Economics of Climate Change – Problem Set 1 (5 pts total)

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Question 1: Externalities (20% – each subquestion is worth 5% of total)

Three friends—Xavier, Yvette, and Zev—go out to lunch together at the same restaurant every week to eat burgers at Bessie's Burgers. Because of inflation-induced wage changes, the price of a burger changes each week based on market forces outside the control of the restaurant. The following schedule is how many burgers each individual would consume based on different prices, as well as how many burgers Bessie would supply at any given price.

Price	Bessie's		Demand	
($/burger)	Supply	Xavier	Yvette	Zev
$1	4	8	6	10
$2	6	7	5	9
$3	8	6	4	8
$4	10	5	3	7
$5	12	4	2	6
$6	14	3	1	5
$7	16	2	0	4
$8	18	1	0	3
$9	20	1	0	2
$10	22	1	0	1

1.1

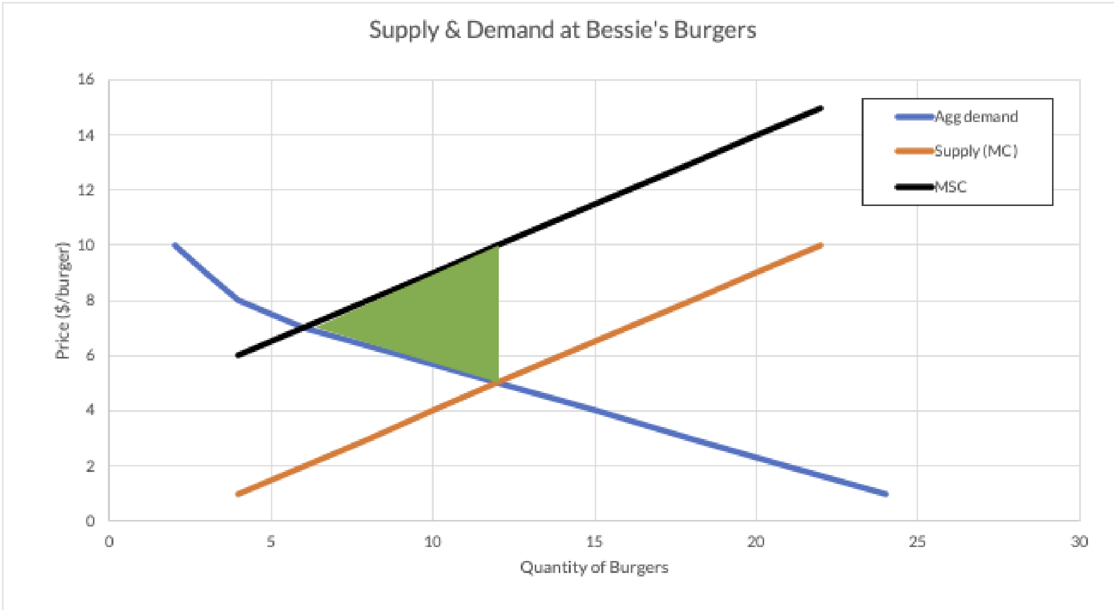
Plot the three friends' aggregate demand function as well as the supply curve for Bessie's Burgers. How many burgers will Bessie sell to the three friends in equilibrium?

Suggested answer:

Price	Bessie's		Demand		Agg.
($/burger)	Supply	Xavier	Yvette	Zev	Demand
$1	4	8	6	10	24
$2	6	7	5	9	21
$3	8	6	4	8	18
$4	10	5	3	7	15
$5	12	4	2	6	12
$6	14	3	1	5	9
$7	16	2	0	4	6
$8	18	1	0	3	4
$9	20	1	0	2	3
$10	22	1	0	1	2

We can plot the aggregate demand curve and the MC curve in a standard supply and demand framework in Figure 1: The three friends will jointly consume approximately 12 burgers each week (at a price of $5/burger) in the private equilibrium. This is represented by the intersection of the MC and Agg. Demand curve.

Figure 1: Bessie's Burgers in 1.1 and 1.2



1.2

A headline in the *New York Times* comes out one week that states: *"New* Nature *study suggests that external damages from methane emissions from each additional burger costs the planet $5 in climate change costs."* Assuming that headline is true, plot the marginal social cost curve from the three friends' weekly lunches.

Suggested answer: We can add the marginal external damage (MD) of $5 to the supply curve "vertically" to obtain the marginal social cost curve (MSC), which is also plotted in Figure 1. Another way to think about this is that you want to add the marginal external damage to the price for each quantity of burger produced. At 4 burgers (the amount supplied at a price of $1), add the $5 of MD to the price to get the MSC of 4 burgers = $6. At 6 burgers (the amount supplied at a price of $2), add the $5 of MD to the price to get the MSC of 4 burgers = $7. And so forth...

1.3

Because the three friends are diligent readers of the *NYTimes*, they now know the true cost of their hamburger consumption. If they really cared about internalizing the social costs they impose on the planet, how many burgers would they consume?

Suggested answer: If the three friends wanted to internalize the external costs of their burger consumption, they would consume about 6 burgers. The socially optimal price of burgers would be ∼$7/burger. At that price, the external damages ($5/burger) would be internalized. But, the market price would be $2 because there is nothing forcing the friends to pay $7/burger.

1.4

Show, graphically, the deadweight loss (DWL) of socially optimal burger consumption. How would you interpret DWL in this case? Are the three friends likely to consume the socially optimal amount of burgers? Why or why not?

Suggested answer: DWL is represented in Figure 1 by the green shaded triangle. It's the area between above the aggregate demand curve but below the marginal social cost curve up to the private equilibrium point of consumption. DWL represents the welfare of individuals not in the market that are being affected by inefficient overconsumption of burgers. We can think of DWL as the loss in welfare to society (e.g., in terms of climate damages) when we don't take into account the external costs of our actions. Conversely, if we moved from the private equilibrium point (9 burgers) to the socially optimal level of consumption ($\sim$6 burgers), then the DWL would represent the increase in welfare from incorporating of those external benefits into our consumption/production decisions.

Without any policy to internalize the marginal external damages, the three friends may or may not consume the socially optimal level of burgers. If they were self-interested individuals only focus on their own private welfare, they might consume the 9 burgers at the private equilibrium level. If, however, they wanted to incorporate the additional social cost into their own consumption decisions (e.g., maybe they feel "morally bad" about consuming burgers now that they know cows emit methane), then perhaps they'll choose to consume the socially optimal amount on their own. In general, though, without policies that "price-in" the external damages, we're unlikely to arrive at the social equilibrium on our own.

Question 2: Public goods (30% – each subquestion is worth 6% of total)

Consider three individuals—Andre, Billie, and Chan—who all live in on the same street in a very small coastal community. They are the only residents on their street. Climate change has been increasing the frequency and severity of flooding in their neighborhood during hurricane season. The three residents have decided to build a barrier made of rocks and sand at the end of their street to reduce the likelihood that their homes will flood. Each additional foot of the flood barrier provides additional protection. Andre lives furthest from the beach at the highest elevation and Chan is closest to the beach at the lowest elevation, so they have different expected benefits from building the flood barrier (defined below). The seawall can be built from materials (rocks and sand) freely available on the beach, but the opportunity cost of their time (i.e., not lounging on the beach) costs \$2 thousand per foot of flood barrier built (that is, their marginal cost of building the seawall is $\$2x$, where x is the height of the seawall and monetary units represent thousands of dollars). For the purposes of this example, assume that the expected storm surge is sufficiently large that there is an equally likely chance of each home being flooded without the barrier.

Each of the individual's marginal benefit curves are defined below (where x is the height of the flood barrier in feet) and marginal benefits are in thousands of dollars per year (e.g., with no flood barrier (i.e., $x = 0$), Andre expects to have \$9,000 in property damage from flooding):

$$\text{Andre's MB} : MB^A(x) = 9 - x \text{ if } 0 \leq x \leq 9 \text{ and zero otherwise}$$

$$\text{Billie's MB} : MB^B(x) = 9 - 0.5x \text{ if } 0 \leq x \leq 18 \text{ and zero otherwise}$$

$$\text{Chan's MB} : MB^C(x) = 18 - x \text{ if } 0 \leq x \leq 18 \text{ and zero otherwise}$$

2.1

Plot the marginal benefit curve for all three individuals along with the marginal cost curve.

Suggested answer: See Figure 2 for the graph of each MB curve and the MC curve.

2.2

How many feet of the flood barrier will be provided in the *private equilibrium* (i.e., if everyone acted in their own self-interest)? How much would each person provide? Describe why this is the case.

Suggested answer: At the private equilibrium, Chan's MB curve exceeds that of the other residents, so he would be willing to construct the entire barrier himself to protect his home. So, we can determine the privately optimal barrier height by setting $MB^C = MC$.

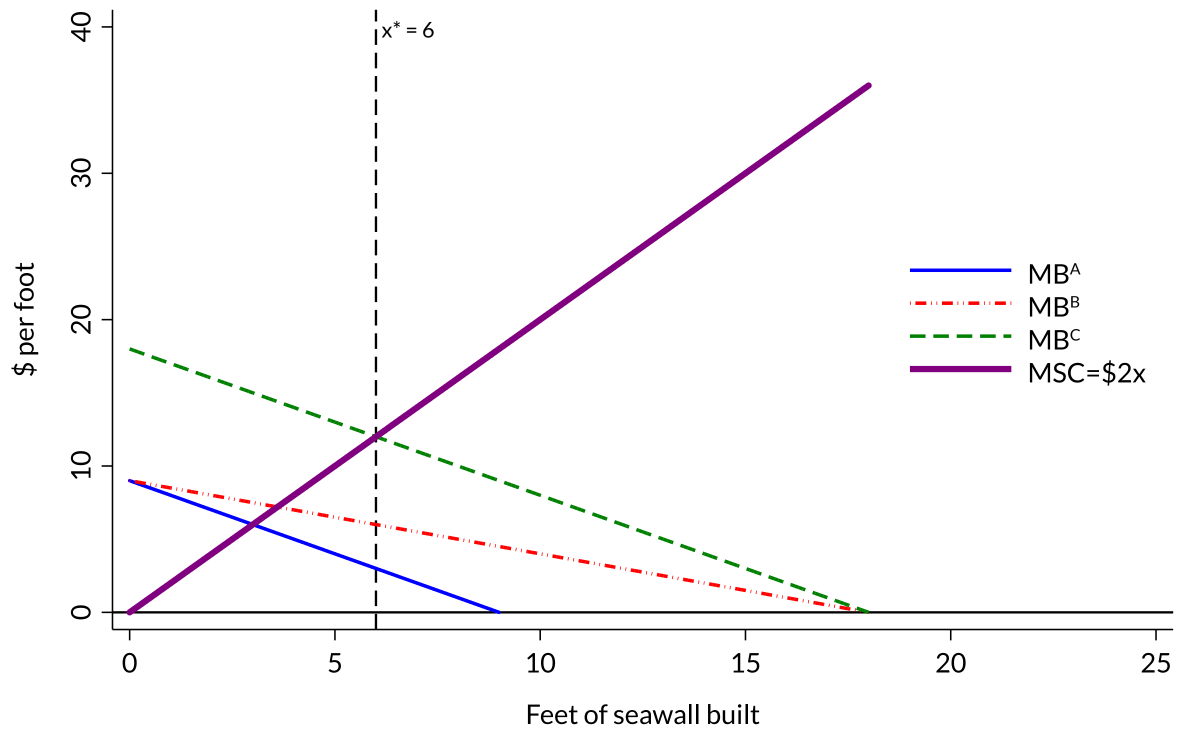
$$\begin{aligned} MB^C(x) &= 18 - x \\ MC(x) &= 2x \\ \text{Setting } MB^C(x) = MC(x) \implies 18 - x &= 2x \\ x^\star &= \frac{18}{3} = 6 \text{ feet} \end{aligned}$$

So, Chan would build 6 feet of the flood barrier by himself. Note, he might want a higher flood barrier, but it's not worth his time to build the barrier any higher based on his marginal costs. Recognizing this, Andre and Billie will not contribute any feet to the barrier because doing so would exceed their marginal cost. Their marginal benefits are already covered by Andre's contribution, so they will free-ride on his work.

2.3

Calculate each individual's consumer surplus at the private equilibrium quantity. (*Hints: Use standard equations for the area of rectangles and triangles. Note that it's possible that only one individual will contribute to*

Figure 2: Graph for Q–2.1



building the seawall (and, hence, they might bear all of the costs)).

Suggested answer: Consumer surplus is the area below the marginal benefit curve and above the marginal cost curve.

Let's start with Chan, who bears all costs of building the barrier. Consumer surplus is the triangle above the MC, but below Chan's MB^A curve, from 0 to $x^\star = 6$. So, $CS^C(x = 6) = 0.5 \times 18 \times 6 = \$54$.

For Andre and Billie, remember that they have contributed nothing to the public good, so they will free ride, bearing no costs whatsoever. So, their consumer surplus is the entire area under their MB curves from 0 to $x^\star = 6$. There are several ways to calculate this, but the math below shows the approach for calculating the total area under each MB curve and subtracting the "little" triangle for the area above 6 feet of provision.

For Andre, $CS^A(x = 6) = (0.5 \times 9 \times 9) - (0.5 \times (9 - 6) \times (9 - 6)) = \$36$.

For Billie, $CS^B(x = 6) = (0.5 \times 9 \times 18) - (0.5 \times (18 - 6) \times (9 - 6/2) = \$45$.

Thus, total consumer surplus from building the wall at 6 feet is $CS^{Total} = CS^A + CS^B + CS^C = \$135$. Andre bears the entire cost of building the wall, and his total costs (the area below the marginal cost curve) are $0.5 \times \$2 \times 6 = \$6$. With net social benefits of \$129, building this seawall seems like a good idea!

2.4

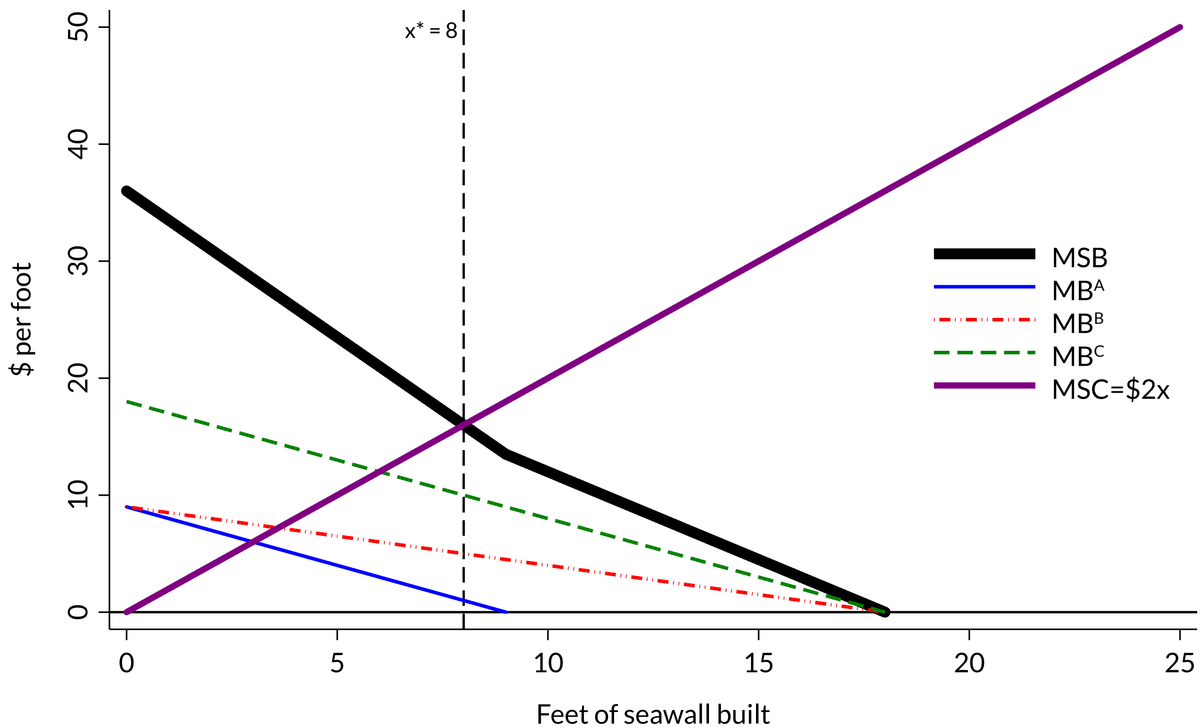
Derive the equation for the social marginal benefit curve and plot it. How many feet of the barrier would be provided in the *social equilibrium*? Show this graphically.

Suggested answer: The social marginal benefit curve is derived by "adding up" each marginal benefit curve vertically, which can be defined by the piecewise function:

$$MB^\star = \begin{cases} 36 - 2.5x \text{ if } 0 \leq x \leq 9 \\ 27 - 1.5x \text{ if } 9 \leq x \leq 18 \end{cases}$$

The socially optimal equilibrium is located in the "first" section of that piecewise function (i.e., where $0 \leq x \leq 9$). So, to determine the optimal height of the barrier for the social equilibrium, we set $MB^{\star} = MC$ and solve for x, which gives us $x^{\star} = 8$ feet. This can be seen in the following figure:

Figure 3: Graph for Q–2.4



2.5

Calculate total net benefits (i.e., total benefits minus total costs) at the social equilibrium quantity. How does total net surplus compare with the total net surplus in the private equilibrium (i.e., $CS^A + CS^B + CS^C$)?

Suggested answer: For this, we simply need the area under the SMB curve, but above the MC curve, from 0 to $x^{\star} = 8$. This is simply a triangle with a base of 36 and a height of 8, so net benefits $= 0.5 \times 36 \times 8 = \$144$. This is higher than the total net surplus at the private equilibrium (\$135), so the social equilibrium is preferred to the private equilibrium.

Question 3: Climate science and fossil fuels (20% – each subquestion is worth 4% of total)

Prof. Wichman invites the class over for dinner at the end of the semester. Prof. Wichman's uncle happens to stop by unannounced and you get trapped in a conversation with him. Unfortunately, he gets all of his news from Facebook and, because he has had very little formal training in economics or climate science, he is generally uninformed about climate change. That said, he is open to new ideas. He makes the following statements to you – can you provide a short response (no more than a few sentences) to convince him otherwise, perhaps pointing him towards valid academic sources like the IPCC Assessment Reports?

There are many correct ways to answer the following questions. I will outline a few key points that I had in mind, but these are not exhaustive.

3.1

"Climate change is a natural phenomenon, and there's no scientific consensus about human involvement"

Suggested answer:

- We have climate models that can "net out" the human influence, thus comparing a simulated climate from natural variation to a simulated climate with human drivers. We're on a CO2 emissions pathway that corresponds with the "with human influence" simulation.
- CO2 concentrations have been increasing at an unprecedented rate (relative to the entire history of atmospheric records) in the last 100 years, which corresponds with heavy use of fossil fuels.

3.2

"Where I'm from, we had one of the coldest winters ever measured last year. So, much for global warming, eh?"

Suggested answer:

- Climate *change* can entail experiencing extremes on either end of the temperature spectrum, as well as changes in precipitation and extreme weather events.
- Global warming refers to global mean temperatures which can have different effects on the climate depending on where you live.

3.3

"Environmental regulations hurt the economy and cost jobs. We should prioritize economic growth over climate action."

Suggested answer:

- The costs of fixing climate change are almost certainly less than the costs of letting climate change run rampant. We are experiencing climate change costs *today* and, left unchecked, climate change will deliver much greater costs than climate change policy.

3.4

"Renewable energy is too expensive and unreliable to replace fossil fuels on a large scale."

Suggested answer:

- As we saw in the Covert et al. (2016) article, we are not going to run out of fossil fuels because we continue to find about as many new fossil fuel resource stocks as we use each year. Part of this is due to technological advancements, like fracking, to extract previously unrecoverable oil and natural gas.

- Second, the costs of renewable energy has been falling dramatically and, in many instances, is now cost-competitive with fossil fuel energy for electricity generation and for gasoline vehicles.

3.5

"A 2.5 degree temperature change doesn't seem like a big deal. On some days the temperature swings by 20 degrees or more."

Suggested answer:

- To clarify, a 2.5-degree temperature increase is measured in celsius, so that's more like an average 5-degree Fahrenheit increase in *global mean temperatures*. Some areas will get much hotter than that. Hsiang and Kopp (2018) show that many states in the Southern US will experience new climates by the end of the century that have never been experienced in the US previously.
- Warming of 2.5°C will also trigger other changes in our climate, like sea-level rise, melting of permafrost which releases methane into the atmosphere, increased severity and frequency of tropical storms and hurricanes, so just because the weather can fluctuate a lot throughout the day, a large change in global mean temperatures will lead to climatic change in many dimensions other than temperature swings that we have not experienced on this planet previously.

Question 4: Discounting (30% – each subquestion is worth 5% of total)

You are trying to figure out whether to buy an internal combustion engine vehicle (ICE) that runs on gasoline or an electric car. The electric car costs \$40,000 and the gasoline car costs \$37,000. The fuel costs (whether gas or electric) and other maintenance costs are identical throughout the life of the vehicle. A friend of yours developed a "CO_2 social cost calculator" that shows that the CO_2 benefits from purchasing the electric vehicle (or, correspondingly, the CO_2 costs of purchasing the gasoline vehicle) will increase linearly from \$0 in year 0 to \$200 in year 100 and then decline linearly from \$200 to \$0 over the next 200 years (i.e., from year 100 to year 300). No costs/benefits from CO_2 will occur beyond 300 years. Assume that CO_2 emissions reductions over the lifetime of the electric vehicle will occur immediately after your purchase, and there are no other local air pollution damages. Assume also that there are no other differences between the two vehicles that you might care about.

(Hint: It may be easiest to set this up in an Excel spreadsheet or other software to calculate the present value of the stream of benefits. Each row will be a year (from 0, 1, 2, ..., 298, 299, 300) and the columns will be the nominal or discounted benefits in that year. You can then sum the discounted benefits to get the total present value of the benefits.)

4.1

Using a discount rate of 5%, calculate the present value of the full stream of CO_2 benefits of purchasing the electric vehicle today.

Suggested answer: Because the benefits are nonlinear, you can't simply apply the PV formula once. Set-up a spreadsheet with year 0 through year 300 as the first column. Then, make the second column the benefits in each year. Year 0 is \$0; year 1 is \$2; year 2 is \$4; ...; year 100 is \$200; year 101 is \$199; year 102 is \$198, and so forth... all the way to year 300, which is \$0.

In the third column calculate the present value for that year using a 5% discount rate, e.g.,

$$\text{PV in year 59} = \text{benefits in year 59} \times \frac{1}{(1+0.05)^{59}}.$$

Then, sum up all of the annual PV values in that third column. This is effectively what the PV formula is doing, you just need to do the calculation manually. The PV at a 5% discount rate should be $\approx$ \$830.42.

4.2

Using a discount rate of 2%, calculate the present value of the full stream of CO_2 benefits of purchasing the electric vehicle today.

Suggested answer: Follow the same steps as above, but use a 2% discount rate each year. The PV at a 2% discount rate should be $\approx$ \$4050.72.

4.3

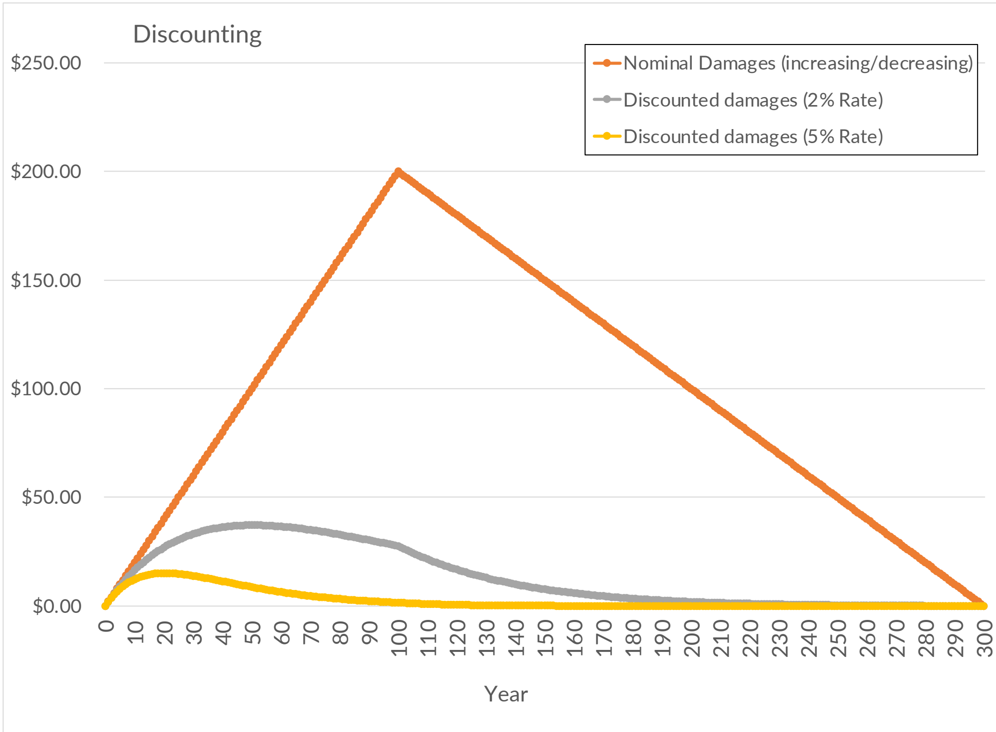
Plot the stream of discounted benefits (as well as the undiscounted, "nominal" benefits) in a graphing software of your choice (e.g., on graph paper, Excel, R, Stata, etc.).

Suggested answer: The equation for the stream of benefits can be represented as follows:

$$\text{Annual Benefits in year } t = \begin{cases} \$2t \text{ if } 0 \leq t \leq 100 \\ \$300 - \$1t \text{ if } 100 \leq t \leq 300 \\ \$0 \text{ otherwise.} \end{cases}$$

The figure below represents the "nominal" costs as well as thes stream of discounted costs for each year from 0 to 300.

Figure 4: Graph for Q–4.1 through 4.3



4.4

Explain in intuitive terms why the PV of the benefits at a 5% discount rate is different from the PV at 2%.

Suggested answer: At a 5% discount rate, we're weighing the benefits that occur far in the future relatively less than we are when we use a 2% discount rate. A 5% discount rate essentially says that we're valuing benefits that occur very far in the future as virtually zero (as we see in Figure 4, the PV at more than $100 years is effectively 0 (or something very small)). A 2% rate puts slightly more weight on future benefits; in Figure 4, the annual PV doesn't become very close to zero until after 200 years or so.

4.5

If you want to internalize the full social cost of your purchase, should you purchase the electric vehicle at a 5% discount rate? What about at a 2% discount rate?

Suggested answer: The difference in the cost of the vehicles is $3000. That is, the electric vehicle costs $3000 more today. You can ignore all other (potentially different) costs of vehicle ownership. So, the key is, if the PV of the CO_2 benefits is greater than the additional cost of the electric car (i.e., if $PV^{Benefits} > \$3000$), then we should purchase the electric vehicle. This assumes that we want to internalize the climate benefits into our purchasing decision.

At the 5% discount rate, the PV of benefits is $830. So, the additional $3000 cost of the electric vehicle aren't worth it in terms of the climate benefits. In other words, the private + social costs of the gasoline vehicle are cheaper than the private cost of the electric vehicle. So, I should buy the gasoline vehicle.

At the 2% discount rate, the PV of benefits is $4050. This means that the private + social cost of the gasoline vehicle is $37,000 + $4050 = $41,050. But, the electric vehicle costs $40,000 and generates no social costs in this example. So, the electric vehicle is "cheaper". I should buy the electric vehicle (but I am very close to being indifferent between the two!).

4.6

Justify which discount rate is the more appropriate rate to use for this decision. (Note: there is not necessarily a correct answer).

Suggested answer: There is no right answer because the choice of the discount rate can be subjective and often relies on ethical judgments.

Here are a few nonexhaustive reasons why 2% might be an appropriate rate:

- We should place equal weight on future generations' welfare, which can lead to a lower discount rate.
- A lower discount rate is more consistent with the fact that discount rates are inherently uncertain (due to uncertainties in financial markets as well as uncertainties in economic growth per capita, especially over long time horizons).
- A higher discount rate might reflect the "opportunity cost of capital" but climate damages tend to affect consumption, so a lower rate is more appropriate for discounting climate benefits.

Here are a few nonexhaustive reasons why 5% might be an appropriate rate:

- 5% discount rates accord with the rate of return on capital investments in financial markets, so 5% is a (probably conservative) estimate of the opportunity cost of capital. Therefore, 5% is a more valid discount rate because it's based on trade-offs we observe in the real world (and, as a result, is not based on subjective judgment).
- Future generations will be wealthier than us, so we should value our own (relatively poorer) consumption relatively more than we should value consumption to the Jeff Bezos' of the future.