***Earth 104 Activity: Modeling the Economics of Climate Change***

The global climate system and the global economic system are intertwined — warming will entail costs that will burden the economy, there are costs associated with reducing carbon emissions, and policy decisions about regulating emissions will affect the climate. These interconnections make for a complicated system — one that is difficult to predict and understand — thus the need for a model to help us make sense of how these interconnections might work out. In this activity, we’ll do some experiments with a model that will help us do a kind of informal cost-benefit analysis of emissions reductions and climate change.

The economic part of the model we will explore here is based on work by William Nordhaus of Yale University, who is considered by many to be the leading authority on the economics of climate change. His model is called DICE, for Dynamic, Integrated Climate and Economics model. It consists of many different parts and to fully understand the model and all of the logic within it is well beyond the scope of this class, but with a bit of background we can carry out some experiments with this model to explore the consequences of different policy options regarding the reduction of carbon emissions.

Nordhaus’ economic model has been connected to the global carbon cycle model we used in Module 8, connected to a simple climate model like the one we used in Module 4.

The economic components are shown in a highly simplified version of a STELLA model below:



*Credit: David Bice*

In this diagram, the gray boxes are reservoirs of carbon that represent in a very simple fashion the global carbon cycle model from Module 8; the black arrows with green circles in the middle are the flows between the reservoirs. The brown boxes are the reservoir components of the economic model, which include *Global Capital*, *Productivity, Population*, and something called *Social Utility*. The economic sector and the carbon sector are intertwined — the emission of fossil fuel carbon into the atmosphere is governed by the *Emissions Control* part of the economics model, and the global temperature change part of the carbon cycle model affects the economic sector via the *Climate Damage* costs. Let’s now have a look at the economic portions of the model. You should [view this video DICE economic model first](https://www.youtube.com/watch?v=mLFhUOZj_IU), and then study the text that follows.

***The Global Capital Reservoir***

In this model, *Global Capital* is a reservoir that represents all the goods and services of the global economic system; so this is much more than just money in the bank. This reservoir increases as a function of investments and decreases due to depreciation. Depreciation means that value is lost as things age, and the model assumes a 10% depreciation per year; the 10% value comes from observations of rates of depreciation across the global economy in the past. The investment part is calculated as follows:

Investment = Savings Rate x (GDP - Abatement Costs – Climate Damages)

The savings rate is 18.5% per year (again based on observations). The *GDP* is the total economic output for each year, which depends on the global population, a productivity factor, and *Global Capital*.

***Abatement Costs***

The Abatement Costs are the costs of reducing carbon emissions, and are directly related to the amount by which we to reduce carbon emissions. If we take steps to reduce our carbon emissions either by switching to renewable energy or improving efficiency or by direct removal of CO2 from the atmosphere, then there are costs associated with these steps. The model includes something called the abatement cost per GT C — this is the cost in trillions of dollars for each gigaton of carbon removed, and it can be changed over time. The default value is $3 trillion/GT C, which is a lot because it also includes the costs of large battery systems and new electrical transmission lines. But, the good thing about these costs is that once you pay for a GT of C removed, you don’t keep paying for it. If we were to completely cut all carbon emissions (currently around 10 GT C/yr), and do it in one year, it would cost $30 trillion or about 1/3 of the global GDP.

The diagram below shows how the abatement costs each year are figured out.



Caption: The red curve shows a history of carbon emissions with no abatement; the green curve shows lower emissions due to abatement efforts. The vertical double-headed arrows show the amount (GT of C) of emissions reductions at two points in time. The difference in those two emissions reductions values represents new abatement that has to be paid for in that time period. What this means is that each year, we are only paying for the new emissions reductions — we don’t keep paying for it in later years.

Source: David Bice

***Climate Damages***

Climate Damages are the costs associated with rising global temperatures, including the costs of dealing with sea level change along coasts, extreme weather events (hurricanes, flooding, droughts, wildfires, etc.), labor (reduced productivity at higher temps), and increased human mortality (loss of workers hurts the economy). In the model, the climate damages are calculated as a fraction (think of this as a percentage) of the GDP. The fraction is a quadratic equation that looks like this:

$$damage fraction=slope×ΔT+ coefficient×ΔT^{exponent}$$

The DT is the global temperature change in °C. Both the slope and exponent can be adjusted in the model; the coefficient is set at 0.003. The default slope is 0.025 and the exponent is 2, which means that if we have a global temperature change of 4°C, damages equal to 15% of GDP; this rises to a devastating 55% for a temperature increase of 10°C. The diagram below shows what this damage fraction equation looks like, plotted as a function of temperature change in °C.



***Relative Climate Costs***

It will be useful to have a way of comparing the climate costs — the sum of the *Abatement Costs* and the *Climate Damages* — in a relative sense so that we see what the percentage of these costs is relative to the *GDP* of the economy. The model includes this relative measure of the climate costs (in trillions of dollars) as follows:

Relative Climate Costs = *(Abatement Costs + Climate Damages) x GDP/initial GDP*

***Consumption***

Also related to the *Global Capital* reservoir is a converter called *Consumption*. A central premise of most economic models is that consumption is good and more consumption is great. This sounds shallow, but it makes more sense if you realize that consumption can mean more than just using things it up; in this context, it can mean spending money on goods and services, and since services includes things like education, health care, infrastructure development, and basic research, you can see how more consumption of this kind can be equated with a better quality of life. So, perhaps it helps to think of consumption, or better, consumption per capita, as being one way to measure quality of life in the economic model, which provides a measure for the total value of consumed goods and services (in trillions of dollars), which is defined as follows:

*Consumption = GDP – Climate Damages – Abatement Costs – Investment*

This is essentially what remains of the *GDP* after accounting for the damages related to climate change, abatement costs, and investment.

The model also calculates the *per capita consumption* by just dividing the Consumption by the Population, and it also includes a converter called *relative per capita consumption*, which is just the per capita consumption divided by the GDP. In the model, this is in thousands of dollars per person.

 ***Population***

The population in this model is highly constrained — it is not free to vary according to other parameters in the model. Instead, it starts at 6.5 billion people in the year 2000 and grows according to a net growth rate that steadily declines until it reaches 12 billion, at which point the population stabilizes. The declining rate of growth means that as time goes on, the rate of growth decreases, so we approach 12 billion very gradually.

***Productivity Factor***

The model assumes that our economic productivity will increase due to technological improvements, but the rate of increase will decrease (but will not go negative), just like the rate of population growth.  So the productivity keeps increasing, but it does not accelerate, which would lead to exponential growth in productivity. This decline in the rate of technological advances is once again something that is based on observations from the past.

***Emissions***

The model calculates the carbon emissions as a function of the *GDP* of the global economy and two adjustable parameters, one of which (*carbon intensity*) sets the emissions per dollar value of the *GDP* (units are in gigatons of carbon per trillion dollars of *GDP*) and something called the *Emissions Control Rate* (ECR). The equation is simply:

Emissions = carbon intensity\*(1 -ECR)\*GDP

Currently, *carbon intensity* has a value of about 0.118, and the model assumes that this will decrease as time goes on due to improvements in efficiency of our economy — we will use less carbon to generate a dollar’s worth of goods and services in the future, reflecting what has happened in the recent past. The *ECR* can vary from 0 to 1, with 0 reflecting a policy of doing nothing with respect to reducing emissions, and 1 reflecting a policy where we do the maximum possible. Note that when *ECR* = 1, then the whole *Emissions* equation above gives a result of 0 — that is, no human emissions of carbon to the atmosphere from the burning of fossil fuels.  In our model, the ECR is initially set to 0.005, but it can be altered as a graphical function of time to represent different policy scenarios. In other words, by changing this graph, we are effectively making a policy — and everyone follows this policy in our model world!

***Making Comparisons — the Discount Rate***

We would like to be able to see whether one policy for reducing emissions of carbon is economically better than another. Different policies will call for different histories of reductions, and to compare them, we need to find a way to compare the expected future damages associated with each policy. A problem comes when we try to compare 200 million in damages at some time in the future vs. 20 million in damages today. Economists use something called a ***discount rate*** to do this. Here is an example to help you see how this idea works: imagine you have a pig farm with 100 pigs, and the pigs increase at 5% per year by natural means. If you do nothing but sit back and watch the pigs do their thing, you’d have 105 pigs next year. So 105 pigs next year can be equated to 100 pigs in the present, with a 5% discount rate.  Thus, the discount rate is kind of like the return on an investment. Now think about climate damages. If we assume that there is a 4% discount rate, then $1092 million in damages 100 years from now is $20 million in present day terms. Here is how this works in an equation:

$$FutureCost=PresentCost × e^{(rt)}$$

$$\$1092E6=\$20E6 × e^{(0.04 × 100 yrs)}$$

This is a standard exponential growth equation; *e* is called Euler’s number and has a value of about 2.7. Now, let’s say we calculate some cost in the future — 8 million dollars 200 years from now — we can apply a discount rate to this future cost in order to put it into today’s context. Here is how that would look:

$$PresentCost=\$8E6 × e^{(-0.04×200 yrs)}=\$2684$$

It is important to remember that this assumes our global economy will grow at a 4% annual rate for the next 200 years. The 4% figure is the estimated long-term market return on capital, but this may very well grow smaller in the future, as it does in our model. Although we’re not going to dwell on the discount rate any more in this exercise, it is good to understand the basic concept.

A simpler way of comparing future costs or benefits with respect to the present is to express these costs and benefits relative to the size of the economy at any one time — which our model will calculate. This gets around the kind of shaky assumption that the economy is going to grow at some fixed rate. These relative economic measures are easy to do — just divide some parameter from the model, like the *per capita consumption*, by the *GDP*. Below is a list of the model parameters that we will keep an eye on in the following experiments:

***Global capital*** *— the size of the global economy in trillions of dollars*

***GDP*** *— the yearly global economic production in trillions of dollars*

***Per capita consumption*** *— consumption/population;* ***this is a good indicator of the quality of life*** *— the higher it is, the better off we all are; units are in thousands of dollars per person*

***Relative per capita consumption*** *— annual per capita consumption x (GDP/initial GDP); again,* ***a good indicator of the quality of life****, in a form that enables comparison across different times; units are in thousands of starting time dollars per person*

***Sum of relative pc consumption*** *— the sum of the above— kind of like the final grade on quality of life. If you take the ending sum and divide by 200 yrs, it gives the average per capita consumption for the whole period of the model run*

***Relative climate costs*** *— an annual measure of (abatement costs + climate damages) x (GDP /initial GDP); this combines the costs of reducing emissions with the climate damages, in a form that can be compared across different times; the units are trillions of dollars.*

***Sum of relative climate costs*** *— sum of the relative climate costs — the final grade on costs related to dealing with emissions reductions (abatement) and climate; this is the sum of a bunch of fractions, so it is still dimensionless.*

***Global temp change*** *— in °C, from the climate model*

**Experiment 1: Changing the Emissions Control Rate (ECR)**

In [the model](https://exchange.iseesystems.com/public/davidbice/earth-104-dice20), the ECR can vary from 0 to 1, and it expresses the degree to which we take steps to curb emissions; a value of 0 means we do nothing, while a value of 1 means that we essentially bring carbon emissions to a halt. According to Nordhaus, the most efficient way of implementing this control is through some kind of carbon tax, in which case a value close to 1 represents a very hefty carbon tax that would provide strong incentives to develop other forms of energy. In this experiment, we’ll explore 3 scenarios — in A, we’ll keep ECR at a very low level — this is the “do nothing” policy scenario, in B we'll ramp it up steadily through time — this is the “slow and steady” policy scenario, and in C, we’ll ramp it much more quickly, eventually reaching a value of 1.0 — this is the “get serious” policy scenario. You can make these changes in the ECR by altering the graphical converter.

The three different scenarios consist of 5 numbers that are the ECR values for 5 points in time (corresponding to the five vertical lines in the graph); these times are years 2000, 2050, 2100, 2150, and 2200. There are 2 videos to watch — one gives you an overview of the model and the other explains how to modify the model to do these problems. They are both on Canvas.

|  |  |  |  |
| --- | --- | --- | --- |
|  | A. Do nothing ECR data | B. Slow & Steady | C. Get Serious |
| **Practice** | Use default values (no need to change anything) | 0.005; 0.15; 0.3; 0.45; 0.6 *(see video about adjusting these)* | 0.005; 0.33; 0.66; 1.0; 1.0 |
| **Graded** | Use default values (no need to change anything) | 0.005; 0.2; 0.4; 0.6; 0.8 | 0.005; 0.5; 1.0; 1.0; 1.0 |

For each scenario, run the model, study the model results, and record the results indicated in the table below and then refer to your results in answering the questions below.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Practice |  |  | Graded |  |
| ECR scenario | A. Do nothing | B. Slow & steady | C. Get serious | A. Do nothing | B. Slow & steady | C. Get serious |
| 1. Global temp change @2200 Graph #2 | 6.8°C | 5.4°C |  2.8°C |  |  |  |
| 2. Global capital@2200 ($trillion) Graph #15 | 769  | 904 | 1103 |  |  |  |
| 3. Per capita consumption@2200 Graph #17 (k$/person) | 29 | 34 | 42 |  |  |  |
| 4. Per capita consump. rel. to GDP@2200 Graph #18 (k$/person) | 3.2 | 3.6 | 4.2 |  |  |  |
| 5. Total Abatement Costs@2200 Graph #7 ($trillion) | 90 | 55 | 104 |  |  |  |
| 6. Total Climate Damages@2200 Graph #9. ($trillion) | 14101 | 11216 | 6908 |  |  |  |
| 7. Total Climate and Abatement Costs @2200 (just add rows 5 and 6 above) | 14191 | 11271 | 7012 |  |  |  |

**1. Which of these 3 scenarios leads to the lowest global temperature change?**

1. Do nothing
2. Slow and steady
3. Get serious *[answer for practice version]*

**2. The lowest global temperature change @2200 of the three scenarios =**  (±0.2°C) *[2.8 for practice version]*

**3. Which of these 3 scenarios leads to the highest global capital?**

1. Do nothing
2. Slow and steady
3. Get serious *[answer for practice version]*

**4. Highest global capital @2200 of the three scenarios = (trillion$ ±10)** *[1103 for practice version]*

**5. Which of these 3 scenarios leads to the lowest total abatement costs?**

1. Do nothing
2. Slow and steady
3. Get serious *[answer for practice version]*

**6. Which of these 3 scenarios leads to the lowest total climate damage costs?**

1. Do nothing
2. Slow and steady
3. Get serious *[answer for practice version]*

**7. Which of these 3 scenarios leads to the lowest total abatement and climate damage costs?**

1. Do nothing
2. Slow and steady
3. Get serious *[answer for practice version]*

**8.  In terms of both economic costs (lowest abatement and climate costs) and benefits (highest relative per capita consumption, highest global capital), which scenario is the best?**

1. Do nothing — best in both costs and benefits
2. Slow and steady — best in both costs and benefits
3. Get serious — best in both costs and benefits *[answer for practice version]*
4. Do nothing — best in benefits; Get serious — best in costs
5. Slow and steady — best in benefits; Do nothing — best in costs

Now we step back and consider what we’ve done and learned by responding to the following questions.

**9. You have probably heard people (mainly from the realms of business and politics) say that we should not do anything about global climate change because it is too expensive and will hurt our economy. After experimenting with this model, do you agree with them, or do you think they are missing something (and if so, what is it they are missing)?**

**10. Remember that each ECR history reflects a different economic/political policy. Briefly explain how you came to figure out which policy was the best. In answering this, you have to think about what “best” means — the least environmental damage; the greatest economic gain per person; the easiest policy to implement; or some combination of these?**