Policy and Decision Models
Final Examination
29 January 2009

Topic: Copenhagen Climate Conference

Instructions

The following exam consists of 15 questions, for a sum total of 100 points. The questions all discuss implications of the recent Copenhagen climate conference. There is no one single text for the case; instead there is a running discussion throughout.

The questions are selected and ordered as appropriate for the case. They are not, for instance, ordered according to the presentation in Straffin. Some questions are analytical while others are interpretative. If asked your opinion, what is expected is a clear and defensible answer. In fact, for these interpretive questions there may be multiple possible answers. Note that some questions are worth 10 points, while others are worth 5 points.

You have three hours; collect your points wisely. You will be given three warnings as the exam completes. The exam is open book. You may use a calculator. Please write your answers with the paper provided. Please include your name and student number on every sheet.

Question 1 (5 points). Carbon Apportionment

Table 1 below shows some comparative world statistics for Europe, U.S., China, and the rest of the world. Suppose the industrial era was just about to begin, and we knew that carbon dioxide was a "bad" which was to be apportioned carefully among the world's citizens. Select the metric of your choice for apportioning carbon, and defend your choice.

		GDP		Population		Person-Years
		billions 2010 USD$		millions		billion people-years
		2000	2050	2000	2050	1750-2050
	Rest of the World	24694	150005	4115	7366	574600
	Europe	10855	45425	386	471	74675
	US	12468	63426	272	420	37150
	China	7138	47783	1240	1437	187000
Units	Total	55155	306639	6013	9694	873425
	Rest of the World	44.8%	48.9%	68.4%	76.0%	65.8%
	Europe	19.7%	14.8%	6.4%	4.9%	8.5%
	US	22.6%	20.7%	4.5%	4.3%	4.3%
	China	12.9%	15.6%	20.6%	14.8%	21.4%
Percent	Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 1: Comparative World Statistics

Question 2 (5 points). Carbon Balances

The table below shows the actual total consumption of CO_2 by nation as of 2010. Of the total 511 billion tons which some say we can safely introduced into the atmosphere, we have used all but 26. We have, perhaps unknowingly, used almost the entirety of the permissible store of carbon dioxide in the atmosphere. Using your answer from question 1, and the summary values below, conclude which nations have spent too much, and which nations have spent too little.

	CO_2 Consumption to Date	
	Billion metric tons of CO2	Percentage
Rest of the World	315	64.9%
Europe	51	10.5%
U.S.	91	18.8%
China	28	5.8%
Total	485	100.0%

Table 2: Actual World Consumption CO_2 to Date

Question 3 (5 points). Calculating the Status Quo

The 2009 Copenhagen Climate Conference faced the following apparent status quo. The calculation involves calculating the costs of disastrous climate change (356 trillion USD), which in the table below is distributed according to world population. There are also benefits, which involve the potential unconstrained usage of carbon at today's rates. The table below shows that the status quo is most beneficial for the United States, which has a comparatively high usage, and a relatively low fraction of the world population. On the contrary, the rest of the world despite its high carbon usage cannot overcome the expected high burden of damage.

	Costs		Benefits		net
	percent population	Damages (trillion USD)	yearly carbon consumption (billion metric tons)	market value of continued consumption (trillion USD)	trillion 2010 USD
Rest of the World	76.0%	-270.56	6.16	7.55	-263.01
Europe	4.9%	-17.44	0.74	0.91	-16.54
U.S.	4.3%	-15.31	1.18	1.44	-13.87
China	14.8%	-52.69	2.52	3.09	-49.60

Table 3: The Status Quo

The calculated status quo is predicated on many assumptions. One is the discount rate for future generations. These calculations use 4% which assumes we only consider the next 25 years of cost. Another is the value per metric ton of carbon. These figures use a price of $49 metric tons, which is higher than current European market price ($18). Yet another is the distribution of damages. These figures distribute damage according to the proportion of world population. Arguably the rest of the world will have higher costs than shown here, since it lacks the wealth to mitigate the worst effects of change. A final assumption involves the total costs of disastrous climate change. The Stern Report places the costs at 4.5% of the world economy, while acknowledging that the true costs may be four times higher or lower.

In your opinion how robust are these estimates of the status quo? Which assumptions critically underpin these estimates? Defend your answer.

Question 4 (10 points). N-Person Games of Remediation

For the following question assume that the rest of the world continues to pollute. The players in the game are Europe, U.S. and China. Each player has two strategic options -- continue to pollute, or to remediate. Remediation involves paying the market value of carbon consumed by the polluting players. If multiple players remediate, they share the costs of remediation equally. If all players remediate then they divide the value of the remaining carbon equally. If no player remediates then climate change occurs, and the status quo payoffs given above apply.

The strategic form of the three person game based upon these assumptions is as follows. Draw the movement diagram associated with this game. Identify and interpret any pure strategy Nash equilibria you may have found.

China P

Europe \ US	P	R
P	(-16.5,-13.9,-49.6)	(0.9,-11.6,3.1)
R	(-12.1,1.4,3.1)	(-5.3,-5.3,3.1)

China R

Europe \ US	P	R
P	(0.9,1.4,-8.1)	(0.9,-4.2,-4.2)
R	(-3.7,1.4,-3.7)	(0.4,0.4,0.4)

Figure 1: Three-Person Game of Carbon Remediation. Payoffs in trillion USD to (Europe, US, China).

Question 5 (5 points). Climate Change as the Prisoner's Dilemma

Is the game presented above an N-Person Prisoner's dilemma? Or is it another dilemma such as Chicken?

Question 6 (10 points). Chinese Strategic Moves

In the real world China is attempting to force Europe and the United States to move first in the game by having them commit to carbon abatement. Use the N-person game presented above, and Schelling's concept of strategic moves, to evaluate whether this is an effective strategy for China. Can you suggest other strategic moves which might work better?

Question 7 (10 points). Mixed Strategies

Suppose Europe was committed to a strategy of pollution. Simplify the game above for the players U.S. and China. Is a mixed strategy solution possible?

Question 8 (5 points). Climate Change and Institutional Arrangements

Were all the outcomes achieved in the n-person game discussed above Pareto optimal? Is there any apparent need for cooperation or arbitration? Is complete carbon abatement for all parties actually Pareto optimal?

Question 9 (5 points). Arbitration for Sustainable Development

In this question you are asked to help arbitrate aid payments to the “rest of the world” to encourage sustainable development, and to abate the worst effects of climate change. Let player A be the "rest of the world," and player B is "Europe, U.S. and China."

Our analysis of the N-player setting above assures us that at least one of the major players will abate the worst effects of climate change. Therefore set the status quo to be 7.55 for player A, and -13.00 for player B. This reflects unabated consumption on the part of the rest of the world, while Europe, U.S. and China presumably pays for its amelioration. The Pareto optimal outcome would be to agree to divide the remaining 26 billion tons of carbon and to spend no further carbon. The pool of carbon remaining provides an industrial market value of 1.3 trillion USD. Assume all distribution of costs and benefits is possible, although you should not permit either party to be made worse off by the negotiation.

Draw the pay-off polygon.

Question 10 (10 points). Nash Arbitration of Climate Change

Using the information provided from the previous question, use the Nash arbitration to calculate a fair payoff to the two players. What do these results suggest about the possibility of linking aid to low carbon development? Would the required value per metric ton of carbon need to be higher or lower than the assumed $49 rate?

Question 11 (5 points). Cooperative Games and Framework Negotiations

The previous questions demonstrate that climate change operates within a multi-actor setting. New institutional arrangements are needed for the benefit of all. Cooperative games attempt to model the effects of multi-actor negotiations and bargaining. Which concept from Straffin do you think best models the actual dynamics of the climate change conference? Why do you think so?

Question 12 (5 points). Characteristic Function of Climate Change Cooperation

For the next several questions we use a short-hand to consider the four players discussed above. Let the "rest of the world" be player A, let Europe be player B, let the United States be player C, and let China be player D.

Assume that all coalitions face the lesser of two costs: abating the pollution of others, or facing the costs of climate change. All of the one player coalitions can secure the benefits of continued consumption, and all coalitions consisting of two or greater players can share the economic benefits of sustainable carbon emissions. The resulting game in characteristic function is shown below. Note that these figures are in trillions of US $ (rounded).

$$\nu\{\phi\}=0$$

	$\nu\{A\}=2$	$\nu\{B\}=-11$	$\nu\{C\}=-10$	$\nu\{D\}=-7$	
$\nu\{A,B\}=-3$	$\nu\{A,C\}=-3$	$\nu\{A,D\}=-1$	$\nu\{B,C\}=-9$	$\nu\{B,D\}=-8$	$\nu\{C,D\}=-7$
	$\nu\{B,C,D\}=6$	$\nu\{A,C,D\}=0$	$\nu\{A,B,D\}=0$	$\nu\{A,B,C\}=-2$	

$$\nu\{A,B,C,D\}=1$$

Figure 2: Characteristic Function of Climate Negotiations Game

Is the game constant sum? Is the game super-additive? Find the strategic equivalent of this game.

Question 13 (10 points). Shapley Value of Climate Negotiations

In this question we calculate the Shapley value of a game involving climate change negotiation. The Shapley value is a natural extension of Nash arbitration to a multi-actor setting. The Shapley value is arguably the most fair process available for mediating games which in themselves may not be very fair. The Shapley value does not claim that it can be easily adopted or implemented. Nonetheless in this problem it is helpful for setting appropriate expectations in the climate change negotiation process.

Find the Shapley Value for the game in characteristic function form as given in the previous question. Convert the figures into billions of tons of carbon. Interpret the results, and provide brief recommendations for implementation.

Question 14 (5 points). China's Bargaining Position

Consider the Shapley value for China, as calculated in the previous question. Explain why Shapley recommends this value for China. Shapley recommends a "fair value" for the game as played today. Is this value also normatively fair based on your previous conclusions in question 2?

The United States and Europe state that they expect China to make immediate commitment to reducing emissions in Copenhagen. Is this a reasonable request, at least according to Shapley?

Question 15 (5 points). Green Innovation

The climate change negotiations ended without any binding commitment for future change. Investors and green innovators were expressly disappointed with the outcomes. The following question provides a "story which could be true" regarding the link between climate negotiation and new innovation.

Some commentators suggest that green innovation could be a $1.8 trillion dollar industry. While on the face of it this is a huge sum, when amortized on an annual basis this figure is less than 0.3% of the combined economy of U.S. and Europe.

Assume three players: governments, investors and inventors. Governments can commit, investors can invest, and inventors can invent. Investors can profit if the government commits; the long-term price of carbon is liable to increase from today's $18 per metric tons to figures in the range of $49 metric tons. Inventors profit only if they invent, are funded by investors, and there is government commitment for climate change. Governments must pay up to $1500 billion if they commit to climate change treaties. On the other hand, they can also profit from collecting on a portion of the profits of investors and inventors in taxes. The game is shown below.

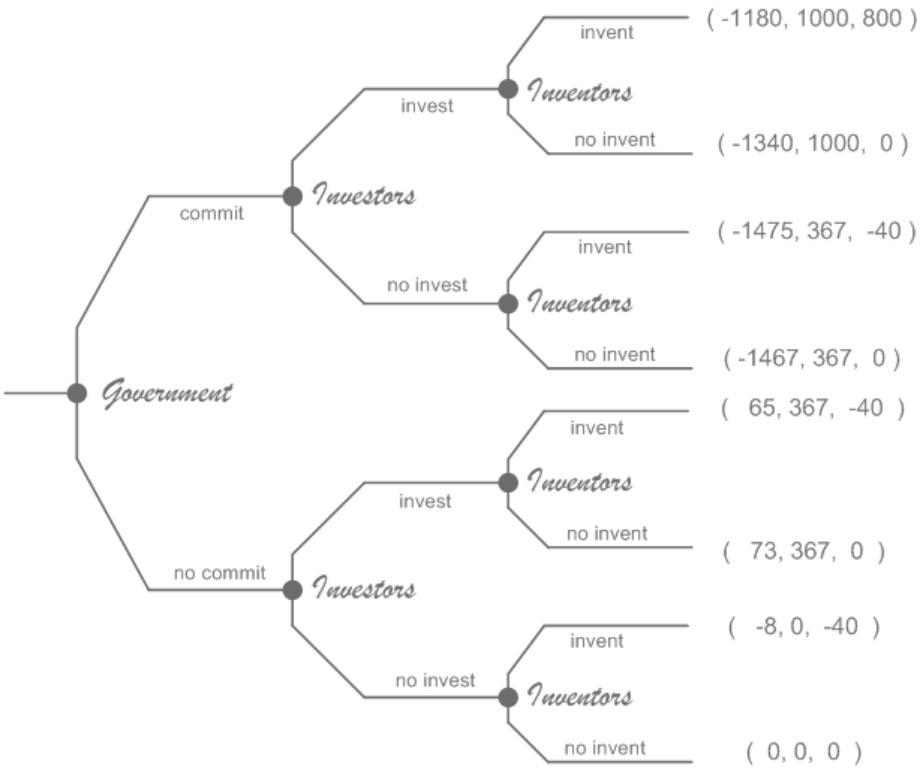

Figure 3: A Game of Green Innovation

Calculate the pure strategy equilibrium of this game.