Contents

BASIC FAQ

10th August 2012

1 What is webDICE?

webDICE is a web-based version of the most widely-used model of the economics of climate change. It allows users to see the effects of climate change and also to see how assumptions about what the future will bring, such as how fast we discover carbon-free energy or how large the harms from climate change will be, changes those effects.

webDICE is based on a model of the global ecomony in which industrial activity produces emissions, which cause climate change, which in turn harms the economy. The basic model runs under the assumption that there is no policy in place to control emissions. The model uses available data and, where there is no data, our best guess assumption. Many these guesses are just that – guesses – and you should view the outcome as just one possible scenario. Clicking on the "run model" button shows the results under this scenario.

The default scenario is only one possible scenario, and we do not know what the future will bring. You can change the assumptions to see how these changes affect the economy and people in the future. For example, you can change how soon we will discover carbon-free sources of energy, how fast the economy will grow, the size of the harms from climate change, and most of the other assumptions of the model to see what your views on these matters mean for the future. None of us know what the future will bring, so we encourage you to run the model under a number of different choices to see how the results change.

The assumptions, which we call model parameters, are separated into basic controls and other (but still important) controls, which you can see by clicking on the Advanced tab. You can also add limits on emissions to simulate a climate change treaty. To change the assumptions or to see how controls on emissions affect the future, move the sliders to your preferred position and click run. webDICE will show how the results change for each run. You can also download all of your results as a CSV file (readable by Excel).

webDICE has a separate mode called optimization mode. In this mode, webDICE will compute the limits on emissions that best balances costs of reducing emissions with the resulting improvements to the economy.

2 Where does webDICE come from?

webDICE is based on the DICE-2007 model developed by Professor William Nordhaus of Yale University. DICE is the most widely used model of the economics of climate change, but until now has required sophisticated computational expertise to run. DICE has become a standard tool used by academics to study climate change and has been used by the U.S. government in setting climate change policies.

Professor Nordhaus's book, A Question of Balance, Weighing the Options on Global Warming Policies, is a good place to find more details. We thank Professor Nordhaus for making his model equations and code pubicly available (at [http://nordhaus.econ.yale.edu/DICE2007.htm]). Because of computational considerations, we have re-coded the model into a different computer language, so that this version may not run identically to the version in A Question of Balance or to other versions found on Professor Nordhaus's website.

3 How does webDICE operate?

webDICE is based on a standard but simple model of the economy in which capital and labor combine to produce income. The amount produced depends on the total amount of capital, the number of workers, and their productivity. Production results in emissions of CO_2. webDICE computes how these emissions change global temperatures through a model of the climate. The temperature increases feed back into and harm the economy. For example, temperature increases may harm the economy by making it more difficult to grow crops or by increasing the number of storms. Given this structure and the set of assumptions you choose, webDICE calculates how the economy will perform in the future.

Although webDICE involves a large number of equations, it is vastly simpler than the actual economy. It only crudely models many important drivers of the economy and does not consider other important economic factors, such as unemployment or trade. We think of webDICE as a way of understanding how some of the most important factors interact and of understanding how the results change when we change assumptions. We do not think of it as a tool for predicting what will actually happen. It allows us to see which effects of climate change are relatively robust and which economic factors are the central drivers of our future.

In the default mode, there are no controls on emissions, representing a "business as usual" scenario. You can choose to control emisisons, either by setting specific reductions in 2050, 2100, and 2150, or, in optimization mode, by finding the carbon tax that produces reductions that maximizes the welfare of people living both now and in the future.

4 What is climate change?

The term climate change or global warming refers to the likely effects of emissions of greenhouse gases into the atmosphere. The primary greenhouse gas is carbon dioxide, which we emit when we use of fossil fuels. In simplest terms, greenhouse gases act as a blanket and warm the surface of the earth. As we put more greenhouse gas in the atmosphere, we in effect put on a thicker blanket, warming the planet more.

The basic science behind climate change has been understood for more than 100 years. It is the same science that is used to explain why the Moon is cold, the Earth is the right temperature to support life, and Venus is too hot. The Earth's (and the moon's and Venus's) temperature is determined by the relationship between the energy the Earth absorbs from the Sun and the energy it emits back. These two have to be in balance for the temperature to remain stable. Because the Sun is hot, most of its energy is in the form of visible and near-infrared light. The Earth is much cooler, so the energy it emits back into space is has longer wavelengths; it is mostly in the infrared region of the spectrum. Without an atmosphere, the resulting balance of incoming and outgoing energy would mean that the average temperature of the Earth's surface would be about -20 C (which is -4 F)–too cold to support life. The reason the Earth is not actually this cold is that it is blanketed by the atmosphere. The atmosphere is nearly transparent to incoming solar radiation but it absorbs the infrared radiation coming from the Earth. In a sense, it acts like planetary insulation. The effect is to warm the Earth by nearly 35 C, to an average temperature of around 15 C.

The absorption of infrared radiation is due to only minor elements in the atmosphere – the greenhouse gases. The major components of the atmosphere, nitrogen and oxygen, are as transparent to infrared radiation as they are to visible light. The most abundant/significant human-caused greenhouse gas is carbon dioxide. It is only a trace element in the atmosphere, comprising now only about 380 parts per million (ppm), but it has strong effects.

Carbon dioxide occurs naturally in the atmosphere. Pre-industrial concentrations were about 280 ppm. Over the last century or so, however, humans significantly increased the concentration of carbon dioxide, largely through burning fossil fuels, land use change, and agriculture. When we burn fossil fuels, we inevitably emit the carbon in these fuels in the form of carbon dioxide. Roughly 60 percent of the annual emissions of greenhouse gases on a global basis come from fossil fuels (and 80 percent of U.S. emissions). Land use change alters the concentration of carbon dioxide in the atmosphere for many reasons. The most important reason is that trees absorb carbon dioxide through photosynthesis. When we cut down trees, we eliminate this carbon sink. In addition, if we burn the timber or it decomposes naturally, we release the carbon that they stored. A little more than 18 percent of global emissions are from forestry practices. Most of the remainder is from agriculture (13.5 percent globally), which produces emissions from the use of fertilizer and by releasing carbon stored in the soil.

There are some people who dispute the science behind climate change. It is not our goal to engage in this dispute; there are many places those who are skeptical or who want to be better informed can turn to. The Intergovernmental Panel on Climage Change has attempted to summarize the core scientific findings, and they have explanations of the basic ideas as well as detailed discussions of the most recent scientific results. For those who want to understand the core issues, we highly recommend the IPCC's FAQ on climate change, [http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faqs.html]. For those interested in an accessible discussion of the most recent scientific papers, we recommend [http://realclimate.org/]

We take the science to be beyond dispute and believe it is time to consider solultions. Our goal is to allow people to simulate the likely effects of climate change and how economic policies will change those effects.

While we take the science to be beyond dispute, the likely size of the effects – both how much temperatures will increase and how that increase will affect the economy – is highly uncertain. We allow you to change these assumptions so that you can see how your views on these matters may affect the future. For example, if you believe that climate change will likely be small or that it will not affect the economy very much, you can choose assumptions so that the model reflects these views. No matter how firmly you hold your views (either way) we recommend that you also see what happens if your views are not correct, as none of us can be sure about the magnitude of the effects.

5 Is climate change a hoax?

We understand that there are people who are skeptical about the science of climate change. There are many places to turn to for discussions of the science. This website is not one of them. For those who want more information about climate science, we recommend [http://realclimate.org/]

If you are skeptical of the science, however, this website might still be useful. You can set the model so that the temperature increases from emissions are relatively small and see how the economy performs. You can also see what happens if you are wrong by setting the model so that the temperature increases are high. Although we may hold our views strongly, any of us could be wrong and it is important to understand what might happen in that event. Everyone should test their assumptions and see what happens if we are wrong. Betting our future is a serious matter.

6 How good (or bad) is the economic model used?

The model is an attempt to consider how the core factors driving the economy interact, using a very simple set of equations (at least as economic models go). It is, at best, only a very rough guide, and is best thought of as producing scenarios that help us understand the interaction of these core factors. It is not a prediction. Most things cannot be predicted, from inventions that improve everyone's lives to financial crises to world wars. Any or all of these may dramatically change the future in ways that we cannot yet imagine, and the model does not try to anticipate these events.

As economics models go, the model used here is very simple. For example, it includes only two factors of production, labor and capital and it treats the entire globe as a single region rather than having separate countries which trade with one another. The advantage of this simplicity is that the model can be easily understood and it allows us to see how some of the core features of the economy potentially interact. The disadvantage is that many other things that drive the economy are not included in the model.

7 What are the core assumptions of webDICE?

While all of the details of the webDICE affect its output, there are five core features.

7.1 Productivity: the efficiency of combining capital and labor.

webDICE assumes that we produce goods by working, using machines, land, and other forms of capital. A key to how much we produce is how efficiently workers can use capital, which is known as productivity or total factor productivity. webDICE assumes that productivity increases over time, as it has over the last 200 years, but that these increases slow down, so that productivity growth, while still positive, will be lower in the future.

7.2 Emissions intensity.

webDICE assumes that production requires fossil fuels and creates emissions. Emissions are central to the model because emissions determine the amount of carbon dioxide in the atmosphere and the extent of global warming. The emissions intensity for the current year is based on the actual emisions per unit of GDP in the current economy. webDICE assumes that emissions intensity go down over time as we become more efficient.

7.3 Climate sensitivity.

The climate sensitivity is the central parameter for determining the extent to which temperatures increase when we add greenhouse gases to the atmosphere. It is defined as the temperature increase from a doubling of carbon dioxide compared to the concentrations in the atmosphere prior to the industrial revolution. The default value in the model is 3°C, which reflects the current consensus as reported by the IPCC. That is, the default value in webDICE is set so that temperatures increase by 3°C when we double the concentration of CO_2 in the atmosphere.

7.4 Harm from climate change.

webDICE assumes that temperature increases cause harm to the economy. These harms are modeled as a percentage of total output that is unusuable, which means that current consumption goes down and, moreover, as there is less output, savings go down, reducing capital that can be used for production in the future. Climate damages are both a central component to understanding the effects of climate change and also highly uncertain. We do not know how temperature increases will affect the economy, particularly as temperature changes go beyond human experience.

webDICE, in its default mode, follows the original DICE model and makes harms from climate change increase with the square of temperature increases. It also sets the damage function so that the harm is 1.7% of GDP when temperatures increase by 2.5°C. You can change both the amount that damages go up when temperatures increase and the size of damages for a 2.5°C temperature increase, so that they can see the results when climate damages are higher than or lower than the default settings. In future versions, you will be able to change the functional form of damages. For example, users can choose to have climate damages reduce the capital stock directly instead of reducing usable output in a given year.

7.5 Abatement costs.

Abatement costs are the expenditures made to reduce emissions, such as by using more expensive sources of energy or by investing in systems that can capture and store carbon dioxide underground. In the default mode, there is no abatement, so abatement costs are zero. If you impose carbon controls or use the optimization mode, abatement costs will be positive.

The abatement cost function is one of the most complex functions in webDICE. It has three components. The first is the direct cost of reducing emisisons by a given percent. These costs are assumed to go up quickly as we choose to reduce emissions more: it is relatively easy to reduce emissions a little but much harder to reduce emissions by a lot. Reducing emissions to zero in the immediate future would be prohibitively expensive. The way that this is represented in the model is that costs go up by the fraction of emissions reduced, raised to an exponent, with a default value of 2.8.

The second component of abatement costs is the "participation markup." This reflects the fact that if some nations do not reduce emissions or if some sectors of the economy do not reduce emissions, the costs on those nations or sectors who do reduce emissions will be higher. For example, if only the developed countries reduce emissions, the costs of reducing global emisisons by a given percentage will be higher than if all countries participate. The default is that all countries participate, so that there is no participation markup.

The third factor in abatement costs is the costs of carbon-free energy. This is modeled as an estimate of the current cost (per ton) of replacing all fossil fuels with carbon-free energy such as solar, nuclear, or wind power. The current estimate is very high: $1,170/ton of CO_2. This is much higher than the current market price of solar or wind power because it reflects the cost of replacing *all* energy with carbon-free sources. The model assumes that this cost goes down over time with the default estimate that it is cut in half in the future as we improve our technology.

8 What is the output of webDICE?

The model produces four default graphs showing the results. The most important is per capita income or GDP. This is the measure most commonly used in economics to measure how well a society is doing. The higher per capita income is, the richer we are. The graph shows how per capita income changes over time, which is a result of economic growth and harms from climate change. The other three graphs show (i) temperature increase over time as a result of emissions; (ii) the carbon dioxide concentrations in the atmosphere; and (iii) emissions per year.

If you click on the "customized graph' tab [need to conform web page to this title] you can graph any of the data produced by the model. You can do this by selecting the x and y-axes for the graph. Most of the time, you will want to leave the x-axis as time as most of the data reflects how variables change over time. You can also download all of the data as a CSV file (readable by Excel).

One important use of the customized graphing option is to see how your choices result in changes to the assumptions over time. For example, if you want to see how abatement costs change in the model based on your choices of the marginal cost of abatement and how fast the costs of abatement go down, you can do so. This is valuable as it is not always apparent how changing the values in the sliders change the inputs into the model.

9 User controls (basic tab)

Parameters. On the Basic tab, you can change four assumptions of the model.

1. *Climate sensitivity* – the temperature increase from a doubling of the CO_2 in the atmosphere. The default value is 3°C which is consistent with current climate models. You can set it anywhere between 1°C and 7°C to reflect a climate that turns out to be relatively insensitive to greenhouse gases (the optimistic cst), to a climate that is highly sensitive to greenhouse gases (the pessimistic case).

2. *Exponent of damage function* – the amount that damages increase when temperatures increase. The default is set to 2, so that damages go up with the square of temperatures. You can choose any value between 1 and 3. The lower the value, the lower the harms from climate change.

3. *Technological growth* – the rate of decline of growth of productivity over time. The ability to produce goods with a given amount of capital and labor is assumed to increase, consistent with historical experience. The rate of increase, however, is assumed to decline. You can choose how fast technological growth increases or declines. Lower numbers – less decline – mean that productivity *increases* more over time as we invent better production methods. The lower the number, the more optimistic you are. Higher numbers – faster decline – mean that productivity gains slow down. Higher numbers are pessimistic about future growth rates. For technically minded users, the parameter you are chosing is the percentage growth rate of the growth rate of productivity.

4. *Energy intensity* – the decline in emissions per unit of output. Producing goods requires energy, resulting in emissions of carbon dioxide. As we get more efficient, the energy required to produce goods goes down, so emissions per unit of output declines. You can choose how fast we become more efficient. The default value is 0.3% and users can set the value between 0% to 0.6%. The lower the number the slower our efficiency gains, so lowering this number results in higher future emissions and a more pessimistic outcome. The higher the number, the more quickly we reduce our energy use, so

higher numbers result in a more optimistic outcome. The parameter choice here is the percentage change in the growth rate of energy effficiency (or decline in energy intensity).

Emissions controls. The default mode assumes that there are no limits on emissions of greenhouse gases. It simulates a business as usual economy. You can impose controls on emissions by choosing to cap emissions in 2050, 2100, and 2150. The value in these sliders reflects how much emissions are capped as a percent of the emissions in 2005. For example, if you set the value in 2050 to be 50%, it means that emissions in 2050 have to be half of what they were in 2005, reflecting a fairly ambitious reduction goal. If you set caps in all three years, you might try scenarios such as 50% in 2050, 80% in 2100, and 100% in 2150. By using these controls, you can see the possible effects of a climate treaty.

10 User controls (advanced tab)

The advanced tab allows you to control many of the other assumptions of the model.

1. Abatement cost function

Reducing emissions costs money. The choice of the abatement cost function determines how much it will cost, over time. Note that the default mode simulates the economy with no controls on emissions so there is no abatement. Changing the parameters in the abatement cost function will not matter. *Changing the abatement function only matters if you have chosen emissions controls or if you are in optimization mode.*

The abatement cost function reflects three drivers of abatement costs: the increase in costs as we elimating a higher percentage of emissions, the increase in costs when less than all countries reduce emissions, and the reduction in costs from declines in the cost of carbon-free energy (such as solar panels becoming less expensive). You can set the assumptions for all three factors.

2. Additional assumptions

Maximum population – the maximum global population. The default is set to 8.6 billion people. You can choose between 8 billion and 12 billion. The current global population is just under 7 billion people.

Depreciation rate – rate of capital depreciation per year. As we use machines, buildings, and other durable goods, they wear out. You can choose how fast they wear out by selecting the depreciation rate. The default is 10% per year.

Savings rate – the portion of income which is saved. The default is 20%.

Fossil fuel reserves – fossil fuels reserves, measured in CO_2 emissions. Fossil fuel reserves reflect the total amount of coal, oil, and natural gas that we can extract. The current value is 6,000 gigatons of CO_2, which reflects known reserves. You can increase this value if you believe that we are likely to discover additional reserves in the future or develop technology to better extract fuels from known deposits.

3. Model design

Yet to be implemented.

11 Optimization mode

In optimization mode, webDICE weighs the costs and benefits of reducing emissions and finds the set of emissions reductions that balance the two. By doing so, it finds emissions reductions that produce the overall best economic performance given the costs of climate change and the costs of reducing emissions.

The choices you make elsewhere, regarding climate sensitivity, harms from climate change, technological growth, abatement costs and so on will affect how much we should reduce emissions. For example, if you choose a pessimistic scenario, such as high climate sensitivity or very bad harms from climate change, it will be desirable to reduce emissions more. Conversely, if you choose an optimistic scenario, we will not want to reduce emissions as much. Optimization mode allows you to see how your choices affect climate change policy.

There are two parameters you can choose only in optimization mode, as these parameters only matter for optimization.

11.1 The declining value of additional income

The optimization finds the emissions reductions that make people as well off as possible by balancing the costs of reductions and the benefits. The model measures how well off people are not in terms of total consumption but instead in terms of their well-being or utility. The difference is that the measre of well-being assumes that as people get richer, the same increment in income or consumption matters less, something known as declining marginal utility of income. A dollar given to a poor person is more meaningful to him than the same dollar given to Mark Zuckerberg. If we get richer over time, say because of economic growth, it makes less sense to sacrifice today to help people in the future.

You can choose how fast marginal utility declines with income by choosing the value called the elasticity of marginal utility. A lower number means that marginal utility declines less with income – the dollar matters almost as much to Mark Zuckerberg as to a poor person. A higher number means that marginal utility declines more with income.

11.2 The discount rate

In optimization mode, webDICE finds the balance between costs emissions reductions and the benefits of those reductions to maximize well being. Because climate change will occur over hundreds of years and affect billions of people, we have to determine whose well being matters. The current version of webDICE does not allow you to choose who within a given generation matters – everyone alive at a given point is time is treated equally. You can, however, choose how to weight people living at different points in time. You can choose how much we care about the future. You do this by setting the "pure rate of time preference." This is a discount rate.

The default mode uses a value of 1.5%. This is based on the value used by Professor Nordhaus in DICE 2007. Because it is set to a postiive number, the default model discounts the well-being of people living in the future. It treats them as counting less than people living today and the future in the future they live, the less that they count. The effects are quite dramatic as even a very small positive number means people in the distant future matter very little.

Setting the pure rate of time preference is one of the most controversial choices in climate change policy. Many people believe that it should be set to a positive number while many other people just as firmly believe that it should be zero. The designers of webDICE have our own views on the proper number. The default mode reflects some of our views but not all. It is set based on the value used in DICE 2007. We encourage you to try different values.

11.3 What are emissions controls?

Optimization mode finds limits on emissions in each time period. It computes a series of caps, as if nations agreed to particular global limits. It is equivalent to a "cap-and-trade" system. Cap-and-trade systems are the standard design for global-warming policies today, for example, in the European Union and under California's proposal for a state policy. Under this approach, total emissions are limited by governmental regulations (the cap), and emissions permits that sum to the total are allocated to firms and other entities or are auctioned. However, those who own the permits are allowed to sell them to others (the trade).

webDICE can also compute an equivalent "carbon tax." A carbon tax is a tax when someone, such as a powerplant or a refinery, emits carbon dioxide. It makes using fossil fuels more expensive, to reflect the fact that using fossil fuels results harms to other people because of climate change. With no tax, markets are not really free in the sense that people can use the atmosphere – dumping their waste there – without paying for it. In a free market, when people use resources, land, machines, and so forth, they have to pay for them. The price reflects alternative uses of those resources. A carbon tax effectively makes people pay to use the atmosphere just like they pay to use automobiles, land, and livestock. Most economists believe that a carbon tax is the best way to control emissions. When webDICE computes a carbon tax, it finds the tax that results in the same emissions reductions as those found directly in optimization mode.