Economics of Climate Change – Problem Set 2 (5 pts total)

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Question 1: The social discount rate (30%)

1.1 (20 pts)

One common approach to discounting is to use the Ramsey equation, which is given as follows:

$$r = \delta + \mu g$$

where r is the social discount rate. Describe what each element on the right-hand side of the Ramsey equation is intended to represent (in intuitive terms) and how each of those elements affects our valuation of economic damages that occur far in the future.

Suggested answer:

- δ is the **pure rate of time preference**. This parameter governs how impatient we are as a society. As δ increases, this raises the marginal utility of consuming now vs. later (that is, how much weight we place on our wellbeing now vs. later). As δ increases, our overall discount rate (r) increases, which means that we will value climate damages that occur far into the future less. If we thought that future generations' welfare should count equally to ours, we would choose a very low value of δ (like 0% or 0.1%).
  - Common values of δ range from 0% to 2%.
- μ is the **coefficient of relative risk aversion** or **inequality aversion parameter**. This parameter describes how much we dislike inequality in consumption levels over time. As μ increases, that means that the ratio of the value of an additional dollar to future generations to the value of an additional dollar to poorer generations increases. In other words, μ captures how much less we value a dollar paid to Jeff Bezos' of the future relative to a dollar paid to ourselves. With a larger μ that means we would value a dollar in climate damages to future generations less than a dollar in climate damages today because our generation is comparatively poorer. Increasing this parameter increases the overall social discount rate. Importantly, even if you think the pure rate of time preference should be zero (i.e., we should value all future generations' welfare equally), the inequality aversion parameter permits a positive social discount rate if you believe that an additional dollar to Jeff Bezos in the future should be worth less than an additional dollar to a college student today.
  - Common values of μ range from 1 to 4.
- g is the (expected) **growth rate in consumption per capita**, or economic growth rate per capita. This parameter captures how consumption changes over time, and is often used as a proxy for the relative income or relative wealth of future generations compared to our own generation's income/wealth. Long-run economic growth rates tend to be around 2%. As economic growth rates increase, that increases the social discount rate (so long as $\mu \geq 1$, which is typically the case.)
  - Common values of g range from 1% to 8%, but this is informed by data. g is not an "ethical" parameter like δ and μ, so we typically use economic projections to forecast g (which is a tricky business in itself...).

1.2 (10 pts)

Some economists have argued that uncertainty in the discount rate should lead us to using a lower (or declining) discount rate for discounting future climate damages. Describe two (or more) ways in which the discount rate might be uncertain.

Suggested answer: There are a variety of ways in which future discount rates could be uncertain. Here are a few examples:

- Based on the Ramsey equation, the social discount rate depends on the economic growth rate (g). Economic growth in the future is inherently uncertain, therefore the discount rate itself is uncertain.
- Discount rates are often tied to interest rates (which reflect the rate of return on investments or capital), and those interest rates may be uncertain because they are tied to fluctuations in the economy.
- Climate change itself may affect economic growth rates. It's both possible that climate damages are positively or negatively correlated with market returns and that could justify a higher/lower discount rate than 3%. We don't necessarily know which is likely to be true. Even if there's a 1% chance the correlation is positive, a 1% chance the correlation is negative, and a 98% chance that they are uncorrelated, that's enough uncertainty to influence the choice of discount rate.

Question 2: Social Cost of Carbon (50%)

Imagine President Ulysses S. Morecoal takes office in 2024 and he has a very strong anti-environment agenda. You are a lifetime civil servant in the EPA and your new directive is to minimize the size of climate damages in cost-benefit analyses to make environmental regulations look more costly (relative to their benefits). You are a respectable civil servant, so you cannot do anything unlawful and have to work within the confines of standard regulatory protocols. And, unfortunately, you can't quit. You must obey the orders from Pres. Morecoal.

2.1 (10 pts)

Your first task is to minimize the effect of climate change by providing a recommendation for a new discount rate to use for benefit-cost analysis for policies that reduce CO_2 emissions but impose regulatory costs on industry. Justify your answer so that it is difficult for opponents of Pres. Morecoal to oppose this change.

Suggested answer: There really is no wrong answer here so long as it is justifiable. In my estimation, discount rates below 1% and above 7% would be relatively difficult to defend (although probably not impossible). Full credit for this answer would be given for sound economic or ethical arguments for the choice of a discount rate, ideally pointing back to the Ramsey equation (but that's not necessary if you rely on a descriptive argument for discounting [e.g., by tying the discount rate to observed market interest rates]). The key point is that an argument for a higher discount rate would be more likely to make climate damages look smaller, all else equal. But! You can't let the ends justify the means. Just because you think climate change is/isn't important is not a valid reason to choose a low/high discount rate. You must justify your choice based on economic or ethical arguments.

2.2 (10 pts)

Your next task is to reduce the scope of whose benefits should count in U.S. regulatory analysis to make climate change damages look less extreme. Again, justify your answer.

Suggested answer: To make climate benefits look smaller, we might only consider climate damages that occur within US borders. OMB's circular A-4 actually provides fairly clear guidance that only benefits to US citizens should count for US regulatory analysis. I've actually written a somewhat nuanced interpretation here, if you're curious in reading more. The key, of course, to solving a global externality, however, is to fully account for the damages that occur regardless of where they occur.

2.3 (10 pts)

In 2028, Pres. Rashida E. Newable is elected. Pres. R. E. Newable rewards you for your commitment to climate policy and appoints you to be the U.S. climate czar. For your first task, you are given a blank slate and you must make a recommendation for a single primary discount rate that the U.S. government should use for measuring climate change damages. (You may additionally include a range of discount rates, if you so desire). This decision will be highly scrutnized from political opponents, so it is important to justify this choice based on economic (or other) arguments. There is no right answer (and your answer could be the same as in Q2.1), but you must provide a persuasive argument for your recommendation.

Suggested answer: Again, just like in 2.1, there really is no wrong answer here so long as it is justifiable. In my estimation, discount rates below 1% and above 7% would be relatively difficult to defend (although probably not impossible). Full credit for this answer would be given for sound economic or ethical arguments for the choice of a discount rate, ideally pointing back to the Ramsey equation (but that's not necessary if you rely on a descriptive argument for discounting [e.g., by tying the discount rate to observed market interest rates]). The key point is that an argument for a higher discount rate would be more likely to make climate damages look smaller, all else equal. But! You can't let the ends justify the means. Just because you think climate change is/isn't important is not a valid reason to choose a low/high discount rate. You must justify your choice based on economic or ethical arguments.

2.4 (20 pts)

You are now tasked with calculating a new social cost of carbon estimate using your discount rate. Your climate science colleagues have shared output from their state-of-the-art climate model with you that shows the trajectory of global mean temperature change for 300 years. They give you the following representations of how temperature will change:

$$T_y^{Base} = 0.02y$$

where T_y^{Base} is global surface mean temperature change in year y (from $y = 1, 2, ..., 299, 300$). Ignore any temperature change that occurs after year 300. Your climate science colleagues have also run a "perturbed" scenario where they simulated the temperature change from injecting 10,000 additional tons of CO_2 in year 0 and its resulting impact on global mean surface temperature is given as follows:

$$T_y^{Base+10{,}000tCO_2} = 0.02000000001y$$

You decide to use an empirical damage function that was published somewhat recently in *Science* by Hsiang et al. (2017). That damage function is:

$$Damages_y = GDP_{2020} \times \left(0.283T_y + 0.146T_y^2\right)$$

where $Damages_y$ are the economic damages in year y, which is a function of global GDP in 2020 (which is \$85 trillion) and a quadratic function of temperature that year. For simplicity, assume that GDP growth is zero and constant over time.

Calculate the social cost of carbon (in dollars per ton of CO_2) using your discount rate from the previous question. Compare your SCC to the current value used by the U.S. goverment: \$190/ton at a 2% discount rate).

A few hints: Similar to the discounting problem on Problem Set 1, it will be easiest to do this in a spreadsheet (or another program). Calculate the full stream of discounted economic damages each year for both the "base" scenario and the "base+10,000 tons of CO_2" scenario. Also, be mindful of your units—your initial calculations will likely be in trillions of dollars per 10,000 tons of CO_2, but you will want the SCC to be in dollars per ton.*

Suggested answer: To answer this question, set up a spreadsheet with years 1 through 300 in the first column. Then, apply the "baseline" temperature equation to get the temperature change each year. In year 300, this should be 6 degrees. Then calculate damages by applying the given damage function to this stream of temperature changes. Then, calculate the stream of discounted damages in each year using the standard PV formula (i.e., $PV_t = \text{damages}_t/(1+r)^t$, where t indicates years). Take the sum of those discounted annual damages to get the PV of damages. That's the PV of damages for the baseline scenario.

Now, do this again, but but for the "perturbed" scenario with an additional 10,000 tons of CO_2. Now you have the PV of damages for the "perturbed" scenario. The difference between those two values is your estimated SCC. Now, you just need to adjust the units to \$/ton of CO_2. I've calculated these values for a range of discount rates in the screenshot below.

	A	B	C	D	E	F	G	H
1	t	temp_base	temp_base+	damages_base ($T)	damages_base+ ($T)	discount rate	PV damages_base	PV damages_base+
2	1	0.02	0.02	0.486064	0.486064	0.03	0.471906796	0.471906796
3	2	0.04	0.04	0.982056	0.982056001	0.03	0.925681968	0.925681969
4	3	0.06	0.06	1.487976	1.487976001	0.03	1.361708826	1.361708826
5	4	0.08	0.08	2.003824	2.003824001	0.03	1.78037167	1.780371671
6	5	0.1	0.1	2.5296	2.529600001	0.03	2.182055181	2.182055182
7	6	0.12	0.12	3.065304	3.065304002	0.03	2.567143842	2.567143843
8	7	0.14	0.14	3.610936	3.610936002	0.03	2.93602141	2.936021411
9	8	0.16	0.16	4.166496	4.166496002	0.03	3.289070417	3.289070419
10	9	0.18	0.18	4.731984	4.731984003	0.03	=D10/(1+F10)^A10	3.626671717
11	10	0.2	0.2	5.3074	5.307400003	0.03	3.949204044	3.949204046
12	11	0.22	0.22	5.892744	5.892744003	0.03	4.257043643	4.257043645
13	12	0.24	0.24	6.488016	6.488016004	0.03	4.550563885	4.550563887
14	13	0.26	0.26	7.093216	7.093216004	0.03	4.83013494	4.830134943
15	14	0.28	0.28	7.708344	7.708344004	0.03	5.096123472	5.096123475
16	15	0.3	0.3	8.3334	8.333400005	0.03	5.348892352	5.348892355
17	16	0.32	0.32	8.968384	8.968384005	0.03	5.588800407	5.58880041
18	17	0.34	0.34	9.613296	9.613296006	0.03	5.816202179	5.816202182
19	18	0.36	0.36	10.268136	10.26813601	0.03	6.031447717	6.03144772
20	19	0.38	0.38	10.932904	10.93290401	0.03	6.234882384	6.234882387
21	20	0.4	0.4	11.6076	11.60760001	0.03	6.426846684	6.426846688
22	21	0.42	0.42	12.292224	12.29222401	0.03	6.607676111	6.607676114

	J	K	L
2	PV damages ($T / 10k tons)	931.6205019	<- baseline scenario
3	PV damages+ ($T / 10k tons)	931.6205026	<- "perturbed" scenario
5	SCC=	6.56702E-07	$T per 10,000 tons
6		656701.7863	$ per 10,000 ton
7		65.67017863	$ per ton
10	**Summary**		
11	SCC (at 0% rate)	$5,576.05	$ / ton CO2
12	SCC (at 1% rate)	$773.24	$ / ton CO2
13	SCC (at 2% rate)	$179.87	$ / ton CO2
14	SCC (at 3% rate)	$65.67	$ / ton CO2
15	SCC (at 4% rate)	$32.08	$ / ton CO2
16	SCC (at 5% rate)	$18.65	$ / ton CO2
17	SCC (at 6% rate)	$12.10	$ / ton CO2
18	SCC (at 7% rate)	$8.46	$ / ton CO2

How do these compare to the SCC that the US federal government uses? Well, if you chose a 3% discount rate, your SCC would be $65/ton, which is smaller than EPA's $190/ton estimate. If you chose a 2% discount rate, then your SCC value will be pretty close to the current value. If you chose a higher discount rate (e.g., 5% or 6%), then your SCC value would be much lower than the official estimate of $190/ton.

Question 3: Estimating climate damages (20%)

The following figure is from Davis & Gertler (*PNAS*, 2015).[1] The authors estimate the effect of extreme temperatures on residential electricity demand in Mexico using historical data. The figure can be interpreted as the percentage change in electricity demand as a function of the number of days each month that fall within each temperature "bin". For example, for every day >90°F in a month, electricity demand increases by 3.2% (relative to the electricity demand on a day with moderate 65–70°F temperatures that month).

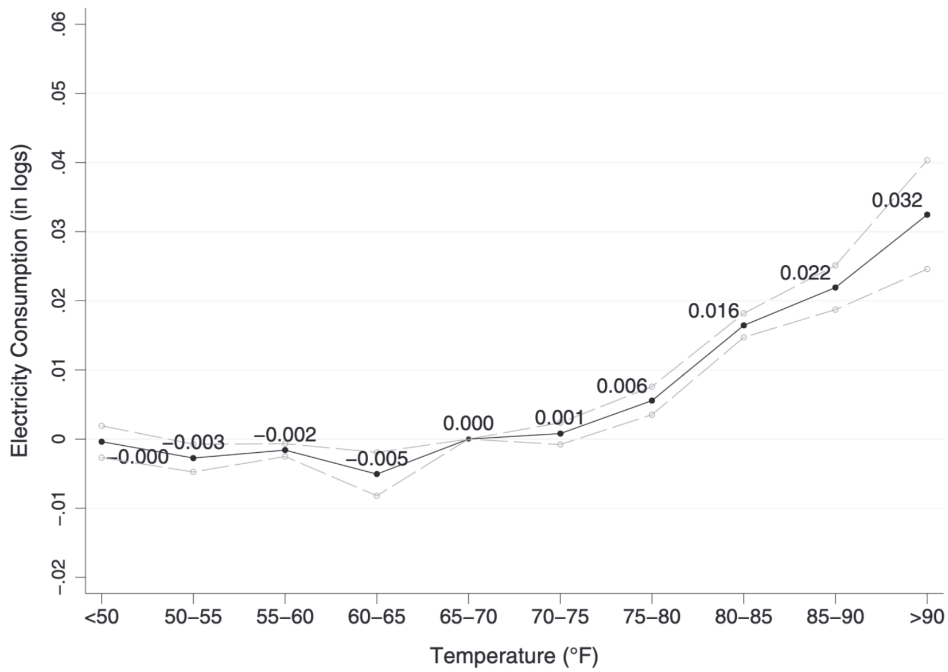

Fig. 3. The effect of temperature on residential electricity demand.

3.1 (8 pts)

As a result of climate change, the temperature distribution shifts rightward so there are fewer colder days each year, but more extremely hot days each year. What does the figure imply will happen to electricity demand in Mexico?

Suggested answer: Think about the example in class based on Prof. Wichman's household electricity consumption. If the temperature distribution moves rightward, then we'll experience more extremely hot days, so electricity demand will increase. This likely reflects increases in demand for air conditioning on hot days (or increased use of fans, etc.).

3.2 (12 pts)

Imagine that baseline rates of air conditioning are low in Mexico, but that adoption of air conditioning is expected to increase rapidly in the coming decades as Mexicans adapt to the new climate (which is potentially enabled by rising household incomes). How would this change the shape of the "weather-response function" that relates electricity demand to extreme temperatures (feel free to draw this on the figure above)? What implications might this have on the economic damages of climate change?

[1] Davis, Lucas W., and Paul J. Gertler. "Contribution of air conditioning adoption to future energy use under global warming." Proceedings of the National Academy of Sciences 112.19 (2015).

Suggested answer: If air conditioning adoption is low, then the electricity demand response to extreme temperatures will be relatively flat. As air conditioning adoption increases, the electricity demand response to extreme temperatures will become more steep in the 80–85, 85–90, and >90° temperature bins. The figure below illustrates this effect.

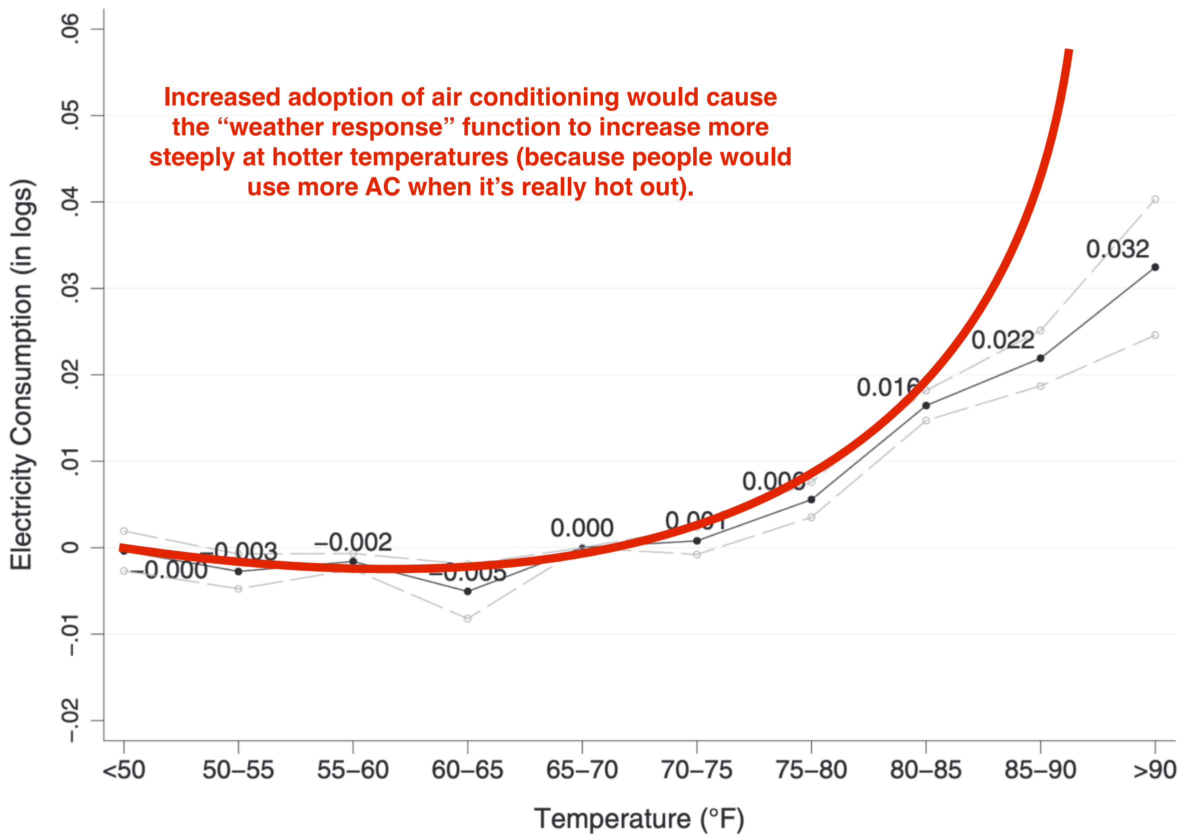

Fig. 3. The effect of temperature on residential electricity demand.

If electricity demand increases more steeply in response to extreme temperatures, then the economic damages of climate change may increase because electricity expenditures are a measure of climate damages. On the other hand, increased AC adoption might mitigate health damages from extreme temperatures (i.e., by reducing heat related mortality), so the net effect is unclear. Moreover, if the increased energy use is produced using fossil fuels, then increased AC adoption and usage could exacerbate climate change, which would increase the economic damages of climate change. On the other hand, if the increase in energy use is produced using renewable energy, then increased AC adoption and usage could mitigate the effects of climate change without adding to the problem.