***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 (Gross Output - Abatement Costs – Climate Damages)

The savings rate is 18.5% per year (again based on observations). The *Gross Output* 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 try to reduce carbon emissions. If you think back to the model we worked with that calculated emissions scenarios and energy consumption, abatement is essentially the same as reducing the fraction of our energy that comes from fossil fuels — there are costs associated with making those changes. If we do nothing in terms of reducing our consumption of fossil fuels, the abatement costs are zero, but as we try to do more and more in terms of emissions reductions, the abatement costs go up. If we go all out in this department, the *Abatement Costs* can rise to be 15% of the *Gross Output*.

***Climate Damages***

*Climate Damages* are the costs associated with rising global temperatures. The way the model is set up, a 2°C increase in global temperature results in damages equal to 2.4% of *Gross Output*, but this rises to 9.6% for a temperature increase of 4°C, and 21.6% of *Gross Output* for a 6°C increase. This relationship between temperature change and damage involves temperature raised to an exponent that is initially set at 2, but can be adjusted.

***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 *Gross Output* of the economy. The model includes this relative measure of the climate costs as follows:

Relative Climate Costs = (Abatement Costs + Climate Damages)/Gross Output

***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, which is defined as follows:

*Consumption = Gross Output – Climate Damages – Abatement Costs – Investment*

This is essentially what remains of the *Gross Output* 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 gross output.

 ***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, 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 *Gross Output* of the global economy and two adjustable parameters, one of which (*sigma*) sets the emissions per dollar value of the *Gross Output* (units are in metric tons of carbon per trillion dollars of *Gross Output*) and something called the *Emissions Control Rate* (ECR). The equation is simply:

Emissions = sigma\*(1 -ECR)\*Gross\_Output

Currently, *sigma* has a value of about 0.118, and the model we will use 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 *Gross Output*. 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*

***Gross Output*** *— 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*** *— per capita consumption divided by the gross output; 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 relative per capita consumption — 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*** *— (abatement costs + climate damages)/gross output; this combines the costs of reducing emissions with the climate damages, in a form that can be compared across different times; the units are $/$, so this is just a dimensionless fraction — multiply it by 100 and you have the % of the gross output that goes to abatement and climate damages.*

***Sum of relative climate costs*** *— sum of the relative climate costs — the final grade on costs related to dealing with emissions reductions 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](http://forio.com/simulate/dmb53/carbon-cycle-dice15/simulation/), 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.

In your ANGEL mail, you will be provided with the Form letter (A,B,C,D) for the assessment document. Details of the ECR for your three scenarios will be related to this letter. The details consists of a string 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. This short [video Dice model ECR](https://www.youtube.com/watch?v=ougtOEq0c8w) explains how to make changes to the model.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Do nothing ECR data | Slow & Steady | Get Serious |
| **Practice** | Use defaults values (no need to change anything) | 0.005; 0.2; 0.4; 0.6; 0.8 *(these are the values of ECR at each of the 5 vertical lines on the graph)* | 0.005; 0.5; 1.0; 1.0; 1.0 |
| **Graded** | Use defaults values (no need to change anything) | 0.005; 0.15; 0.3; 0.45; 0.6 | 0.005; 0.33; 0.66; 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. Where possible, fill these out to a one decimal point precision.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Practice |  |  | Graded |  |
| ECR scenario | Do nothing | Slow & steady | Get serious | Do nothing | Slow & steady | Get serious |
| 1. Global temp change @2200 | 6.6°C | 5.2°C |  2.1°C |  |  |  |
| 2. Global capital@2200 | 1302 | 1492 | 1583 |  |  |  |
| 3. Per capita consumption@2200 | 49 | 56 | 60 |  |  |  |
| 4. Relative per capita consumption@2200 | 3.8 | 4.15 | 4.3 |  |  |  |
| 5. Sum of relative pc consumption@2200 | 1005 | 1034 | 1038 |  |  |  |
| 6. Relative climate costs@2200 | 12.5 | 7.3 | 4.4 |  |  |  |
| 7. Sum of relative climate costs@2200 | 1077 | 687 | 613 |  |  |  |

**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) *[2.1 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)** *[1583 for practice version]*

**5. Which of these 3 scenarios leads to the lowest relative climate costs?**

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

**6. Lowest relative climate costs @2200 of the three scenarios = (±0.2)** Units displayed in the model are % of the gross output that goes to abatement and climate damages. *[4.4 for practice version]*

**7. Which of these 3 scenarios leads to the greatest relative per capita consumption?**

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

**8.  In terms of both economic costs (lowest relative climate costs) and benefits (highest relative per capita consumption), 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?**