latitudes would lead to tangible losses of 6.0% of GDP in the industrialised countries and 6.6% of GDP in the less industrialised countries (Kandlikar, 1994). Nordhaus' (1994a) poll of experts provides the most direct information: a doubling of the warming by 2090 from 3°C to 6°C almost triples the costs of global warming. The probability of an impact catastrophe (i.e. damages greater than 25% of GNP) could also be considerable. The average probability stated in the survey varies between 4.8% and 17.5%, depending on the underlying warming scenario (see Table 3.7). Interestingly, natural scientists were far more pessimistic in their assessment than economists.

3.5 Regional Implications of Global Warming Damage

3.5.1 Regional Damage Estimates

Section 3.2 surveyed the available literature on monetised damages from global warming. These are heavily biased toward the USA and to a lesser extent Europe, due to the concentration of work there. This section looks at case studies available for other regions. Focusing mostly on agricultural impacts and sea level rise, regional studies predict impacts ranging from slightly beneficial to truly catastrophic. It is difficult to compare studies across regions, though, due to different underlying assumptions in the GCMs used, the nature of the model runs (transient or equilibrium), the models' capabilities for simulating control conditions for the relevant country (e.g. precipitation), and differences in assumptions and scenarios. Some scenarios include assumed adaptation measures, other do not. Moreover, few studies examine interlinkages between areas, so that they are not truly integrated assessments.

3.5.2 Japan

In terms of *agriculture*, research has focused on the effects of climate change and increased CO_2 on rice production (Nishioka *et al.*, 1993). Laboratory experiments with increased CO_2 concentrations (a rather high 700 ppm), produced grain yield increases of 23-71%.

An increase in effective accumulated temperature (EAT) in most of the country (except parts of Hokkaido) would reduce the vulnerability of rice to cool summer weather in the North of Japan, perhaps stabilising production. Rice producing regions may themselves be extended. Commercial rice cultivation in Japan could shift northward by 200-500 km by the end of the next century. In the north, $2 \times \text{CO}_2$ conditions could open up most of the land below 500m altitude for rice cultivation. Currently most cultivated areas are at elevations below 200m. In light of the altered climate predicted by the GISS model, the transplanting date of rice would be advanced by 20-30 days and the maturing period would be reduced by 25-50 days. For spring wheat and winter wheat respectively, the heading date would advance by 2-5 days and 30 days, and the maturing period would reduce by 3-5 days and 3-6 days. For *forests*, some replacement of the understorey is expected due to inability of forests to migrate in the short term.

Japan's economic activities are concentrated along the *coast*. Major cities like Tokyo, Osaka and Nagoya are all located in the coastal zone. Together the three cities account for more than 50% of Japan's industrial production. Already now, about 860 km² of coastal land is below mean high water level, an area supporting 2 million people and 54 trillion yen (\$450 billion) value of physical assets. For a 1 metre rise in sea level this area would expand by a factor of 2.7 to embrace 4.1 million people and assets worth 109 trillion yen (\$908 billion). The same sea level rise would expand the flood prone area from 6270 km² to 8,900 km², with an additional 3 million people at risk (Nishioka *et al.*, 1993). Coastal protection will be central to the country's response strategy. The costs of adjusting existing protection measures has been estimated at about \$80 billion. However, extensive coastal protection would put additional pressure on Japan's remaining natural shorelines (IPCC, 1992b).

3.5.3 Africa

Very little work on impact assessment in Africa has been done. Magazda (1991) predicts reduced precipitation in the rain forests of Zaire and Uganda under doubled CO₂ concentrations. Citing Cummings on general relationships between precipitation and herbivores, Magazda predicts reductions in large herbivores as Savannah productivity is reduced, affecting buffalos and elephants among others. Shallow lakes, such as Lake Abiata in Ethiopia and Lake Turkana in Kenya, and savannah wetlands are likely to be reduced, affecting resident wildlife and bird migrations.

Omiude and Juma (1991) emphasise the greater vulnerability of Africa to climate change due to the high agricultural dependence and the limited capacity for adaptation. For Egypt, Rosenzweig *et al.* (1993) predict aggregate yield losses in the order of 25-50% for 2xCO₂. The implications of agricultural damages on consumer welfare in Africa are expected to be negative even in the most optimistic scenarios (Reilly *et al.*, 1994).

Sea level rise is predicted to affect some 20% of Egypt's 35,000 km² of arable land. A 1 metre rise in sea level could destroy up to 25% of the Nile Delta's agricultural land and displace about 8 million people. Cotton and rice would be the main crops affected (El-Racy, 1990). Awosika *et al.* (1990) estimate that sea level rise would greatly exacerbate existing erosion at Lagos Beach in Nigeria, whilst even a modest rise will affect mangroves and

wetlands which support timber and fishery industries. In the absence of protection a 1 metre rise in sea level could flood over 18,000 km² of Nigeria's land, damaging assets currently worth \$18 billion. Over 3 million people would have to be relocated. Protecting at least the highly developed areas would cost \$550-700 million (IPCC, 1994, 1992b). A similar case study for Senegal estimates that in the absence of protection over 6,000 km² of land would be lost under a 1 metre rise, some 3% of the total area. Two thirds of the population and 90% of the industry are located in the coastal zone. Protecting these areas would cost \$250-850 million, about three quarters of which would go toward beach nourishment (IPCC, 1994, 1992b).

3.5.4 Bangladesh

Bangladesh is one of the few developing countries that has been the subject of detailed projections of climate change impact. Taking the coastal zone of Bangladesh to be defined by districts with a maritime boundary, the zone is a delta of the combined Ganges-Jamuna-Meghna river system and accounts for some 22% of the total land area and 16% of the population (Asaduzzaman, 1994). It also accounts for 24% of agricultural value added, 40% of manufacturing fixed assets and 22% of manufacturing employment. A 45 cm rise in sea levels (SLR) along the Bay of Bengal coast would submerge some 15,700 km² of land (about 11% of the total land area), including some 75% of the Sundarban mangrove forests. Several ports would also be affected. A 1 metre rise would affect nearly 30,000 km² (about 21% of the land area) (Asaduzzaman, 1994). This is somewhat higher than earlier estimates by the Commonwealth Secretariat (1989) which predicted a loss of just under 16% of total land area for a 1 metre rise. 1 metre sea level rise would result in all the Sundarban mangrove forests disappearing. Sea level rise will result in saline intrusion further inland than the existing freshwater-saline water interface. Changes in cyclone frequency appear to be small and soil erosion effects appear to be unknown.

Impacts on *agriculture* remain difficult to predict. A study by the Bangladesh Institute of Development Studies suggests losses of rice output due to sea level rise as shown in Table 3.9.

[Table 3.9]

Asaduzzaman (1994) suggests that the overall macroeconomic impact of sea level rise would amount to some 30% of current GNP in the coastal zone, or some 5% of overall Bangladesh GNP. Damages in absolute terms would be perhaps \$4.8 billion in terms of 'lost' output in 2070.

The loss of the Sundarbans would impose a particularly severe loss on the poorest people of Bangladesh, relying as they do on the mangroves for fuelwood, timber, fish and many raw materials. Biodiversity losses are incalculable due to the extensive lack of knowledge about the ecological functioning of the Sundarbans. Many shrimp fisheries are likely to disappear, offset to some extent by the emergence of new estuarine fisheries as sea levels rise. Salinisation will also affect industries relying on freshwater intakes, including electricity generating plants, raising costs of production. Other industries would have to move and some would be irretrievably lost, e.g. those relying on shrimp processing. Road and rail links between Dhaka and Chittagong/Khulna would be disrupted by sea level rise, seriously affecting all international trade. Asaduzzaman (1994) suggests that 45cm sea level rise would affect infrastructure affecting 195,000 jobs and some 790 km of roads; 100 cm rise would affect 735,000 jobs and 1460 km of roads.

Population displacement would be dramatic if impacts are assumed to be 'sudden'. Some 5% of people would be displaced by 45cm rise, and 13.5% for 1 metre rise, i.e. in terms of 2070 population perhaps 12 million and 32 million people respectively. In practice, migration away from the likely to be affected areas is already taking place, partly for weather-related reasons. The health impacts of such migration to cities would be significant.

3.5.5 India

Some 70% of India's annual rainfall occurs in the June-September monsoon season. Chakraborty and Lal (1994) project increases in precipitation in most parts of India due to doubled CO₂ concentrations. The Central Plains and East Coast might expect pronounced increases in annual average precipitation (1 mm/day) and this may be 2 mm/day in the monsoon period. 2 mm/day is also estimated for West Bengal in the pre-monsoon season. Monsoons thus intensify for many regions and more frequent heavy rainfall events are predicted.

In *agriculture*, yields may be lowered due to the decrease in the number of growing degree days due to enhanced temperatures. Seshu and Cady (cited in SAARC, 1992) suggest a decline in rice yields of 0.7 t/ha for an increase in minimum temperature from 18°C to 19°C, a decrease of 0.4 t/ha for 22 to 23°C and 0.04 t/ha for 27 to 28°C. As for wheat, it has been estimated that each 0.5°C increase in temperature would reduce productivity in Punjab, Haryana and Uttar Pradesh by about 10%. In Central India, where productivity is lower, the decrease would be lower (SAARC, 1992). In comparison, the global study by Rosenzweig *et al.* (1993) predict changes in aggregate agricultural yields of +3% to -33% under 2xCO₂ (including CO₂ fertilization).

Sea level rise would affect many regions, with the Andaman and Nicobar islands and the coral atolls of the Lakshadweep archipelago being among the most vulnerable areas. The east coast would be more subject to storm surges than the west coast. The western coastline south of 12° North is likely to become more eroded. No overall estimates of macroeconomic impact are available, though. In a case study of the Orissa and West Bengal region, IPCC (1992b) estimated that in the absence of protection a 1 metre sea level rise would inundate an area of 1,700 km², predominantly prime agricultural land, and displace 700,000 people. Protecting the area would require the construction of an additional 4,000 km of dikes and sea walls.

3.5.6 Indonesia

Parry *et al.* (1991) suggest that 2xCO₂ could raise the mean annual temperature in Indonesia by about 3°C and produce a rise in sea levels of 60 cm. Precipitation is likely to decline in some regions, but might generally increase. Increases in rainfall could lead to a 30% increase in the irrigation area of Brantas and Citarum Basins in western Java. Soil erosion might increase by 14, 18 and 40% in the Citarum, Brantas and Saddan watersheds, with resulting soybean production losses of 2,000 to 2,700 tonnes in each region.

Enhanced temperatures and, at certain sites, reduced water availability could reduce rice yields, especially for early season rice. This could be offset to some extent by increases in late season rice. Net yields might decline by 4%. Soybean production might decline by around 10%, largely due to lower yields in the early season. Appropriate adaptive measures

may lead to productivity increases which could offset potential losses, though, and overall yields may increase. The biggest yield effects are likely to be on maize output with declines of 25-65%.

Indonesia is the world's largest archipelagic state, with over 17,500 islands and an shoreline of approximately 81,000 km (IPCC, 1994). *Sea level rise* will affect coastal ecosystems, industrial production and agriculture alike. In the Krawang and Subang districts, 95% of the predicted reduction in local rice supply (about 300,000 tonnes) and half of the loss in maize output is due to the inundation of coastal land. As a consequence, over 81,000 farmers may lose their source of income in the Subang district alone, and about 43,000 farm labourers could lose their job (Parry *et al.*, 1991).

3.5.7 Malaysia

Parry *et al.* (1991) suggest that $2\times\text{CO}_2$ will raise Malaysian mean temperature by 3-4°C. Rainfall increases are likely in January-February in the coastal regions of Sarawak, and in March-May in Southwestern Peninsular Malaysia. Runs of the CERES rice model predict a 12-22% yield decline for rice in the largest rice growing region of Muda. A 10% reduction in solar radiation in the Serdang region could result in maize production losses of about 20%. Rainfall increases in March-May could increase oil palm productivity in alluvial coastal areas. Temperature and rainfall changes on the eastern coast of Malaysia could make the area too wet for rubber cultivation due to interference with tapping. Dry margin rubber cultivations, on the other hand, may become too dry. National yield levels could decline by 15%, but improved varieties could more than offset this loss.

The frequency of peak discharges in the Kelantan river basin in NE Peninsular Malaysia could increase by 9% under $2\times\text{CO}_2$, implying more flood damage and a 5% increase in the population affected by floods. Water deficits in the dry season are likely to increase due to higher evaporation, reducing water availability for irrigation.

About 70% of the total population of Malaysia live in the *coastal zone*, which is also the centre of most of the country's economic activities. In addition, important natural ecosystems are located along the coast, with 44 of the 1000 islands being designated as marine parks.

Sea level rise could have significant consequences for the low lying coastal plains of Malaysia. Parry *et al.* (1991) report that a 1 metre rise could lead to a landward retreat of the shoreline of as much as 2.5 km. Midun and Lee (1989) suggest that such a rise could result in the near-total loss of existing mangroves with little chance of inland migration.

3.5.8 Thailand

Parry *et al.* (1991) suggest that $2\times\text{CO}_2$ could result in a 3-6°C mean annual temperature change in Thailand. GCM predictions for rainfall diverge, but generally show a reduction under the GISS scenario. Northern Thailand will tend to be drier in most months except July. For Ayuthaya Province, the GISS model predicts rainfall reductions in August-September but other models do not produce this result. With respect to agriculture, preliminary runs with the CERES agricultural model for the province of Ayuthaya suggest that transplanted rice yields might decline but rise for direct seeded rice. The analysis suggested an 8% increase in cultivation in the province, substantially less than the currently observed year-to-year fluctuations. Off-season rice showed average yield increases of 5%. Model validation is weak, however, and the results should be treated with caution. Results for Chiang Mai, for example, suggest average yield reductions of 5%.

For the Suratthani province in Southern Thailand, a case study calculated that 37% of the area would be affected by a 1 metre *rise in sea level*, with losses of over 4200 ha of agricultural land and many shrimp ponds (Parry *et al.*, 1991).

3.5.9 Latin America

IPCC (1992b, 1994) summarises *sea level rise* case studies for several Latin American countries, including, Argentina, Uruguay and Venezuela. In Argentina a 1 metre sea level rise would inundate an area of about 3,400 km² (0.1% of total area). Erosion would claim assets and land worth \$5 billion. Venezuela could lose about 5,700 km² or 0.6% of its area under a 1 metre rise (assuming no protection). Particularly at risk would be the country's low lying coastal plains and deltas. While only a small area would be at risk in Uruguay, the coastlines affected would be highly valuable tourist beaches. Uruguay's tourist industry creates over \$200 million in revenue per annum, and attracts over 1 million visitors each summer. Protecting the beaches would be expensive. The capital costs of developed areas

protection (mainly beach nourishment) were estimated at \$2.9-8.6 billion, more than five times the costs expected for Venezuela. If spread over 50 years, this would correspond to annual investments of 6-19% compared to 1987 gross investments (Nicholls *et al.*, 1992).

The impacts of climate change on *agriculture* are less well studied. Using climate analogues Magalhães and Glantz (1992) illustrate the consequences of climate extremes on Brazilian agriculture and society. In the semi-arid Northeast of Brazil, agriculture is characteristically vulnerable to droughts. Drops in agricultural production cause mass unemployment in the agricultural sector, followed by malnutrition and hunger. Increased migration to urban centres is one of the consequences. In the global agricultural model of Rosenzweig *et al.* (1993), yield impacts in Brazil are among the most severe of all regions. Under 2xCO₂ yields are expected to fall by 17-33% with CO₂ fertilization, and 38-53% without. Similar reductions are also reported for Uruguay.

3.5.10 The Small Island States

The small island states (SISs) are self-evidently vulnerable to sea level rise. Table 3.10 summarises the results of computing a *vulnerability index* for different categories of country. Vulnerability is defined in terms of exposure to foreign economic conditions (export dependence); insularity and remoteness; and proneness to natural disasters. In the full list for 113 countries, 9 out of the 10 most vulnerable countries are island states (Briguglio, 1993).

[Table 3.10]

Pernetta (1989) suggests a ranking of SISs in the Pacific in terms of their extreme vulnerability to sea level rise. 'Profound impacts', including non-existence in the worst cases, could be felt by Tokelau, Marshall islands, Tuvalu, Line Islands and Kiribati; severe impacts resulting in major population displacement would be experienced by Micronesia, Palau, Nauru, French Polynesia, Cook Islands, Niue and Tonga; moderate to severe impacts would be felt by Fiji, American Samoa, New Caledonia, Northern Marianas and the Solomon Islands; and local severe to catastrophic events would be experienced by Vanuatu, Wallis and Futuna, Papua New Guinea, Guam and Western Samoa.

Pernetta (1992) outlines various impacts that SISs may suffer. These include increased frequency of tropical cyclones in areas not normally affected by them; increases in altitudinal vegetation zones, affecting alpine grasslands in Papua New Guinea and threatening mid-montane rain forests as they come under pressure for cultivation; some increased capillarity in limestone soils, reducing soil fertility in some areas; some increases in disease due to drier conditions in some countries and longer wet seasons in others; increases in humidity and hence human discomfort and adaptation costs. Sea level rise will have dramatic effects since most agriculture occurs on the coasts. Agriculture will be pushed inland on to less suitable soils, increasing erosion. Exclusive economic zones based on outlying islands will be affected as some of the islands are submerged. Protection measures are limited and expensive. For the Marshall Island, for example, IPCC (1992b) reports that protecting the Majuro atoll alone would cost 1.5 to 3 times the present GDP.

Since many hermatypic corals are growing at their limit of thermal tolerance, any rise in sea water temperature could result in increased coral bleaching, with consequent loss of coral fishery resources and tourism. Although the reactions of corals to such changes appear not to be known in any detail, consequences could be significant. In the Maldives, for example, dependence on the corals is high: they are mined for building materials while fish and marine products account for over 50% of exports. Tourism based on the corals is also vital. Coral deaths have already occurred probably due to increased lagoon temperatures, but pollution is also implicated.

3.5.11 Conclusions on Regional Impacts

Economic analyses of damage to developing countries from climatic change remain limited. Nonetheless, the preceding overview supports the general finding of the broader economic studies by showing that impacts on developing countries are likely to be more severe relative to the wealth of those countries. In some cases, sea level rise alone results in dramatic impacts on the economies. Summarising studies for Bangladesh, Brazil, China, Egypt, Malaysia, Nigeria and Senegal, for example, Nicholls *et al.* (1990) suggest that 1 metre sea level rise could displace nearly 100 million people in those countries alone (with China accounting for 75% of these). This strongly supports the 'equity' case for action on climate change over and above any results from aggregated benefit-cost studies.

3.6 From Greenhouse Damages to Abatement Benefits

There is a distinction between *global warming damage* and the *benefits of policy measures*, although the two concepts are related. In general, *the benefits of greenhouse action are at least equal to the amount of damage avoided*, that is to the extra damage which would have occurred in the absence of action. In addition, there may also be ancillary benefits which are not related to climate change (see Section 3.7). The above principal rule is complicated somewhat by the dynamic character of global warming, however.

Figure 3.2 considers schematically the development of atmospheric greenhouse gas concentration and damage over time under two scenarios. Under business-as-usual concentration levels are assumed to continue rising over the next 100 years or so (upper curve in the concentration chart). Global mean temperature levels will therefore rise as well, and so, too, will the level of global warming damage (including the influence of adaptation, see Section 3.1.7). The upper curve in the damage chart shows how annual damages may rise over time. The estimates of benchmark warming damage of Section 3.2 relate to only one particular point on this time path: the point t_{2xCO_2} , when the warming assumptions underlying the estimates are realized. In a business-as-usual scenario, this may for example be in the year 2060. If damage levels grow in proportion to GNP and assuming the earlier assessment is correct, damage at time t_{2xCO_2} will be in the order of $D_{t_{2xCO_2}} = 1 - 2\%$ of Gross World Product (GWP)¹⁷. Before this date, annual damage levels (relative to GNP) are lower. In subsequent decades they are higher, due to the rising atmospheric concentration.

[Figure 3.2]

The $2xCO_2$ benchmark is contrasted with the consequences of a particular greenhouse gas abatement strategy, say a stabilisation of atmospheric concentration at time t_0 (represented by the lower concentration and damage curves). Due to the thermal inertia of the climate system, annual damage levels will react only gradually to this policy change, and will initially continue to grow. Despite the stabilisation policy, the world is still committed to a

¹⁷ Abstracting from possible differences between transient and equilibrium damage.

certain degree of additional warming, which was already "in the pipeline" at t_0 . Eventually, however, damage may level off. To which level the trajectory will converge in the long run is unclear. The final level depends on how reversible damage is, and to what extent it represents transitional adjustment costs.

What, then, are the benefits of the stabilisation policy? They are represented by the shaded area in Figure 3.2, which depicts the difference in annual damage levels between business as usual and the control scenario, summed up over the relevant time horizon. In each future time period damage is lower than it would have been otherwise, and the benefit of greenhouse gas abatement is the (discounted) sum of these avoided future damages.

As Figure 3.2 makes clear, there is thus no direct connection between *damage associated with $2xCO_2$* and the *benefits of greenhouse gas abatement*. The benefits of abatement occur as a *stream* of reduced damage over time, while $2xCO_2$ concerns only one point. Annual damage reduction levels will generally not coincide with the $2xCO_2$ assessment either, for two reasons: firstly, because even the most stringent abatement scheme is unlikely to succeed in avoiding all damage - some damages have already been done, i.e. they are irreversible; secondly, because damage reductions will chiefly concern years in which the business as usual damage would not be that of $2xCO_2$.

Despite this difference, $2xCO_2$ assessments still provide some indication of the size of abatement benefits. For a more precise assessment much more information would be necessary, though. A careful analysis would in particular require a better knowledge about the *slope* of the damage trajectory, that is about how global warming damage alters over time, as a consequence of both climate change and economic and population growth. A further need would be information about the degree of damage which can be avoided through a particular policy measure, that is the distance between the two damage trajectories of Figure 3.2. The answer here depends chiefly on the exact character of impacts - whether they are reversible or not, whether damage depends on the rate of change or on absolute temperature levels, whether damage is persistent or a transitional adjustment cost, and so on.

Knowledge about damage beyond the $2xCO_2$ benchmark is very limited. The small literature

aiming at estimating the benefits of greenhouse gas abatement relies on several rather *ad hoc* assumptions. Damage costs are typically specified as a polynomial (usually linear to cubic) function of global mean temperature, calibrated around the $2\times\text{CO}_2$ estimates. Damage is usually fully reversible and typically assumed to grow with GNP. Table 3.11 provides a list of estimates of the marginal benefits of CO_2 abatement based on such assumptions. Several of them are derived from optimal control, or dynamic cost-benefit models. In these models, the marginal benefit from abatement, or the 'shadow price of carbon', is calculated as the carbon tax necessary to keep emissions on the trajectory which is considered socially optimal by the model. In other models the marginal benefits are calculated directly by comparing the present value of the stream of damages associated with a certain emissions scenario to that of an alternative scenario with marginally different emissions in the base period. Estimates vary widely, mainly as a consequence of different assumptions about the discount rate (see Section 3.1). They rise over time as a consequence of economic growth and increasing concentration levels.

[Table 3.11]

Using the base case in DICE, Nordhaus (1993a, b) finds that the shadow price begins at only about \$5 per ton of carbon in 1995, rises to about \$10 by 2025, and reaches \$21 by 2095 (at 1990 prices). Peck and Teisberg (1992, 1993a, b) find only moderately higher values. These low shadow prices reflect the small amount of abatement found optimal in these two models. In contrast, Cline (1992b, 1993d) finds that with the sum of pure time preference and the elasticity of marginal utility (absolute value) set to 1.5%, the DICE model generates a path of shadow prices beginning at \$45 per ton, reaching \$84 by 2025, \$133 by 2055, and \$243 by 2105. Other parameter specifications provide even higher values.

In comparison, Fankhauser (1994a, b) identifies a lower and flatter trajectory for the shadow price of carbon, rising from \$20 per ton 1991-2000 to \$28 per ton by 2021-2030. An important source of the difference is that Fankhauser uses a probabilistic approach to the range of discount rates, thereby including considerable weight on rates substantially higher than suggested by most other authors. Conceptually Fankhauser's method differs as well, because it seeks to identify the shadow price on a basis of discounted greenhouse damages

under probability-weighted scenarios of public action and inaction.

3.7 The Secondary Benefits of Abatement Strategies

The benefits of greenhouse gas abatement will not be limited to reduced climate change costs alone, but are likely to spill over to other sectors. This is a further reason why greenhouse damage is different to the benefits of greenhouse gas abatement (see Section 3.6). For example, if abatement is brought about by an environmental tax (e.g. a carbon tax), the resulting revenues can be used to lower other, distortionary taxes, such as those on labour. This will lower the welfare costs of governmental revenue raising - the so called *double dividend* of carbon abatement (see Chapter xxx). Efforts to halt deforestation will reduce the emission of CO_2 as well as contributing to the conservation of the world's biological diversity. Other ancillary benefits could occur in the form of local and regional air quality improvements, as a reduction in traffic related externalities like accidents or congestion, and as a reduced risk of tanker accidents and oil spills. These problems are tied to global warming in that they are caused by largely the same activities, in particular the consumption of fossil fuels. Because no economical CO_2 -removal technologies currently exist, attempts to limit CO_2 emissions will by and large concentrate on cutting down the use of fossil fuels. A reduction in CO_2 emissions will therefore also reduce other environmental problems related to fuel combustion. In particular, CO_2 abatement will curb the emission of classic air pollutants like SO_2 , NO_x and particulates. These effects are often called the *secondary benefits* of carbon abatement¹⁸.

Secondary benefits may be quite large, as is shown in Table 3.12. The Table provides estimates from several studies on reduced air pollution levels as a consequence of carbon abatement. Reduction levels range from 1% to over 30%, depending on the pollutant and the underlying carbon abatement level. Figures are not necessarily comparable since the assumed abatement policies differ from study to study, although they all roughly aim at stabilising

¹⁸ There are further connection between global warming and air pollution. Sulphur abatement, if achieved through the installation of end of pipe scrubbers, could lead to an increase in CO_2 emissions. The accumulation of sulphur aerosols in the atmosphere causes a reduction in global mean temperature, thus masking the extent of global warming. A warmer temperature on the other hand will aggravate air pollution.

CO₂ emissions at about 1990 levels.

[Table 3.12]

What is the value of these emission reductions? Estimates which measure the social costs of each pollutant vary widely between regions, depending on local factors like baseline air quality standards, ecosystem vulnerability, population at risk etc. Figures may also differ because impacts caused by a combination of gases are attributed to the initial sources in different ways. A selection of illustrative results is given in Table 3.13. The average secondary benefits implied by these estimates vary widely, from about \$2 per tonne of carbon abated to over 500 \$/tC. In absolute terms secondary benefits offset about 30-50% of the initial abatement costs in the case of Norway (Alfsen *et al.*, 1992) and over 100% in the UK (Barker, 1993).

[Table 3.13]

The figures in Table 3.12 relate to Europe or the United States. A first indication about the importance of secondary benefits elsewhere is provided by Amano (1994), who has extended the Alfsen *et al.* (1992) study to several Asian regions, using the same benefit-abatement ratios (air quality benefits, in percent of GDP, per percentage cut in air pollution). Although the use of the Norwegian ratios is certainly questionable, given the difference in baseline air quality between these countries, the Amano calculations imply that secondary benefits could be similarly important in Asian countries. In the case of Japan and India estimated secondary benefits exceed the primary costs of stabilising emissions at 1990 levels. For China and the group of "Dynamic Asian Economies"¹⁹ secondary benefits are estimated to offset about one third of the initial abatement costs.

An alternative way to measure secondary benefits is by estimating the change in the costs of meeting air quality standards. Many industrialized countries are committed to significant cuts in the emission of air pollutants. The Helsinki protocol of 1985 required a cut in sulphur

¹⁹ The group includes Hong Kong, the Philippines, Singapore, South Korea, Taiwan and Thailand.

emissions of 30% by 1993, compared to 1980 levels, for selected European countries. Under the 'Second Sulphur Protocol' further reductions will be required up to 2010. The Sofia Protocol on nitrogen dioxide commits signatories to a freeze on emissions at 1987 levels. Greenhouse gas abatement will lower the amount of traditional air pollution abatement needed to meet these targets. Alfsen *et al.* (1993), for example, calculate that the introduction of a carbon/energy tax would reduce the expenses for traditional SO₂ and NO_x abatement in the nine countries considered by 25 - 30% and 12 - 25 %, respectively, implying average secondary benefits of about 2.5 \$/tC for NO_x and 4.0 \$/tC for SO₂.

It is important to underline the different character of secondary benefits compared to their primary counterpart. Most critically, secondary benefits do not depend on climate variables but only arise in connection with greenhouse gas *abatement*. They occur locally or regionally and do not share the global character of greenhouse damages. The question of secondary benefits from carbon abatement should also be distinguished from the more comprehensive one about the optimal abatement mix with respect to all pollutants. The secondary benefit argument is characterized by an implicit primacy of the greenhouse problem, in that improvements in other areas are greeted as welcome side effects of a global warming policy, but are not considered or sought in their own right. This is not necessarily the ideal way to proceed. Strictly, each pollutant should be taxed in proportion to the environmental damage it causes. If there are interdependencies between them, as is the case with global warming and air pollution, these would have to be reflected in the relative tax rates. The currently considered abatement strategies may then no longer constitute the optimal tools.

3.8 Comparing Benefits and Costs of Response Strategies

3.8.1 Social Efficiency of Abatement

Economic models comparing the costs and benefits of greenhouse gas abatement are discussed in Chapter xxx. Among the most prominent examples are Cline (1992a), Nordhaus (1993a, b), Manne *et al.* (1993), Hope *et al.* (1993), and Peck and Teisberg (1992, 1993a, b).

Cline (1992a) analyses the time profile of abatement and damage costs under a policy of

limiting carbon emissions to 4 GtC annually and similarly reducing other greenhouse gas emissions. The abatement cost curve is low at first, then peaks at about 3.5% of gross world product, and thereafter declines to a plateau of about 2.5% as a consequence of widening technological alternatives. On the damage side, Cline assumes that the damage profile for the United States is also representative of international effects. This assumption may be a moderate understatement, given the results of Table 3.6. The benefits of abatement are set at only 80% of greenhouse damage, under the assumption that a significant portion of warming cannot be avoided.

The cost-benefit decision for greenhouse policy involves a tradeoff between substantial abatement costs early in the horizon, in return for avoidance of potentially large damages later in the horizon. As discussed above, the discounting methodology is crucial in such a tradeoff. Cline also stresses the importance of taking high damage and low damage cases into account instead of just the central case. On grounds that policy makers should be risk averse, Cline weights the representative high-damage case three times as heavily as the low-damage case. Discounting at a zero rate of pure time preference (see Section 3.1.5), he finds that the overall benefit-cost ratio for aggressive international action limiting carbon emissions to 4 GtC is a favourable 1.3.

Nordhaus (1993a, b - the DICE model) and, to a lesser extent, also Peck and Teisberg (1992 - the CETA model), reach essentially the opposite conclusion: that only relatively small cutbacks of some 10% - 15% from the baseline of carbon emissions are economically optimal. Because the baseline under business-as-usual reaches many times today's emissions, this finding means that it would be optimal on economic grounds to permit emissions to rise far beyond 1990 levels. Nordhaus (1993a, b) finds that freezing emissions at their current level would have net social costs equivalent to 0.7% of discounted future consumption. When he incorporates spillover benefits from greater tax efficiency, Nordhaus (1993a) raises the optimal cutback to some 35% from baseline, but even this result leaves the optimal emissions path above today's levels within a decade or two. In the CETA model significant emission reductions only occur for a sufficiently steep damage function.

Manne *et al.* (1993) have extended the earlier Manne-Richels (1992) carbon-economic-energy

model (Global 2200) to incorporate a climate module for atmospheric concentrations and radiative forcing, and a damage module, to obtain an overall benefit-cost evaluation of greenhouse policy. Specified through the year 2200, their MERGE model has long-term properties (but does not report the extent of eventual warming expected). It adopts a relatively low damage function (0.25% of GDP for market-sector impact of 2.5°C, and a willingness to pay for avoiding non-market sector damage that peaks for rich countries at 2% of GDP but is less than 0.1% of GDP for middle- and low-income countries). The authors apply a pure rate of time preference of 3%. Under these assumptions, their results not surprisingly conclude that a policy of freezing emissions at their 1990 levels would have a benefit/cost ratio of only about one-third; and a policy of setting a ceiling of 415 ppm on carbon concentrations, a benefit/cost ratio of only about 0.14. Hope *et al.* (1993) obtained more favourable results. For the aggressive abatement policy analysed in their study they obtained benefit/cost ratios close to one, and most likely above one, if non-market impacts are integrated. This cautious recommendation for strong abatement could be modified toward of a more balanced adaptation-abatement package, however, once adaptive measures are taken into account.

All model results are highly sensitive to the underlying parameter assumptions, however, in particular the rate used for pure time preference. This was shown by several authors who replicated the Nordhaus DICE model. If DICE is rerun placing the pure time preference rate at zero, for example, it generates an optimal abatement path that cuts emissions by about 50% from baseline by the year 2100 (Cline, 1992b, 1993d). If other model differences are taken into account (e.g. the low long-term warming in DICE, the incorporation of risk-weighting), the Nordhaus dynamic optimization model with arguably valid alternative parameters can generate optimal abatement paths close to those suggested by Cline (1992a).

Other critical features of optimal control models include the availability of a carbon free backstop technology (Cline and Hsieh, 1993) and the treatment of non-market damages. Tol (1994a) has conducted alternative experiments with DICE by shifting intangible (non-market) sector damages from the production side of the DICE model to the utility side, on the argument that they have poor substitutability with standard production inputs. When he makes the additional assumption that valuation of unit intangibles rises proportionately with per

capita income, he obtains optimal emissions cutbacks from baseline amounting to 27% in 2100 and 42% by 2300, even though he applies a pure rate of time preference of 3 percent.

An alternative to attempting a cost-benefit analysis of global warming policy is to adopt a hedging strategy that treats the problem as essentially binary - severe or mild - and undertakes limited action during an initial phase as a hedge until further research can confirm which case is valid. Manne and Richels (1992) explicitly apply their model in such an approach. They assume that scientific research will not demonstrate until 2020 whether the problem is severe or mild. Their model simulations show that the optimal amount of hedging (cutbacks from baseline emissions) will depend on the certainty with which we can count on scientific advance, and on optimism or pessimism about future non-carbon energy technology. If we have little confidence that science will have a nearly definitive evaluation by 2020, and if we are pessimistic about non-carbon energy, then it is best to take more action now, to spread the pain of carbon abatement more evenly over time in case it must be undertaken. If there is great confidence about future scientific clarification, and if one is optimistic about non-carbon energy supplies in the future, then there are large savings (as much as \$100 billion for the United States, total discounted value) in adopting only modest action now and then intensifying or phasing out abatement in 2020 and after in the light of improved scientific knowledge. Even under the latter, favourable circumstances, their optimal hedge involves a cutback of about 12% from baseline in carbon emissions by the year 2000.

3.8.2 Possible Implications

There is a surprising convergence of the various analyses on approaches to action in an initial decade. The Cline (1992a) aggressive action program is a reduction of one-third; but he suggests a milder first phase, pending additional scientific confirmation, implying an initial cutback from baseline by some 10% - 15%. The Nordhaus (1993a, b) optimal cutback of 9% by 1995 is not far from the same outcome. Similarly, the hedging strategy of Manne and Richels (1992) also leads to a cutback from baseline by about 12% by the year 2000.

The carbon tax also tends to converge for this initial period. Thus, the range suggested in Cline (1993d) of \$45 per ton in the 1990s suggests that something like \$20 to \$25 per ton might be appropriate in the initial decade of more moderate contingent action. This range is

consistent with the Fankhauser (1994a, b) initial marginal damage cost figure of about \$20 per ton of carbon. This tax is even within reach of the Monte-Carlo sensitivity results in Nordhaus (1994b), which place the optimal carbon tax at an expected (probability weighted) value of about \$12 per ton of carbon in 1995, and as high as \$45 per ton at the 95th percentile of the distribution. Considering the suggestion of Yohe (1993) that incorporation of risk recommends "focusing on a scenario which describes something around the 75th percentile of potential economic damage," an intermediate point between the two Nordhaus Monte-Carlo estimates would also tend to converge in the \$20-25 per ton range for 1995.

The policy prescriptions would begin to diverge more sharply beyond the first decade, assuming scientific confirmation of the seriousness of the problem. At that point it would become more essential to reach agreement on the fundamental issue of how heavily, if at all, to discount effects on future generations.

Box 3.1: Estimating the Value of a Statistical Life

Valuing statistical lives in monetary terms is highly controversial and raises a number of ethical issues. The reality is, however, that human life is not 'beyond price'. If it were, most of the world's wealth would be spent trying to save lives by reducing accidents and preventing disease. Risks are taken every day, both voluntarily by individuals and by governments in choosing their social and economic expenditures.

It is important to understand that no-one 'values human life' in monetary terms. It is a *statistical life* that has an economic value. It would make no sense to ask an individual how much he or she is willing to pay to avoid certain death. Nor is that the context of social decision-making. But it does make sense to ask what individuals are willing to pay to reduce the risk of death, or what they are willing to accept to tolerate an increased risk of death.

In the past, economic values of life risks have been estimated by the *human capital* approach. This involves treating an individual as an economic agent capable of producing an output that is valued in monetary terms. A life lost is then the loss of that output, less any consumption that individual would have made. One immediate problem with the approach is that, if it is applied literally, the very old would have negative values for their lives - they would not be contributing to output, but they would be consuming. As with many other valuation procedures, it is the value of a statistical life at a mean or median age group that is applied 'across the board' to young and old. But the real problem with the human capital approach is that it has no particular relationship to an individual's willingness to pay to reduce his or her risks of mortality. It is not properly founded in economic theory. Moreover, it tends to produce extremely low values for those with low earnings, clearly discriminating against the already poor.

The alternative is to estimate individuals' willingness to pay or accept for risk changes. Willingness to pay measures include direct approaches such as *contingent valuation* where the individual is asked how much they are willing to pay to reduce risks. Other measures include finding out what people are willing to pay to adopt safety and disease preventing measures. For willingness to accept, the *hedonic wage approach* can be used. For example, if there are 100,000 workers and each is willing to accept \$5 to tolerate an increased risk of mortality of 1/100,000 then the increased risk will result in one statistical death. The value of that statistical life is then $\$5 \times 100,000 = \$500,000$.

Studies of the contingent valuation and hedonic wage risk approaches suggest 'values of statistical lives' (VOSLs) of about \$3 million in the developed world. Since virtually no studies exist for the developing world it is impossible to say what the results would be for these techniques. But since willingness to pay (WTP) is constrained by ability to pay (wealth and income) the results are likely to be very much lower.

'Borrowing' VOSLs from developed economy studies is hazardous. Various rough and ready approaches have been tried. For example, developing country valuations could be estimated as

$$VOSL_{ldc} = VOSL_{dc} \cdot (Y_{ldc}/Y_{dc})^E$$

where ldc = developing economy, dc = developed economy, E is the income elasticity of the demand for risk reduction, and Y is income. Developing countries' VOSLs would simply be 'scaled down' by the ratio of incomes raised to the power E . If $E = 1$, then the scaling down is simply done by the ratio of incomes.

This formula results in lower VOSLs in poorer countries than in rich countries. While this appears 'unfair' it is arguable that what matters is the ratio of the VOSL to the developing country income, i.e. what that country appears to be willing to spend out of its income on life protection. If the right hand side of the above equation (with $E=1$) is divided by Y_{ldc} , the result is $VOSL_{ldc}/Y_{ldc}$, i.e. the VOSL in a developing country is the same proportion of income as it is in the developed economy.

But this still leaves the *absolute* VOSL lower in the developing country. Some people object to this in the context of climate change because, they argue, it is the rich countries that have 'caused' global warming. They should therefore be compensating the poor countries who will suffer damage. Since the rich countries are the polluters, and the polluter pays principle has force in international environmental agreements, the argument goes that $VOSL_{dc}$ is the correct value for *all* lives, regardless of where they are saved (or lost).

Box 3.2 Damage Aggregation Across Countries and Individuals

Benefit-cost analysis assumes that the monetary values of damage can be aggregated across (a) individuals, and (b) countries. This aggregation process raises an important problem of so-called *interpersonal comparisons of utility*, where utility is simply another word for "welfare" or "wellbeing". Basically, introspection allows any one individual to assess his or her *own* preferences, but perhaps not *others'* preferences. Each individual knows by how much he or she is better off in situation X compared to situation Y, but he or she cannot assess how this change compares to the extent to which someone else is better off for the same change of situation. This inability to assess *other minds* produces the theorem that it is impossible to make comparisons of wellbeing between individuals, and hence by extension, between countries.

The willingness-to-pay (WTP) principle can rank different states of the world in a manner that is consistent with individual preferences and provides an objective basis for measuring individual welfare changes. A higher WTP indicates a more preferred state of the world for the individual. WTP provides a measure of what the individual would be willing to sacrifice to attain the more preferred state. Benefit-cost analysis proceeds by aggregating *individuals'* assessment of their own wellbeing to yield a measure of *social* welfare change. There is, however, an endless number of ways to aggregate WTP based changes of individual welfare.

Measuring social welfare change requires interpersonal welfare comparisons, comparisons that require ethical judgements about individuals preferences. Such judgements could include one to the effect that preference measures should not be unduly influenced by income differences. In this case, the individual measures of preference - willingness to pay - could be weighted so as to reflect the WTP of someone with an average income. An appealing way to proceed is to indicate the outcomes of the benefit-cost analysis according to differing value judgements about the weights attached to preferences - a kind of "value sensitivity analysis". Thus, whether a change in the state of the world raises or lowers social welfare depends on the impacts on individual welfare as well as on normative criteria for making interpersonal welfare comparisons. Measures of social welfare change are, therefore, not objective but normative.

Conventional global warming damage formulations present total damages (D) as the sum of individual impacts (d_i),

$$D = \sum_i d_i$$

Instead an alternative formulation could be present the results in the following way,

$$D = \sum_i d_i \left(\frac{Y_a}{Y_i} \right)^e$$

where Y_a is now some reference level of income, say the global average income, or the income of the richer countries, and e is a factor correcting for differences in the utility of income between countries. In the literature, e is usually either the income elasticity of demand or the elasticity of the marginal utility of income (Pearce, 1986).

An example will indicate how the measures differ. Suppose there are just two countries. In country A, damage d_A is \$50 and in country B it is \$30. Country A has an income of \$5,000 and in country B it is \$1,000. The unweighted approach would make the global damage \$80. As a percentage of world income this is $80/6000 \approx 1.33\%$. Note however, that A's damage is 1% of its income, and B's is 3%.

Setting Y_a at the average world income of \$3000, and $e=1$ for convenience, the weighted procedure would produce the following result,

$$D = 50 \cdot \left(\frac{3,000}{5,000} \right) + 30 \cdot \left(\frac{3,000}{1,000} \right) = 30 + 90 = 120$$

Damage is now in "equity weighted" terms, and expressed as a fraction of world income it is 2%. The share of B's income has risen to 9% and the effect of equity weighting is therefore to make B's damage much more important.

How is the value of e selected? If logarithmic utility functions are chosen and e is interpreted as the elasticity of the marginal utility of income, then $e=1$, and we have the results shown above. Various alternative weights could be chosen, e.g. to reflect income elasticities of demand.

There are many problems involved in such procedures, but they illustrate the idea of "value sensitivity". The issue of interpersonal utility comparisons has been addressed above. There is also the question of what per capita income figure to use. Here the answer is surely purchasing parity rather than exchange-rate based per capita income. For low-income countries, the former tend to be about three times as high as the latter, whereas the two are approximately equal for rich countries. The use of exchange-rate based per capita income would inappropriately increase still further the multiple of the developing country welfare weight relative to the industrial country welfare weight. Further, what is the time reference of the per capita income? In principle it should be in the year for which the damage is calculated, and thus, say, 2050 and beyond. By then the per capita income multiple of rich relative to poor nations should have diminished from more rapid growth in the latter, reducing the differences among relative welfare weights.

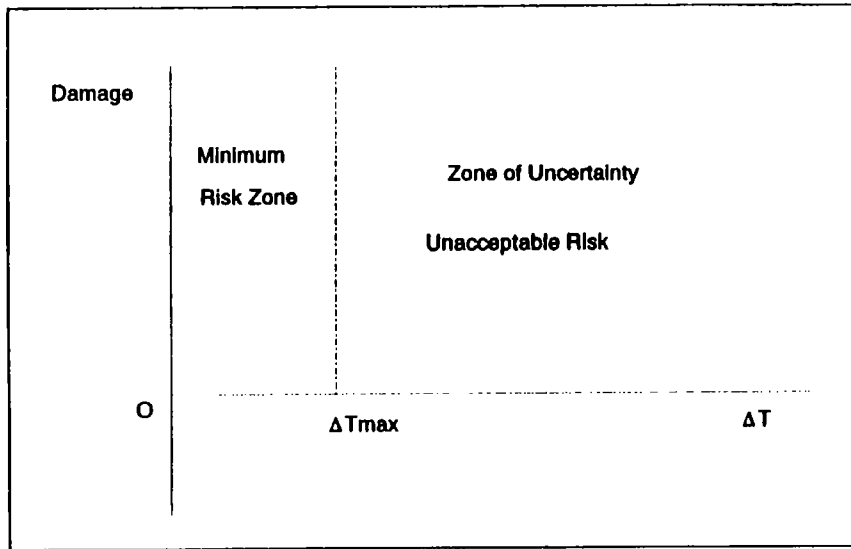
Consideration of welfare-weighted impacts widens the array of policy implications. In one dimension, it helps show how extreme effects for some countries might count for relatively more than minor effects summed over a larger block of countries (e.g. welfare effects for an island state expected to be inundated might be larger than would be attributed solely on the basis of its income or even population). The reason is that the marginal utility rises as per capita income declines, so that utility-based damage for one country with a 30 percent loss in per capita income is greater than the sum for five other countries of equal size but

with 6 percent income reduction each. In another dimension, consideration of welfare-weighting quickly leads to recognition of gains from trade in greenhouse effects. Income available is based on country shares in global income, whereas utility effects essentially involve population weighting. In a cooperative international abatement program, there is a resulting opportunity for efficient trades in which rich countries allocate some of their income to defray the losses of poorer countries that are equivalent in absolute terms to the income transferred but much larger in terms of utility otherwise sacrificed. Of course, this same dynamic suggests that a utility-oriented approach would counsel larger amounts of grant aid to poor countries already today, irrespective of the greenhouse effect. That such larger flows do not presently occur (they would have to completely eliminate per capita income differences to remove the gain from utility trade) is not an argument for failing to consider welfare weighting in greenhouse damage analysis, if only because there is a qualitative and ethical difference between refraining from assisting on the one hand and imposing damage on the other.

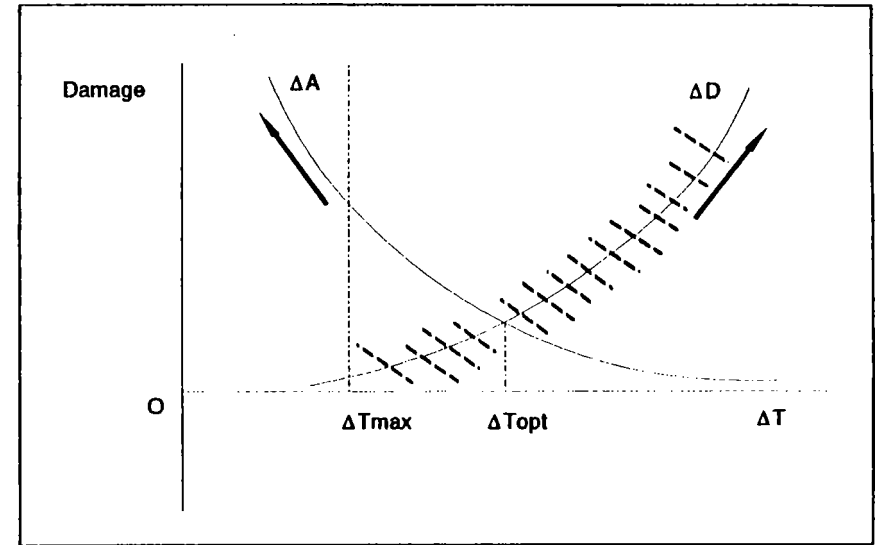
Box 3.3 Relative Damage in Developing and Industrial Countries

Various factors influence expected damage from global warming in less developed countries (LDCs) as opposed to industrial countries (DCs), as a fraction of (purchasing-power) GDP.

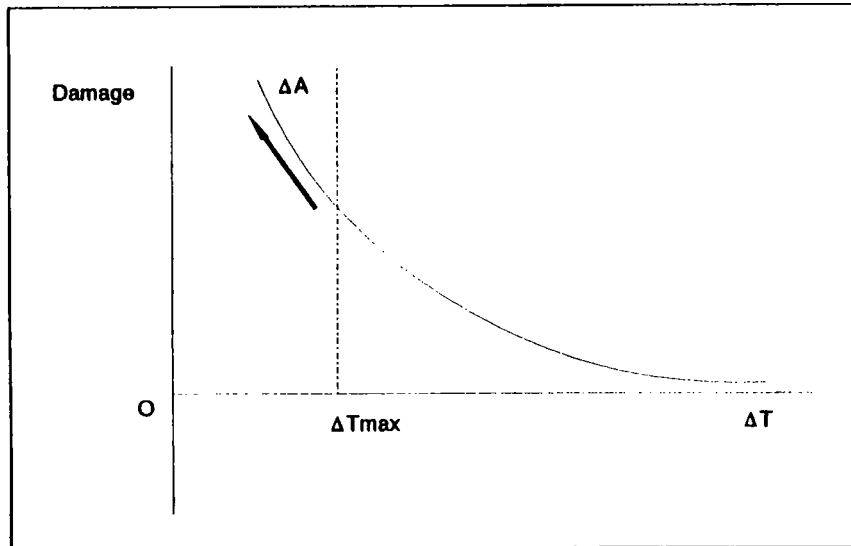
- *Location:* In general, warming is expected to be greater at higher latitudes. Because the developing countries tend to be located closer to the equator, from this standpoint one would expect *lesser* impact on developing than on industrial countries.
- *Economic Structure:* Because LDCs have a much higher share of GDP in agriculture, and therefore a larger share of output directly exposed to climatic influences, one would expect a *greater* impact on LDCs than on DCs from this standpoint.
- *Coastal Vulnerability:* The incidence of coastal vulnerability to sea level rise and possible increase in tropical cyclone damage is probably *greater* in LDCs than DCs. Although vulnerable areas can be found in industrial countries (for example, Louisiana), vulnerability is particularly high for such LDCs as Bangladesh, Egypt, and China. Low-lying island states tend to be LDCs. Of 50 countries or territories identified as having shore protection costs above 0.5 percent of GDP annually as a consequence of a 1-metre rise in sea level, all but one (New Zealand) are LDCs (IPCC, 1990b).
- *Rigidities:* Capacity to adapt to warming may be more limited in developing countries. Adaptation requires an investment outlay, and low-income communities tend to have lower savings rates and flexibility to undertake these investments. Thus, Rosenzweig *et al.* (1993) identify *greater* relative damage to agriculture in LDCs, partly because crops are already grown nearer to heat tolerance limits but also because of lesser expected capacity to adapt than in DCs. A possible consideration in the other direction is that the economy growing more rapidly has a lower fraction of past fixed investment in its total capital stock, and thus easier adjustment.
- *Human Life:* Because of poorer nutrition and health infrastructure, proportionate loss of life from global warming (from heat waves, increased hunger risk, possible tropical storm damage increase) seems likely to be *greater* in LDCs than in DCs. Valuation effects could go either way. Most statistical life valuation techniques would place a lower unit value in a country with lower per capita income (see Box 3.1). However, some would question this differentiation on ethical grounds. Moreover, income-related differences would tend not to affect impacts expressed as a fraction of GDP, as the base would also be proportionately lower.



(a) Absolute Standard Approach



(c) Cost-Benefit Approach



(b) Safe Minimum Standard Approach

Figure 3.1 Global Warming, Cost-Benefit Analysis and Sustainable Development.

Damages	Market Impacts				Non-Market Impacts			
	Primary sector damage	Other sector damage	Property loss	Damage from extreme events	Ecosystem damage	Human amenity impacts	Damage from extreme events	
Fully and suitably estimated	agriculture ¹		dryland loss coastal protect.		wetland loss			
Fully estimated, using approximations	forestry	water supply		hurricanes	forest loss		hurricanes	
Partially estimated	fisheries ²	energy demand leisure activity	urban infrastructure		species loss	human life air pollution water pollution migration		
Not estimated	insurance construction transport energy supply			non trop. storms droughts river floods hot/cold spells other catastrophes	other ecosystems loss	morbidity physical comfort polit. stability human hardship	non trop. storms droughts river floods hot/cold spells other catastrophes	

¹ widespread disagreement
² often included in wetland loss

Source: own graph.

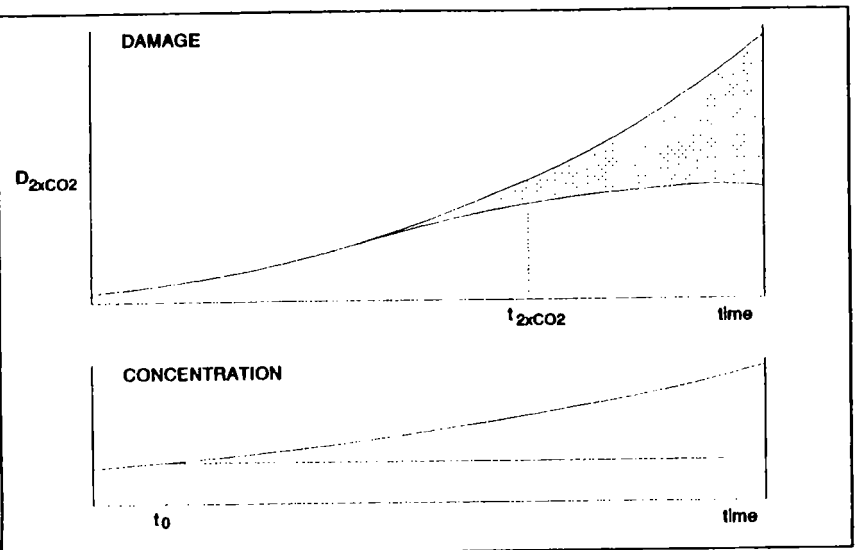


Figure 3.2 2xCO₂ Damage vs. Abatement Benefits. Under business-as-usual greenhouse gas concentration levels will continue to rise over time (upward sloping line in the concentration graph). As a consequence annual global warming damages will rise over time as well (upper line in the damage graph). If instead concentration levels are stabilised at time t_0 , the annual damage curve will follow a more flat trajectory. The benefit of this stabilisation policy is represented by the shaded area: the sum of avoided damages in all time periods.

Table 3.2 *The Economic Value of Endangered Species and Prized Habitats*

Country	Species or Habitat	Value (1990\$/year/person)
Norway	brown bear, wolf and wolverine	15.0
	conservation of rivers against hydroelectric development	59.0-107.0
United States	bald eagle	12.4
	emerald shiner	4.5
	grizzly bear	18.5
	bighorn sheep	8.6
	whooping crane	1.2
	blue whale	9.3
	bottlenose dolphin	7.0
	California sea otter	8.1
	northern elephant seal	8.1
	humpback whale ¹	40-48 (without information) 49-64 (with information)
	Grand Canyon (visibility)	27.0
	Colorado wilderness	9.3-21.2
Australia	Nadgee Nature Reserve (NSW)	28.1
	Kakadu Conservation Zone (NT) ²	40.0 (minor damages) 93.0 (major damages)
UK	nature reserves ³	40.0 (informed individuals)

¹ Respondents divided into two groups one of which was given video information

² Two scenarios of mining development damage were given to respondents

³ Survey of informed individuals only

Source: Pearce (1993).

Table 3.3 *Reported Fatalities due to Weather Events 1989-1992*

Region	Total Number 1989	1990	1991	1992	Average
Africa	31	138	> 621	> 360 > 69 ¹	> 288 > 215 ¹
Asia	> 4,300	> 3,280	> 142,000 > 3,000 ²	> 7,766 > 2,766 ²	> 39,337 > 3,337 ²
South America	> 35	26	> 117	108	> 72
Central & North America	> 75	> 57	> 86	> 131	> 87
South West Pacific	17	804	6,640 296 ³	90	1,888 302 ³
Europe	> 52	> 129	> 65	> 424	> 161
Total:					
all events	> 4,483	> 4,434	> 149,529	> 8,879	> 41,831
excl. major disasters	> 4,483	> 4,434	> 4,185	> 3,588	> 4,173

¹ Excluding the Madagascar 1992 drought and famine.

² Excluding the Bangladesh 1991 and Pakistan 1992 floods

³ Excluding the Philippines 1991 storm

Source: Limbert (1993).

Table 3.5 Quantitative 2xCO₂ Damages in Different World Regions (2.5°C warming)

Type of damage	Damage indicator	EU	USA	Ex USSR	China	Non-OECD	OECD	World
agriculture	welfare loss (% GNP)	0.21	0.16	0.24	2.10	0.28	0.17	0.23
forestry	forest area lost (km ²)	52	282	908	121	334	901	1,235
fishery	reduced catch (1000t)	558	452	814	464	4,326	2,503	6,829
energy	rise in electricity demand (TWh)	54.2	92.0	54.6	17.1	142.7	211.2	353.9
water	reduced water availability (km ³)	15.3	32.7	24.7	32.2	168.5	62.2	230.7
coastal protect.	annual capital costs (m\$/yr)	133	176	51	24	514	493	1,007
dryland loss	area lost (1000 km ²)	1.6	10.7	23.9	0	99.5	40.4	139.9
wetland loss	area lost (1000 km ²)	9.9	11.1	9.8	11.9	219.1	33.9	253.0
ecosystems loss	number of protected habitats lost, assuming 2% loss (section 3.2.12)	16	8	?	4	53	53	106
health/mortality	number of deaths (1000)	8.8	6.6	7.7	29.4	114.8	22.9	137.7
air pollution	equivalent increase in emissions (1000 t NO ₂)	566	1,073	1,584	227	2,602	1,943	4,545
troposph. O ₃	(1000 t sulphur)	285	422	1,100	258	1,864	873	2,737
SO ₂								
migration	additional immigrants (1000)	229	100	153	583	2,279	455	2,734
hurricanes								
casualties	number of deaths	0	72	44	779	7,687	313	8,000
damages	m\$	0	115	1	13	124	506	630

Source: after Fankhauser (1994a).

Table 3.4 Economic Damages from Global Warming: US Economy at Present Scale (base year 1990; billion \$)

	2xCO ₂			
	Cline (2.5°C)	Fankhauser (2.5°C) ¹	Titus (4°C)	Tol (2.5°C) ²
agriculture	17.5	8.4	1.2	10.0
Forest Loss	3.3	0.7	43.6	-
Species Loss	4.0 + a	8.4	-	5.0
Sea Level Rise	7.0	9.0	5.7	8.5
Electricity	11.2	7.9	5.6	-
Non-Electric Heating	- 1.3	-	-	-
Human Amenity	+ b	-	-	12.0
Human Morbidity	+ c	-	-	-
Human Life	5.8	11.4	9.4	37.4
Migration	0.5	0.6	-	1.0
Hurricanes	0.8	0.2	-	0.3
Construction	± d	-	-	-
Leisure Activities	1.7	-	-	-
Water Supply availability	7.0	15.6	11.4	-
pollution	-	-	32.6	-
Urban Infrastructure	0.1	-	-	-
Air Pollution tropospheric Ozone other	3.5 + e	7.3	27.2	-
Mobile Air Cond.	-	-	2.5	-
Total	61.1	69.5	139.2	74.2
(% of GDP)	+a+b+c+d+e (1.1)	(1.3)	(2.5)	(1.5) ²

¹ transformed from 1988 to 1990 base

² USA and Canada, base year 1988

Sources: Cline (1992a), Fankhauser (1994a), Titus (1992), Tol (1994b).

Table 3.6 Monetary 2xCO₂ Damage in Different World Regions

	Fankhauser bn\$	(1994a) %GDP ¹	Tol (1994b) bn\$	%GDP ¹
• European Union	63.6	1.4		
• United States	61.0	1.3		
• Other OECD	55.9	1.4		
• OECD America			74.2	1.5
• OECD Europe			56.5	1.3
• OECD Pacific			59.0	2.8
<i>Total OECD</i>	<i>180.5</i>	<i>1.3</i>	<i>189.5</i>	<i>1.6</i>
• E. Europe / Former USSR	18.2 ²	0.7 ²	- 7.9	-0.3
• Centrally Planned Asia	16.7 ³	4.7 ³	18.0	5.2
• South and South East Asia			53.5	8.6
• Africa			30.3	8.7
• Latin America			31.0	4.3
• Middle East			1.3	4.1
<i>Total Non-OECD</i>	<i>89.1</i>	<i>1.6</i>	<i>126.2</i>	<i>2.7</i>
<i>World</i>	<i>269.6</i>	<i>1.4</i>	<i>315.7</i>	<i>1.9</i>

¹ Note that the GDP base may differ between the studies

² Former Soviet Union only

³ China only

Sources: Fankhauser (1994a), Tol (1994b).

Table 3.7 Expert Opinion on Climate Change Damage

	<i>Scenario A</i> 3°C warming by 2090	<i>Scenario B</i> 6°C warming by 2175	<i>Scenario C</i> 6°C warming by 2090
<i>Damage Relative to World GDP</i> (% of GDP)			
mean answer	3.6	6.7	10.4
median answer	1.9	4.1	5.5
range of answers	0.0 - 21.0	0.0 - 35.0	0.8 - 62.0
<i>Probability of</i> <i>Damage > 25% of GNP (%)</i>			
mean answer	4.8	12.1	17.5
median answer	0.5	3.0	5.0
range of answers	0.0 - 30.0	0.2 - 75.0	0.3 - 95.0

Source: Poll of experts, Nordhaus (1994a).

Table 3.8 *Illustrative Damages from Long Term Warming: US Economy at Present Scale*
(base year 1990; billion \$)

	Long Term Warming (10°C)
Agriculture	95.0
Forest Loss	7.0
Species Loss	16.0 + A
Sea Level Rise	35.0
Electricity	64.1
Non-Electric Heating	- 4.0
Human Amenity	+ B
Human Morbidity	+ C
Human Life	33.0
Migration	2.8
Hurricanes	6.4
Construction	± D
Leisure Activities	4.0
Water Supply availability	56.0
pollution	-
Urban Infrastructure	0.6
Air Pollution tropospheric ozone	19.8
other	+ E
Total	335.7 + A + B + C ± D + E
(% of GDP)	(6.1)

Source: Cline (1992a).

Table 3.9 *Losses of Rice Output in Coastal Zones of Bangladesh*

Year	SLR by 2070: (1000 tonnes)	45 cm (% coastal output)	SLR by 2070: (1000 tonnes)	100 cm (% coastal output)
2020	125	2	412	4
2050	2,122	28	7,708	49
2070	2,619	28	9,514	50

Source: Asaduzzaman (1994).

Table 3.10 *Vulnerability Index for Different Categories of Countries*
(High vulnerability is indicated by values closer to 1)

Country Categories	Number of Countries	Index
All countries	113	0.376
Small Island Developing Countries	20	0.590
Island Developing Countries	28	0.539
Developing Countries	91	0.417
Non-island Developing Countries	85	0.322
Developed Countries	22	0.208

Source: Briguglio (1993). The index for country j is $\Sigma_i V_{ij}/3$, where $V_{ij} = (X_{ij} - \min X_i)/(\max X_i - \min X_i)$. X is the value of the component variable in the index, and $i = 1$ to 3 the number of variables influencing the index.

Table 3.11 *The Social Costs of CO₂ Emissions in Different Decades*
(current value (1990)\$/(tC))

Study	Type	1991-2000	2001-2010	2011-2020	2021-2030
Nordhaus (1991)	MC	7.3 (0.3-65.9)			
Ayres and Walter (1991)	MC	30 - 35			
Nordhaus (1993a, b)	CBA	5.3	6.8	8.6	10.0
Cline (1992b, 1993d)	CBA	5.8 - 124	7.6 - 154	9.8 - 186	11.8 - 221
Peck and Teisberg (1992)	CBA	10 - 12	12 - 14	14 - 18	18 - 22
Fankhauser (1994a, b)	MC	20.3 (6.2-45.2)	22.8 (7.4-52.9)	25.3 (8.3-58.4)	27.8 (9.2-64.2)
Maddison (1994)	CBA/MC	5.9-6.1	8.1 - 8.4	11.1-11.5	14.7-15.2

Note: MC = marginal social cost study,
CBA = shadow value in a cost-benefit study.
Figures in brackets denote 90% confidence intervals.

Sources: as indicated.

Table 3.13 The Social Costs of Air Pollution (\$/tonne)

Country	SO ₂	NO _x	CO	Particulates	VOC	Source
UK	367	124	15	21,333	n.a.	Pearce (1994)
UN ECE ¹	637	490	n.a.	21,333	n.a.	Pearce (1994)
Norway	500 - 7,600	1,600 - 31,400	1 - 13	2,100 - 27,700	n.a.	Alfsen <i>et al.</i> (1992)
US	4,800	2,000	n.a.	2,700	n.a.	Ottinger <i>et al.</i> (1990)
US	300 - 1,800	10 - 100	n.a.	400 - 10,900	360 - 2,400	Scheraga and Leary (1994)

¹ Damage done by a tonne of *UK emissions* to Western and Eastern Europe, incl. UK (UN ECE region).

Sources: as shown.

Table 3.12 Reduced Air Emissions due to CO₂ Abatement
(% reduction compared to baseline)

Country	Year	Policy/Scenario	CO ₂	SO ₂	NO _x	CO	Partic.	VOC	Secondary Benefits (\$/tC)	Sources
Europe ¹	2000	EU carbon/energy tax - current product. structure - cost efficient regime	9.4	7.4	6.2	n.a.	n.a.	n.a.	6.1	Alfsen <i>et al.</i> (1993)
			9.7	9.3	6.4	n.a.	n.a.	n.a.	6.6	
Norway	2000	Emission stabilisation (at 1989 level)	15.0	20.8	10.8	24.1	4.3	n.a.	40 - 140 ²	Alfsen <i>et al.</i> (1992)
UK	2005	EU carbon/energy tax	12.1	38.3	10.6	9.6	30.3	1.1	40 - 1040	Barker (1993)
US	2000	Emission stabilisation - through carbon tax - through Btu tax	8.6	1.9 ³	6.6	1.5	1.0/1.8 ⁴	1.4	2.0 - 20	Scheraga and Leary (1994)
			8.6	2.2 ³	6.6	3.4	1.6/2.2 ⁴	2.7	3.5 - 28	

¹ Western and Eastern Europe (UN ECE region). Tax in 6 EU countries (France, Germany, UK, Italy, Netherlands, Denmark) and Scandinavia (Norway, Finland, Sweden) only

² including road traffic benefits (reduced congestion, noise, accident, and road damage costs)

³ SO_x

⁴ PM 10 / TSP

Sources: as shown.

Extended Bibliography

- Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Ritchie, B.A. McCarl, J.D. Glycer, R.B. Curry, J.W. Jones, K.J. Boote, and L.H. Allen Jr. (1990),
Global Climate Change and US Agriculture, in: *Nature* 345(17 May): 219-223.
- Adger, N. and S. Fankhauser (1993),
Economic Analysis of the Greenhouse Effect: Optimal Abatement Level and Strategies for Mitigation, in: *International Journal of Environment and Pollution* 3(1-3): 104-119.
- Agarwal, A. and S. Narain (1991),
Global Warming in an Unequal World. A Case of Environmental Colonialism, Mimeo, Centre for Science and Environment, New Delhi.
- Amano, A. (1994),
Estimating Secondary Benefits of Limiting CO₂ Emissions in the Asian Region, Mimeo, School of Business Administration, Kobe University.
- Alfsen, K., H. Birkelund, and M. Aaserud (1993),
Secondary Benefits of the EC Carbon/Energy Tax, Research Department Discussion Paper No 104, Statistics Norway, Oslo.
- Alfsen, K.H., A. Brendemoen, and S. Glomsrød (1992),
Benefits of Climate Policies: Some Tentative Calculations, Discussion Paper No. 69, Norwegian Central Bureau of Statistics, Oslo.
- Ali, S. I. and S. Huq (1990),
International Sea Level Rise: National Assessment of Effects and Possible Responses for Bangladesh, Unpublished Report to the University of Maryland, College Park.
- Allen, Bruce D., and Roger Y. Anderson (1993),
Evidence from Western North America for Rapid Shifts in Climate During the Last Glacial Maximum, in: *Science* 260(25 June): 1920-23.
- Anderson, D. and R. Williams (1993),
The Cost Effectiveness of GEF Projects, Working Paper No. 6, Global Environment Facility, Washington DC.
- Anklin, M., et al. (1993),
Climate Instability During the Last Interglacial Period Recorded in the GRIP Ice Core, in: *Nature* 364 (15 July): pp. 203-07.
- Arnell, N.W. and W.R. Dubourg (1994),
Implications for Water Supply and Water Management, in: M.L. Parry (ed.), *Economic Implications of Climate Change in Britain*, London: Earthscan, forthcoming.
- Arrow, K.J. and M. Kurz (1970),
Public Investment, the Rate of Return and Optimal Fiscal Policy, Baltimore: Johns Hopkins University Press.
- Asaduzzaman, S. (1994),
Economic and Social Impacts of Climate Change: a Case Study of Bangladesh Coastal Zone, Mimeo, Bangladesh Institute of Development Studies, Dhaka.
- Awosika, L., A.Ibe, and M.Udo-Aka. (1990),
Impact of Sea Level Rise on the Nigerian Coastal Zone, in Titus, J.G (ed), *Changing Climate and the Coast*, Vol.2, US Environmental Protection Agency, Washington DC.
- Ayres, R. and J. Walter (1991),
The Greenhouse Effect: Damages, Costs and Abatement, in: *Environmental and Resource Economics* 1: 237-270.
- Baan, P.J.A., H. van der Most, G.B.M. Pedrolí and H. van Zuijlen (1993),
Systeemverkenning Gevolgen van Klimaatverandering (in Dutch: System Exploration Impact of Climatic Change), Delft: Delft Hydraulics.
- Barker, T. (1993),
Secondary Benefits of Greenhouse Gas Abatement: The Effects of a UK Carbon/Energy Tax on Air Pollution, Energy Environment Economy Modelling Discussion Paper No. 4, Department of Applied Economics, University of Cambridge.
- Batie, S.S. and H.H. Shugart (1989),
The Biological Consequences of Climate Changes: An Ecological and Economic Assessment, in: N.J. Rosenberg et al. (eds.), *Greenhouse Warming: Abatement and Adaptation*, Washington, DC: Resources for the Future.
- Bazzaz, F. A. and E.D. Fajer (1992),
Plant Life in a CO₂-Rich World, in: *Scientific American*, 266(1): 68-74.
- Berz, G. (1990),
Natural Disasters and Insurance/Reinsurance, in: *UNDRO News*, January/February: 18-19.
- Berz, G.A. and Conrad, K. (1993),
Winds of Change, in: *The Review*, June: 32-35.
- Bigford, T.E. (1991),
Sea Level Rise, Nearshore Fisheries, and the Fishing Industry, in: *Coastal Zone Management* 19: 417-437.
- Birdsall, N. and A. Steer (1993),
Act Now on Global Warming - But Don't Cook the Books, in: *Finance & Development* 30(1): 6-8.
- Blanchard, O.J. and S. Fischer (1989),
Lectures on Macroeconomics, Cambridge, MA: MIT Press.
- Bradford, D.F. (1975),
Constraints on Government Investment Opportunities and the Choice of Discount Rate, in: *American Economic Review* 65(50): 887-899.

- Briguglio, L. (1993),
The Economic Vulnerabilities of Small Island Developing States, Report to UNCTAD, Geneva.
- Broccoli, A.J. and S. Manabe (1990),
Can Existing Climate Models Be Used to Study Anthropogenic Changes in Tropical Cyclone Climate?, in: *Geophysical Research Letters* 17 (11): 1917-1920.
- Broome, J. (1992),
Counting the Costs of Global Warming, Cambridge: White Horse Press.
- Bryant, E.A. (1991),
Natural Hazards, Cambridge: Cambridge University Press.
- Canadian Climate Program Board (1988a),
Implications of Climate Change for Downhill Skiing in Quebec, Climate Change Digest Report, CCD 88-03, Downsview, Ontario.
- Canadian Climate Program Board (1988b),
Implications of Climate Change for Tourism and Recreation in Ontario, Climate Change Digest Report, CCD 88-05, Downsview, Ontario.
- Carson, R., R. Mitchell, W.M. Hanemann, R. Kopp, S. Presser and P. Ruud (1994),
Contingent valuation and Loss Passive Use: Damages from the Exxon Valdez, Discussion Paper 94-18, Resources for the Future, Washington DC.
- Chakraborty, B. and M. Lal (1994),
Monsoon Climate and its Change in Doubled Carbon Dioxide Atmosphere as Simulated by CSIRO9, Mimeo, unpublished.
- Changnon, S.A. and Changnon, J.M. (1992),
Temporal Fluctuations in Weather Disasters: 1950-1989, in: *Climatic Change*, 22: 191-208.
- Clark, K.M. (1988),
Predicting Insurance Getting Easier, in: *National Underwriter*, 29 August 1988.
- Clark, K.M. (1991),
Catastrophe Reinsurers Need More, Better Data, in: *National Underwriter*, September.
- Cline, W. (1991),
Scientific Basis of the Greenhouse Effect, in: *Economic Journal* 101(407): 904-919.
- Cline, W.R. (1992a),
The Economics of Global Warming, Washington, DC: Institute for International Economics.
- Cline, W.R. (1992b),
Optimal Carbon Emissions over Time: Experiments with the Nordhaus DICE Model, Mimeo, Institute for International Economics, Washington, DC.
- Cline, W.R. (1993a),
Give Greenhouse Abatement a Fair Chance, in: *Finance & Development* 30(1): 3-5.

- Cline, W.R. (1993b),
The Impact of Global Warming on the United States: A Survey of Recent Literature, Mimeo, Institute for International Economics, Washington, DC (April).
- Cline, W.R. (1993c),
The Costs and Benefits of Greenhouse Abatement: A Guide to Policy Analysis, Paper presented at the OECD/IEA Conference on "The Economics of Global Warming", June 1993, Paris.
- Cline, W.R. (1993d),
Modelling Economically Efficient Abatement of Greenhouse Gases, Paper presented at the United Nations University Conference on "Global Environment, Energy and Economic Development", September 1993, Tokyo.
- Cline, W.R. (1993e),
A Note on the Impact of Global Warming on Air Conditioning and Heating Costs, Mimeo, Institute for International Economics, Washington, DC (January).
- Cline, W.R. and C.T. Hsieh (1993),
Optimal Carbon Emissions in the Nordhaus DICE Model under Backstop Technology, Mimeo, Institute for International Economics, Washington, DC (July).
- Collard, D. (1988)
Catastrophic Risk: Or the Economics of Being Scared, in: D. Collard, D.W. Pearce and D. Ulph (eds.) *Economics, Growth and Sustainable Environments: Essays in Memory of Richard Lecomber*, New York: Macmillan.
- Commonwealth Secretariat (1989),
Climate Change: Meeting the Challenge, Report of a Commonwealth Group of Experts, Commonwealth Secretariat, London.
- CRU/ERL (1992),
Development of a Framework for the Evaluation of Policy Options to Deal with The Greenhouse Effect: Economic Evaluation of Impacts and Adaptive Measures in the European Community, A Report for the Commission of European Communities, Climate Research Unit (CRU), University of East Anglia, and Environmental Resources Limited (ERL), London.
- Daily, G.C., P.R. Ehrlich, H.A. Mooney, and A.H. Ehrlich (1991),
Greenhouse Economics: Learn before you Leap, in: *Ecological Economics* 4: 1-10.
- Dansgaard, W., J.W.C. White, and S.J. Johnsen (1989),
The Abrupt Termination of the Younger Dryas Climate Event, in: *Nature* 339 (15 June): 532-34.
- Darmstadter, J. and M.A. Toman, eds. (1993),
Assessing Surprises and Nonlinearities in Greenhouse Warming Washington, DC: Resources for the Future.
- den Elzen, M.G.J. and J. Rotmans (1992),
The Socio-Economic Impact of Sea-Level Rise on the Netherlands: A Study of Possible Scenarios, in: *Climatic Change* 20: 169-195.

Dlugolecki, A., D. Clement, C. Elvy, G. Kirby, J. Palutikoff, R. Salthouse, C. Toomer, S. Turner and D. Witt (1994),
The Impact of Changing Weather Patterns on Property Insurance, Report, Chartered Insurance Institute, London.

Dlugolecki *et al.* (1995),
Financial Services Including Insurance, in: IPCC, Second Assessment Report of Working Group II, forthcoming.

Doornkamp, (1993),
 Clay Shrinkage Induced Subsidence, in: *Geographical Journal* 159(2): 196-202.

Dowlatabadi, H. and G. Morgan (1993),
 A Model Framework for Integrated Studies of the Climate Problem, in: *Energy Policy* 21: 209-221.

Easterling III, W.E., P.R. Crosson, N.J. Rosenberg, M.S. McKenney, L.A. Katz and K.M. Lemon (1993),
 Agricultural Impacts of and Responses to Climate Change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region, in: *Climatic Change* 24(1/2): 23-62.

Edmonds, J. and J. Reilly (1985),
Global Energy. Assessing the Future, New York: Institute for Energy Analysis.

El-Reay, M. (1990),
 Responses to the Impacts of Greenhouse-induced Sea Level Rise on the Northern Coastal Regions of Egypt, in Titus, J.G (ed), *Changing Climate and the Coast*, Vol.2, US Environmental Protection Agency, Washington DC.

Emanuel, K.A. (1987),
 The Dependence of Hurricane Intensity on Climate, in: *Nature* 326: 483- 485.

Environmental Protection Agency (1989),
The Potential Effects of Global Climate Change on the United States, J.B. Smith and D. Tirpak, eds., Washington, DC: EPA.

Environmental Protection Agency (1990),
Progress Reports on International Studies of Climate Change Impacts, Draft, EPA, Washington, DC (November).

Erickson, J.D. (1993),
 From Ecology to Economics: The Case against CO₂ Fertilization, in: *Ecological Economics* 8: 157-175.

Evans, D.J. *et al.* (1991),
Policy Implications of Greenhouse Warming, Washington, DC: National Academy Press.

Fankhauser, S. (1994a),
Valuing Climate Change. The Economics of the Greenhouse Effect, London: Earthscan, forthcoming.

Fankhauser, S. (1994b),
 The Social Costs of Greenhouse Gas Emissions: An Expected Value Approach, in: *Energy Journal* 15(2): 157-184.

Fankhauser, S. (1994c),
 Protection vs. Retreat. The Economic Costs of Sea Level Rise, in: *Environment and Planning A*, forthcoming.

Fankhauser, S. and C. Hope (1994),
 Greenhouse Policies and the Costs of Mitigation, in: M.L. Parry (ed.), *Economic Implications of Climate Change in Britain*, London: Earthscan, forthcoming.

Fellner, W. (1967),
 Operational Utility: The Theoretical Background and a Measurement, in: *Ten Economic Studies in the Tradition of Irving Fisher*, New York: John Wiley & Sons.

Fisher, A.C. and W.M. Hahnemann (1993),
 Assessing Climate Change Risks: Valuation of Effects, in: J. Darmstadter and M. Toman (eds.), *Assessing Surprises and Non-Linearities in Greenhouse Warming*, Washington, DC: Resources for the Future.

Gleick, P.H. (1987),
 Regional Hydrologic Consequences of Increases in Atmospheric CO₂ and Other Trace Gases, in: *Climatic Change* 10: 137-61.

Gleick, P.H. (1992),
Water and Conflict, Project on Environmental Change and Acute Conflict, University of Toronto.

Gleick, P.H. and E.P. Maurer (1990),
Assessing the Costs of Adapting to Sea Level Rise. A Case Study of San Francisco Bay, Mimeo, Pacific Institute for Studies in Development, Environment and Security, and Stockholm Environment Institute, Berkeley, CA and Stockholm.

Glynn, P.W. and W.H. de Weerd (1991),
 Elimination of Reef-building Hydrocorals Following the 1982-83 El Niño Warming Event, in: *Science* 253 (5 July): 69-71.

Goering, J.M. (1990),
The Causes of Undocumented Migration to the United States: A Research Note, Working Papers No. 52, Commission for the Study of International Migration and Cooperative Economic Development.

Goklany, I.M. (1989),
 Climate change Effects on Fish, Wildlife and other DOI Programs, in: J.C. Topping, Jr. (ed.), *Coping with Climate Change*.

Graßl, H. *et al.* (1995),
Catastrophes and Extreme Events, in: IPCC, Second Assessment Report of Working Group I, forthcoming.

- Grubb, M. (1993),
The Costs of Climate Change: Critical Elements, in: Y. Kaya, N. Nakićenović, W.D. Nordhaus and F. Toth (eds.), *Costs, Impacts and Benefits of CO₂ Mitigation*, IIASA Collaborative Paper Series, CP93-2, Laxenburg, Austria.
- Intowski, W.J., G.F. McMahon, S.S. Schlachter, and P.H. Kirshen (1992),
Effects of Global Warming on Hurricane-Induced Flooding, Paper prepared for US Department of Energy, Washington, DC.
- Haarsma, R.J., J.F.B. Mitchell and C.A. Senior (1993),
Tropical Disturbances in a GCM, in: *Climate Dynamics* 8: 247-257.
- Haines, A. and C. Fuchs (1991),
Potential Impacts on Health of Atmospheric Change, in: *Journal of Public Health Medicine* 13(2): 69-80.
- Haines, A. and M. Parry (1993),
Climate Change and Human Health, in: *Journal of the Royal Society of Medicine* 86(December): 707-711.
- Han, M., J.Hou and L.Wu (1990),
Adverse Impact of Projected One Meter Sea Level Rise on China's Coastal Environment and Cities, University of Maryland, Maryland, *mimeo*.
- Hansen, J. et. al. (1989),
Regional Greenhouse Climate Effects, in: J.C. Topping, Jr. (ed.), *Coping with Climate Change*, pp. 68-81.
- Heathcote, R.L. (1985),
Extreme Event Analysis, in: R.W. Kates, J.H. Ausubel and M. Berberian (eds.), *Climate Impact Assessment*, Chichester: John Wiley and Sons.
- Hoffert, M.I. and C. Covey (1992),
Deriving Global Climate Sensitivity from Paleoclimate Reconstructions, in: *Nature* 360(10 December): 573-76.
- Hohmeyer, O. and M. Gärtner (1992),
The Costs of Climate Change, Report to the Commission of the European Communities, Fraunhofer Institut für Systemtechnik und Innovations-Forschung, Karlsruhe (Germany).
- Homer-Dixon, T.F., J.H. Boutwell, and G.W. Rathjens (1993),
Environmental Change and Violent Conflict, in: *Scientific American*, 268(2): 38-45.
- Hope, C., J. Anderson, and P. Wenman (1993),
Policy Analysis of the Greenhouse Effect. An Application of the PAGE Model, in: *Energy Policy* 21(3): 327-338.
- Houghton, J. (1994),
Global Warming. The Complete Briefing, London: Lion Book.

- Howarth, R.B. (1992),
International Justice and the Chain of Obligation, *Environmental Values*, 1, 133-140.
- Howarth, R.B. and P.A. Monahan (1992),
Economics, Ethics, and Climate Policy, Mimeo, Lawrence Berkeley Laboratory, Berkeley, CA.
- Idso, S.B., R.C. Balling Jr. and R.S. Cerveny (1990),
Carbon Dioxide and Hurricanes: Implications of Northern Hemispheric Warming for Atlantic/Caribbean Storms, in: *Meteorology and Atmospheric Physics* 42: 259-263.
- Intergovernmental Panel on Climate Change (1990a),
Climate Change, the IPCC Scientific Assessment. Report from Working Group I, Cambridge: Cambridge University Press.
- Intergovernmental Panel on Climate Change (1990b),
Climate Change, the IPCC Impacts Assessment. Report from Working Group II, Canberra: Australian Government Publishing Service.
- Intergovernmental Panel on Climate Change (1990c),
Strategies for Adaptation to Sea Level Rise. Report of the Coastal Zone Management Subgroup, The Hague.
- Intergovernmental Panel on Climate Change (1992a),
Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment, Cambridge: Cambridge University Press.
- Intergovernmental Panel on Climate Change (1992b),
Global Climate Change and the Rising Challenge of the Sea. Supporting Document for the IPCC Update 1992, Geneva: WMO and UNEP.
- Intergovernmental Panel on Climate Change (1994),
Preparing to Meet the Coastal Challenges of the 21st Century. Conference Report of the World Coast Conference, Nordwijk, November 1993, Geneva: WMO and UNEP.
- Intergovernmental Panel on Climate Change (1995),
Second Assessment Report of Working Group I, forthcoming.
- Jansen, H.M.A. (1993),
Are We Underestimating, When Valuing the Benefits of Greenhouse Gas Reduction? in: Y. Kaya, N. Nakićenović, W.D. Nordhaus and F. Toth (eds.), *Costs, Impacts and Benefits of CO₂ Mitigation*, IIASA Collaborative Paper Series, CP93-2, Laxenburg, Austria.
- Kaiser, H.M., S.J. Riha, D.S. Wilks, D.G. Rossiter, and R. Sampath (1992),
A Farm-level Analysis of the Economic and Agronomic Impacts of Gradual Climate Warming, Mimeo, Department of Agricultural Economics, Cornell University, Syracuse, NY (May).
- Kalkstein, L.S. (1989),
The Impact of CO₂ and Trace Gas-Induced Climate Changes upon Human Mortality, in: J.B. Smith and D.A. Tirpak (eds.), *The Potential Effects of Global Climate Change on the United States. Appendix G: Health*, Washington DC: EPA.

- Kandlikar, M. (1994),
Catastrophic Climate Damage: Results from ICAM-2, Mimeo, Carnegie Mellon University, Pittsburgh.
- Kane, S., J. Reilly, and J. Tobey (1992),
An Empirical Study of the Economic Effects of Climate Change on World Agriculture, in: *Climatic Change* 21: 17-35.
- Kimball, B. and N.J. Rosenberg, eds. (1990),
The Impact of CO₂, Trace Gases, and Climate Change, Publication No. 53, American Society of Agronomy, Madison, WI.
- Kirshen, P. H. and N.M. Fennessey (1992),
Potential Impacts of Climate Change upon the Water Supply of the Boston Metropolitan Area, Mimeo, US Environmental Protection Agency, Washington, DC (October).
- Klinedinst, P.L., D.A. Wilhite, G.L. Hahn, and K.G. Hubbard (1993),
The Potential Effects of Climate Change on Summer Season Dair Cattle Milk Production and Reproduction, in: *Climatic Change*, 23(1): 21-36.
- Knox Lovell, C.A. and V.K. Smith (1985),
Microeconomic Analysis, in: R.W. Kates, J.H. Ausubel and M. Berberian (eds.), *Climate Impact Assessment*, Chichester: John Wiley and Sons.
- Körner, C. and J.A. Arnone III (1992),
Responses to Elevated Carbon Dioxide in Artificial Tropical Ecosystems, in: *Science* 257 (18 September): 1672-75.
- Krause, F., W. Bach, and J. Kooney (1989),
Energy Policy in the Greenhouse, London: Earthscan.
- Kunst, A.E., C.W.N. Looman and J.P. Mackenbach (1993),
Outdoor Air Temperature and Mortality in the Netherlands: A Time-Series Analysis, in: *American Journal of Epidemiology* 137(3): 331-341.
- Langford, I.H. and G. Bentham (1993),
The Potential Effects of Climate Change on Winter Mortality in England and Wales, Centre for Social and Economic Research on the Global Environment (CSERGE), Working Paper GEC 93-25, University of East Anglia and University College London.
- Leary, N. (1994),
The Amenity Value of Climate: A Review of Empirical Evidence from Migration, Wages and Rents, US Environmental Protection Agency, Discussion Paper, July.
- Leggett, J. (1993),
Climate Change and the Insurance Industry. Solidarity among the Risk Community, Greenpeace International, Amsterdam.
- Limbert, D.W.S. (1993),
The Human and Economic Impacts of Weather Events in 1992, in: *WMO Bulletin* 42(4): 333-341.

- Lind, R.C., ed. (1982),
Discounting for Time and Risk in Energy Policy, Washington, DC: Resources for the Future.
- Loveland, J.E. and G.Z. Brown (1992),
Impacts of Climate Change on the Energy Performance of Buildings in the United States, Mimeo, US Office of Technology Assessment, Washington, DC.
- MacDonald, G.J. (1990),
Role of Methane Clathrates in Past and Future Climates, in: *Climatic Change* 16: 247-81.
- Maddison, D.J. (1994),
The Shadow Price of Greenhouse Gases and Aerosols, Mimeo, Centre for Social and Economic Research on the Global Environment (CSERGE), University College London and University of East Anglia, Norwich.
- Magadza, C.H.D. (1991),
Some Possible Impacts of Climate Change on African Ecosystems, in: J. Jäger and H.L. Ferguson (eds), *Climate Change. Science, Impacts and Policy. Proceedings of the Second World Climate Conference*, Cambridge: Cambridge University Press.
- Magalhães, A.R. and M.H. Glantz, eds. (1992),
Socioeconomic Impacts of Climate Variations and Policy Responses in Brazil, United Nations Environmental Programme, Nairobi, and Esquel Brazil Foundation, Brasilia.
- Manabe, S. and R.J. Stouffer (1993),
Century-scale Effects of Increased Atmospheric CO₂ on the Ocean-Atmosphere System, in: *Nature* 364(15 July): 215-218.
- Manne, A.S., R. Mendelsohn, and R.G. Richels (1993),
MERGE - A Model for Evaluating Regional and Global Effects of Greenhouse Gas Reduction Policies, Mimeo, Electric Power Research Institute, Palo Alto, CA.
- Manne, A.S. and R.G. Richels (1992),
Buying Greenhouse Insurance, Cambridge MA: MIT Press.
- Markandya, A., and D.W. Pearce (1988),
Environmental Considerations and the Choice of Discount Rate in Developing Countries, Environment Department, World Bank, Washington DC.
- Maunder, W.J. (1994),
Tropical Cyclones in the South Pacific: An Historical Overview Regarding the Intensity, Tracks, and Frequency of Tropical Cyclones in the South Pacific during the Last 100 Years, and an Analysis of any Changes in these Factors, Institute for Environmental Studies, Free University Amsterdam.
- McLean, D.M. (1989),
A Mechanism for Greenhouse-Induced Collapse of Mammalian Faunas in: J.C. Topping Jr. (ed.), *Coping with Climate Change*, pp. 263-67.

- Mearns, L.O., R.W. Katz and S.H. Schneider (1984),
Extreme High Temperature Events: Changes in their Probabilities with Changes in Mean Temperature, in: *Journal of Climate and Applied Meteorology* 23: 1601-1613.
- Mendelsohn, R., W. Nordhaus, and D. Shaw (1992),
The Impact of Climate on Agriculture: A Ricardian Approach, Discussion Paper No. 1010, Cowles Foundation, New Haven, Conn.
- Midun, Z. and S Lee (1989),
Effect of Climate Change and Sea Level Rise on Bangladesh, Report to the Commonwealth Group of Experts, Commonwealth Secretariat, London.
- Milliman, J.D., J.M. Broadus, and F. Gable (1989),
Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples, in: *Ambio* 18(6): 340-345.
- Morgenstern, R.D. (1991),
Towards a Comprehensive Approach to Global Climate Change Mitigation, in: *American Economic Review, Papers and Proceedings* 81(2): 140-145.
- Munich Re (1993),
Winter Storms in Europe - Analysis of 1990 Losses and Future Loss Potential, Munich Re: Munich.
- Nicholls, R., K. Dennis, and S. Leatherman (1990),
Impacts of Sea level Rise on Selected Developing Countries, Proceedings of 3rd European Workshop on Coastal Zones, Cyprus, September 1990.
- Nicholls, R., K. Dennis, C. Volonte and S. Leatherman (1992),
Methods and Problems in Assessing the Impacts of Accelerated Sea level Rise, Proceedings of the Workshop "The World at Risk: Natural Hazards and Climate Change", American Institute for Physics, New York.
- Nishioka, S., H. Harasawa, H. Hashimoto, T. Ookita, K. Masuda, and T. Morita (1993),
The Potential Effects of Climate Change in Japan, Centre for Global Environmental Research, and National Institute for Environmental Studies, Tsukuba (Japan).
- Nordhaus, W.D. (1991),
To Slow or not to Slow: The Economics of the Greenhouse Effect, in: *Economic Journal* 101(407): 920-937.
- Nordhaus, W.D. (1992),
The DICE Model: Background and Structure of a Dynamic Integrated Climate Economy Model of the Economics of Global Warming, Discussion Paper No. 1009, Cowles Foundation, New Haven, Conn.
- Nordhaus, W.D. (1993a),
Optimal Greenhouse Gas Reductions and Tax Policy in the "DICE" Model, in: *American Economic Review, Papers and Proceedings* 83(2): 313-317.

- Nordhaus, W.D. (1993b),
Rolling the "DICE": An Optimal Transition Path for Controlling Greenhouse Gases, in: *Resources and Energy Economics* 15(1): 27-50.
- Nordhaus, W.D. (1993c),
Reflections on the Economics of Climate Change, in: *Journal of Economic Perspectives*, 7(4): pp. 11-25.
- Nordhaus, W.D. (1994a),
Expert Opinion on Climate Change, in: *American Scientist*, January-February.
- Nordhaus, W.D. (1994b),
Managing the Global Commons: The Economics of Climate Change, Cambridge, MA: MIT Press, forthcoming.
- Nordhaus, W.D. and G.W. Yohe (1983),
Future Carbon Dioxide Emissions from Fossil Fuels, in: National Research Council, *Changing Climate*, Washington: National Academy Press.
- Office of Management and Budget (OMB) and US Department of Agriculture (USDA) (1989),
Climate Impact Response Functions, Report of a Workshop Held at Coolfont, West Virginia, Sept. 11-14.
- Ominde, S.H. and C. Juma (1991),
A Change in Weather, African Centre for Technology Studies, Nairobi: ACTS Press.
- Ottinger, R.L., D.R. Wooley, N.A. Robinson, D.R. Hodas and Susan E. Babb (1990),
Environmental Costs of Electricity, Pace University Centre for Environmental and Legal Studies, New York: Oceana Publications.
- Page, T. (1977),
Conservation and Economic Efficiency, Baltimore: Johns Hopkins University Press.
- Parry, M. (1990),
Climate Change and World Agriculture, London: Earthscan.
- Parry, M. (1993),
Climate Change and the Future of Agriculture, in: *International Journal of Environment and Pollution* 3(1-3): 13-30.
- Parry, M.L., M. Blamant de Rozari, A.L. Chong and S. Panich (1991),
The Potential Socio-Economic Effects of Climate Change in South-East Asia, Nairobi: United Nations Environmental Programme, Nairobi.
- Parry, M.L., T.R. Carter, and N.T. Konijn, eds. (1988),
The Impacts of Climate Variations on Agriculture, 2 Volumes, Dordrecht: Kluwer.
- Pearce, D.W. (1986),
Cost-Benefit Analysis, London: Macmillan.

- Pearce, D.W. (1992),
The Secondary Benefits of Greenhouse Gas Control, Global Environmental Change Working Paper GEC 92-12, Centre for Social and Economic Research on the Global Environment, University College London and University of East Anglia, Norwich.
- Pearce, D.W. (1993),
Economic Values and the Natural World. London: Earthscan.
- Pearce, D.W. (1994),
Costing the Environmental Damage from Energy Production, Mimeo, Centre for Social and Economic Research on the Global Environment, University College London and University of East Anglia, Norwich.
- Pearce, D.W., G. Atkinson and R. Dubourg (1994),
 What is Sustainable Development?, in: *Annual Review of Energy*, forthcoming.
- Pearce, D.W., and D. Ulph (1994),
Estimating a Social Discount Rate for the United Kingdom, Mimeo, Centre for Social and Economic Research on the Global Environment, University College London and University of East Anglia.
- Peck, S.C. and T.J. Teisberg (1992),
 CETA: A Model for Carbon Emissions Trajectory Assessment, in: *Energy Journal* 13(1): 55-77.
- Peck, S.C. and T.J. Teisberg (1993a),
 CO₂ Emissions Control: Comparing Policy Instruments, in: *Energy Policy* 21(3): 222-230.
- Peck, S.C. and T.J. Teisberg (1993b),
 Global Warming Uncertainties and the Value of Information: An Analysis Using CETA, in: *Resource and Energy Economics* 15(1): 71-97.
- Penner, J.E., R.E. Dickinson, and C.A. O'Neill (1992),
 Effects of Aerosol from Biomass Burning on the Global Radiation Budget, in: *Science* 256(5 June): 1432-33.
- Pernetta, J.C. (1989),
 Projected Climate Change and Sea-Level-Rise: A Relative Impact Rating for the Countries of the Pacific Basin, in: J.C. Pernetta and P.J. Hughes (eds.), *Implications of Expected Climate Changes in the South Pacific: An Overview*, UNEP Regional Seas Reports and Studies 128, United Nations Environmental Programme, Nairobi.
- Pernetta, J.C. (1992),
 Impacts of Climate Change and Sea Level Rise on Small Island States, *Global Environmental Change*, 2(1), 19-31
- Peters, R.I. and T.E. Lovejoy, eds. (1992),
Global Warming and Biological Diversity, New Haven: Yale University Press.
- Pezzey, J. (1994),
The Optimal Sustainable Depletion of Non-renewable Resources, Mimeo, Department of Economics, University College London.

- Ramsey, F.P. (1928),
 A Mathematical Theory of Saving, in: *Economic Journal* 138(152): 543-559.
- Raper, S.C.B. (1993),
 Observational Data on the Relationships between Climate Change and the Frequency and Magnitude of Severe Tropical Storms, in: W.W. Warrick, E.M. Barrow and T.M.L. Wigley (eds.) *Climate and Sea Level Change*, Cambridge University Press, Cambridge.
- Reilly, J., J.A. Edmonds, R.H. Gardner, and A. L. Brenkert (1987),
 Uncertainty Analysis of the IEA/ORAU CO₂ Emissions Model, in: *Energy Journal*, 8(3): 1-29.
- Reilly, J. and N. Hohmann (1993),
 Climate Change and Agriculture: The Role of International Trade, in: *American Economic Review, Papers and Proceedings* 83(2): 306-312.
- Reilly, J., N. Hohmann and S. Kane (1994),
 Climate Change and Agricultural Trade: Who Benefits, Who Loses?, in: *Global Environmental Change* 4(1): 24-36.
- Revelle, R.R. (1983),
 Probable Future Change in Sea Level Resulting from Increased Atmospheric Carbon Dioxide, in: National Research Council, *Changing Climate*, Washington, DC: National Academy Press.
- Rijkswaterstaat (1991),
Rising Waters. Impacts of the Greenhouse Effect for the Netherlands, Dutch Ministry of Transport and Public Works, The Hague.
- Rijsberman, F. (1991),
 Potential Costs of Adapting to Sea Level Rise in OECD Countries, in: OECD, *Responding to Climate Change: Selected Economic Issues*, Paris: OECD.
- Rijsberman, F. and R.J. Swart, eds. (1990),
Targets and Indicators of Climate Change, Stockholm Environment Institute, Stockholm.
- Rind, D., D. Glodberg, J. Hansen, C. Rosenzweig, and R. Ruedy (1990),
 Potential Evapotranspiration and the Likelihood of Future Drought, in: *Journal of Geophysical Research* 95(D7): 9,983-10,004.
- Ritchie, J.T., B.D. Baer, and T. Y. Chou (1989),
 Effect of Global Climate Change on Agriculture: Great Lakes Region, in: US Environmental Protection Agency, *The Potential Effects of Global Climate Change on the United States*, Washington, DC: EPA.
- Roberts, L. (1991),
 Costs of a Clean Environment, in: *Science* 251 (8 March): 1182.
- Rosebrock, J. (1993),
Time-Weighting Emission Reductions for Global Warming Projects - A Comparison of Shadow Price and Emission Discounting Approaches, Mimeo, The World Bank, Washington, DC.

Rosenberg N.J. (1992),
Adaptation of Agriculture to Climate Change, in: *Climatic Change* 21(4): 385-405.

Rosenberg, N.J. et al. (1989a),
Policy Options for Adaptation to Climate Change, Resources for the Future Discussion Paper
ENR 89-05, RFF, Washington, DC.

Rosenberg, N.J., W.E. Easterling III, P.R. Crosson, and J. Darmstadter, eds. (1989b),
Greenhouse Warming: Abatement and Adaptation, Washington, DC: Resources for the Future.

Rosenberg, N.J., and P.R. Crosson (1991a),
Processes for Identifying Regional Influences of and Responses to Increasing Atmospheric CO₂ and Climate Change - the MINK Project, Resources for the Future, for US Department of
Energy, TR052A, Washington, DC.

Rosenberg, N.J. and P.R. Crosson (1991b),
The MINK Project: A New Methodology for Identifying Regional Influences of, and Responses
to, Increasing Atmospheric CO₂ and Climate Change, in: *Environmental Conservation* 18(4):
313-322.

Rosenthal, D.H., H.K. Gruenspecht, and E.A. Moran (1994),
Effects of Global Warming on Energy Use for Space Heating and Cooling in the United States,
Mimeo, US Department of Energy, Washington, DC (March).

Rosenzweig, C. and D. Hillel (1993),
Agriculture in a Greenhouse World, in: *National Geographic Research & Exploration* 9(2): 208-
21.

Rosenzweig, C. and M.L. Parry (1994),
Potential Impact of Climate Change on World Food Supply, in: *Nature* 367(13 January): 133-
138.

Rosenzweig, C., M. Parry, K. Frohberg, and G. Fisher (1993),
Climate Change and World Food Supply, Environmental Change Unit, Oxford.

Rothenberg, J. (1993),
Economic Perspectives on Time Comparisons, in: C. Nazli (ed.), *Global Accord: Environmental
Challenges and International Responses*, Cambridge, MA: MIT Press.

Ryan, B.F., I.G. Watterson and J.L. Evans (1992),
Tropical Cyclone Frequencies Inferred from Gray's Yearly Genesis Parameter: Validation of
GCM Tropical Climates, in: *Geophysical Research Letters*, 19 (18): 1831-1834.

SAARC (1992),
Regional Study on Greenhouse Effect and its Impact on the Region, Report, South Asian
Association for Regional Cooperation, Kathmandu.

Schelling, T.C. (1983),
Climatic Change: Implications for Welfare and Policy, in: National Research Council, *Changing
Climate*, Washington, DC: National Academy Press.

Schelling, T.C. (1992),
Some Economics of Global Warming, in: *American Economic Review* 82(1): 1-14.

Schelling, T.C. (1993),
Intergenerational Discounting, Mimeo, University of Maryland, College Park (November).

Scheraga, J.D. and N.A. Leary (1994),
Costs and Side Benefits of Using Energy Taxes to Mitigate Global Climate Change, in:
Proceedings of the 86th Annual Conference, National Tax Association, Washington, DC.

Scheraga, J.D., N.A. Leary, R.J. Goettle, D.W. Jorgenson, and P.J. Wilcoxon (1993),
Macroeconomic Modelling and the Assessment of Climate Change Impacts, in: Y. Kaya, N.
Nakićenović, W.D. Nordhaus and F. Toth (eds.), *Costs, Impacts and Benefits of CO₂ Mitigation*,
IIASA Collaborative Paper Series, CP93-2, Laxenburg, Austria.

Schlesinger, M.E. and X. Jiang (1990),
Simple Model Representation of Atmosphere-Ocean GCMs and Estimation of the Time Scale of
CO₂-induced Climate Change, in: *Journal of Climate* 3(December): 12.

Schneider, S.H. (1994),
Detecting Climatic Change Signals: Are There Any "Fingerprints?", in: *Science* 263(21 January):
341-47.

Schneider, S.H. and R. S. Chen (1980),
Carbon Dioxide Warming and Coastline Flooding: Physical Factors and Climatic Impact, in:
American Review of Energy 5: 107-40.

Schneider, S.H. and N.J. Rosenberg (1989),
The Greenhouse Effect: Its Causes, Possible Impacts, and Associated Uncertainties, in: N.J.
Rosenberg, W.E. Easterling III, P.R. Crosson, and J. Darmstadter (eds.), *Greenhouse Warming:
Abatement and Adaptation*, Washington, DC: Resources for the Future.

Scott, M.F. (1989),
A New View of Economic Growth, Oxford: Clarendon Press.

Sedjo, R.A. and A.M. Solomon (1989),
Climate and Forests, in: N.J. Rosenberg, W.E. Easterling III, P.R. Crosson, and J. Darmstadter
(eds.), *Greenhouse Warming: Abatement and Adaptation*, Washington, DC: Resources for the
Future.

Smith, J.B., S. Ragland, and E. Trabka (1993),
Standardized Estimates of Climate Change Damages for the United States, Mimeo, RCG/Hagler
Bailly, Boulder, CO (December).

Smith, J.B., F.D. Stern, C.A. Yermoli, and W.S. Breffle (1994),
The Impact of Climate change on Thermoelectric Power Use in Egypt and Poland, Mimeo,
RCG/Hagler Bailly, Boulder, CO (February).

Smith, K. (1992),
Environmental Hazards: Assessing Risk and Reducing Disaster, London: Routledge.

- Solomou, S. (1990),
The Impact of Climatic Variations on Construction Cycles and Economic Activity, 1856-1913,
 Mimeo, University of Cambridge (August).
- Spash, C. (1994),
 Double CO₂ and Beyond: Benefits, Costs and Compensation, *Ecological Economics*, 10, 27-36.
- Sundquist, E.T. (1990),
 Long-Term Aspects of Future Atmospheric CO₂ and Sea-Level Changes, in: R.R. Revelle *et al.*,
Sea-Level Change, National Research Council, Washington, DC: National Academy Press.
- Titus, J.G. (1987),
 The Causes and Effects of Sea Level Rise, in: H.G. Wind, *Impact of Sea Level Rise on Society*.
- Titus, J.G. (1991),
 Greenhouse Effect and Coastal Wetland Policy: How Americans Could Abandon an Area the
 Size of Massachusetts, in: *Environmental Management Journal* 15(1): 39-58.
- Titus, J.G. (1992),
 The Cost of Climate Change to the United States, in: S.K. Majumdar, L.S. Kalkstein, B. Yarnal,
 E.W. Miller, and L.M. Rosenfeld (eds.), *Global Climate Change: Implications Challenges and
 Mitigation Measures*, Pennsylvania: Pennsylvania Academy of Science.
- Titus, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, S. Brown, C.
 Gaunt, M. Trehan, and G. Yohe (1991),
 Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea, in: *Coastal Zone
 Management* 19: 172-204.
- Tol, R.S.J. (1994a),
 The Damage Costs of Climate Change: A Note on Tangibles and Intangibles Applied to DICE,
 in: *Energy Policy* 22(5): 436-438.
- Tol, R.S.J. (1994b),
The Damage Costs of Climate Change: Towards More Comprehensive Calculations (revised
 version), Working Document W94/?, Free University Amsterdam, forthcoming.
- Tol, R.S.J., C. Dorland, E. van der Hul, F.P.M. Leek, A.A. Olsthoorn, P. Veling and P.E. van
 der Werff (1994),
Climate, Extremes, Risk and Risk Management, Mimeo, Institute for Environmental Studies, Free
 University Amsterdam.
- Turner, R.K., P. Doktor, and N. Adger (1993),
 Sea Level Rise and Coastal Wetlands in the UK: Mitigation Strategies for Sustainable
 Management, in: A.M. Jansson, C. Folke, R. Costanza, and M. Hammer (eds.), *Investing in
 Natural Capital: The Ecological Economic Perspective*, Covelo, CA: Island Press.
- Turner, R.K., S. Subak, N. Adger and J. Parfitt (1994),
*How are Socio-Economic Systems Affected by Climate-Related Changes in the Coastal Zone? A
 Report to IPCC Working Group II, Subgroup B*, Centre for Social and Economic Research on
 the Global Environment (CSERGE), University of East Anglia and University College London.

- UK Climate Impact Review Group (1991),
The Potential Effects of Climate Change in the United Kingdom, Report prepared at the Request
 of the Department of the Environment, London: HMSO.
- US FEMA-FIA (1991),
Projected Impact of Relative Sea Level Rise on the National Flood Insurance Programme,
 Federal Emergency Management Agency and Federal Insurance Administration, Washington DC.
- Viscusi, W.K. (1993). The Value of Risks to Life and Health, in: *Journal of Economic Literature*,
 XXXI(December): 1912-1946.
- Waggoner, P.E. (1990),
Climate Change and US Water Resources, New York: Wiley.
- Waggoner, P.E. *et al* (1992),
Preparing US Agriculture for Global Climate Change, Report No. 119, Council for Agricultural
 Science and Technology, Ames, Iowa.
- Waggoner, P.E. (1994),
How Much Land Can Ten Billion People Spare for Nature? Report No. 121, Council for
 Agricultural Science and Technology, Ames, Iowa.
- Waters, S. (1990),
The Travel Industry World Yearbook: The Big Picture, Madrid: World Tourism Organization.
- Wendland, W.M. (1977),
 Tropical Storm Frequencies Related to Sea Surface Temperatures, in: *Journal of Applied
 Meteorology* 16(5): 477-81.
- Wigley, T.M.L., and S.C.B. Raper (1992),
 Implications for Climate and Sea Level of revised IPCC Emissions Scenarios, in: *Nature* 357:
 293-300.
- World Health Organisation (1990),
Potential Health Effects of Climatic Change, Geneva: WHO.
- World Resources Institute (1990),
World Resources 1990-91: A Guide to the Global Environment, Vol. 4. World Resources Series.
 New York: Oxford University Press.
- World Resources Institute (1992),
World Resources 1992-93: A Guide to the Global Environment, Vol. 5. World Resources Series.
 New York: Oxford University Press.
- Yohe, G.W. (1993),
 Sorting Out Facts and Uncertainties in Economic Response to the Physical Effects of Global
 Climate Change, in: J. Darnstadter and M. Toman (eds.), *Assessing Surprises and Non-
 Linearities in Greenhouse Warming*, Washington, DC: Resources for the Future.