Week Eight

EPA143A

THE ECONOMICS OF GLOBAL WARMING

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LECTURE NOTE W-8

The required reading of Week 8 includes:

- Lecture Note EPA143A 2020-2021 Week 8
- E. Schröder & S. Storm. 2020. "Economic Growth and Carbon Emissions." *The International Journal of Political Economy* 49 (2): 153-173.

Supplementary video:

Steve Keen on the economics of climate change:
https://www.youtube.com/watch?v=aoFiw2jMy-0

Lecture Note W-8 and the exercises of Week 8 are part of the exam material.

Introduction: The Economics of Global Warming

Global warming and its harmful economic and societal impacts are the major economic challenge of the modern age. Global warming poses a unique mix of problems and trials that arise from the fact climate change is a truly global process (it does not matter for the process of warming where on earth the carbon has been emitted), is a slow cumulative process with many unknown unknowns, and carries daunting scientific (to climate and earth systems scientists) and multiple economic uncertainties, casting a shadow over the globe for decades and centuries to come.

Climate-change economics uses the theories and tools of economics and mathematical modeling to analyse efficient and inefficient approaches to slowing global warming. The Intergovernmental Panel on Climate Change (IPCC) uses the outcomes of various economy-climate Impact Assessment Models (IAMs) which have been built by economists in the past 30 years or so. The most widely used IAM is the Dynamic Integrated model of Climate and the Economy (DICE), a neoclassical model of economic growth and climate change developed by William Nordhaus. Nordhaus received the 2018 Nobel Memorial Prize in Economic Sciences "for integrating climate change into long-run macroeconomic analysis."

IAMs like the DICE model are used to estimate the extent of economic damage of global warming in the future and the economic costs of climate-change mitigation policies relative to the ecological benefits of stopping global warming in its tracks. Nordhaus' model results suggest, perhaps surprisingly, that the cost of global warming will remain rather small and manageable and that (carbon tax) policies to slow down warming can be slowly, but steadily ramped up, balancing the economic costs and climate benefits in the future.

In this Lecture Note, we present a simplified version of the DICE model to explain how and why climate economists such as Nordhaus find what they think they are finding. Nordhaus' model is a dynamic optimisation model (in which an omnipotent and all-knowing global social planner chooses the optimal, utility-maximising, propensity to save on behalf of all members of the world population) – the problem being that the more we consume 'today', the less we save and invest in future growth, which implies lower consumption in the future. This trade-off between 'consumption today' versus 'consumption tomorrow' is based is false and spurious – because it is based on the loanable-funds-market fallacy that banks can only lend for investment if they first mobilise savings or loanable funds. In Week 7 we have learned that banks are money-creating institutions – and that investment is not constrained by an *ex-ante* lack of savings, but rather generate the necessary savings *ex-post* through the multiplier process. We simplify the DICE model by assuming a fixed average propensity to save and turning the model into a simulation model (rather than an optimisation model). Our Lecture Note will end with a critique of the neoclassical approach to the economics of global warming, which zooms in on three critical features of this (mainstream climate-economics) approach:

1. The non-trivial choice of the social discount rate.
2. The (deterministic) specification of the damage function and the neglect of risk and uncertainty concerning the non-zero probability of dangerous warming, climate tipping points and catastrophe.
3. The loanable-funds approach to savings and investment which creates a false trade-off between 'consumption today' versus 'consumption tomorrow'.

A neoclassical model of (long-run) economic growth

Neoclassical models of economic growth are built around a production function – a function used to describe the economy's production process. We will use a constant-returns-to-scale Cobb-Douglas production function for global output or world real GDP:

(1) $$y_t = a \times L_t^{(1-\alpha)} \times K_t^{(\alpha)}$$

where y_t = global real GDP in year t; L_t = the global labour force in year t; and K_t = the global stock of capital goods (machines, ships, trucks, robots *etc.*) at constant prices in year t. $\alpha =$ the (constant) share of capital income in GDP; $1-\alpha =$ the (constant) labour income share. In **Box 1**, we highlight two important properties of this production function.

Eq. (1) can be rewritten in terms of (instantaneous) growth rates as follows:

(2) $$g_Y = g_a + (1-\alpha) \times g_L + \alpha \times g_K$$

where $g_Y = \hat{y} = \frac{d\,y}{y} =$ the annual growth rate of real-world GDP; $g_K =$ the annual growth rate of the global capital stock; $g_L =$ the annual growth rate of the global labour force; and the growth of the constant term $g_a = \hat{a} = \frac{d\,a}{a} =$ total factor productivity growth. In neoclassical economic thinking, g_a is interpreted as a measure of exogenous (neutral disembodied) technological progress. In the neoclassical model, the macro-economy works at full employment, because both the real wage and the real price of capital are flexible and capable of bringing about equilibrium in the labour market and the capital market. Since there is no unemployment, the input of L in equation (1) is equal to the global labour force. We can therefore assume that $g_L =$ the annual growth rate of the global labour force; we further assume that it is exogenous (*i.e.,* determined by demographic processes):

(3) $$g_L = \overline{g_L}$$

If $\overline{g_L}$ increases (which means there is faster global labour force growth), there will be an excess supply of workers in the global labour market; the global real wage will then decline, until global labour demand and global labour supply are in balance again.

This means that global real income growth g_Y depends on (*i*) 'demography' (*i.e. exogenous* $\overline{g_L}$), (*ii*) technological progress (*i.e. exogenous* TFP growth or g_a), and (*iii*) endogenous capital accumulation, or the growth of the capital stock g_K. What determines the growth of the global capital stock g_K? The answer is: the growth of the global capital stock depends on investment, which in the neoclassical model in turn depends on savings. Let us however first consider investment.

Equation (4) determines the global capital stock in year (t + 1) as a function of the installed capital stock in year t (minus depreciation) and investment in year t:

(4) $$K_{t+1} = (1-\partial) \times K_t + i_t$$

where $\partial =$ the (constant) rate of depreciation (the scrapping of used-up machines) and *i* = investment in year *t*. We can rewrite eq. (4) to obtain $g_K =$ the growth rate of global capital stock, as follows:

(5) $$K_{t+1} = K_t - \partial \times K_t + i_t \quad \rightarrow$$

$$K_{t+1} - K_t = \Delta K = i_t - \partial \times K_t \quad \rightarrow \; g_K = \frac{\Delta K}{K_t} = \frac{i_t}{K_t} - \partial$$

The growth rate of the world's capital stock g_K depends on investment in year *t* (relative to the capital stock in year *t*) and the rate of depreciation. Note that the deprecation rate is a constant; this means that each and every year, firms scrap a fixed proportion of the installed machines (as these have become obsolete in a technical sense and unprofitable in an economic sense).

The growth of the world capital stock is a function of global real investment in eq. (5). In neoclassical theory, real investment is financed by real savings in the <u>market for loanable funds</u>. The market for loanable funds is a perfectly functioning (competitive) market which clears by adjustments in the real interest rate. If real savings (= the supply of loanable funds) exceed real investment (= the demand for loanable funds), the real interest rate will go down – investment will go up (because borrowing has become cheaper), until savings are equal to investment. If we assume that there exists such a perfectly operating market for loanable funds, we can immediately jump to the final outcome: $\boxed{\text{savings} \rightarrow \text{investment}}$ or

(6) $$s_t = \sigma \times y_t = i_t$$

We assume that real savings are a fixed proportion σ of real income; and that all savings are channelled – through the market for loanable funds – into investment. This means, in turn, that we can forget about investment, since savings are all that matter for the rate of growth of the global capital stock g_K:

(7) $$g_K = \sigma \times \kappa - \partial$$

where $\kappa =$ the output-capital ratio $\frac{y_t}{K_t}$, which we assume to be <u>constant</u> (in the long-run steady state). Using (3) and (7), we can derive the following equation for the growth rate of real global GDP:

(8) $$g_Y = g_a + (1 - \alpha) \times \overline{g_L} + \alpha \times (\sigma \times \kappa - \partial)$$

Global real GDP growth in eq. (8) depends on all <u>supply-side variables</u>, namely: (*a*) exogenous technological progress or TFP growth g_a; (*b*) exogenous labour force growth $\overline{g_L}$; (*c*) the average global propensity to save σ (which is a behavioural variable); (*d*) the exogenous rate of depreciation; (*e*) the capital-income share α; and (*f*) the global output-capital ratio κ. Aggregate demand (shortage) does not play any role in the neoclassical model of long-run growth.

Based on the growth-equation (8) it is straightforward to see that:

$\frac{\partial g_Y}{\partial \sigma} = \alpha\,\kappa > 0$ → a higher propensity to save increases savings and investment and hence growth of real income per worker increases; the more we save, the higher will be investment and the faster is economic growth.

$\frac{\partial g_Y}{\partial g_a} = 1$ → higher total-factor-productivity growth (= faster exogenous technological progress) raises economic growth.

$\frac{\partial g_Y}{\partial g_L} = 1 - \alpha > 0$ → faster labour-force growth (or population growth) increases the growth of global real income.

We have parameterised the neoclassical growth model using data for the world economy in 2020; the parameterisation is shown in Table 1. Using these parameter values and eq. (8), the long-run annual growth rate of real global income can be estimated to equal 2.4%.

Table 1
Model parameter values

y = real global GDP in 2020	0.87 x 10^{14} in 2020 US $
L = global labour force	3.5 billion workers
$\overline{g_L}$ = annual global labour force growth	0.0080
K = real global capital stock	1.74 x 10^{14} in 2020 US $
a = TFP-level in 2020	0.3290
g_a = annual growth rate of TFP	0.0092
α = capital income share	0.4000
$1 - \alpha$ = labour income share	0.6000
∂ = depreciation rate	0.1000
σ = average propensity to save	0.2500
κ = global output-capital ratio	0.5000
$g_Y = g_a + (1-\alpha) \times \overline{g_L} + \alpha \times (\sigma \times \kappa - \partial)$	0.024 → 2.4% per year

Figure 1
Projected real global GDP: 2020 - 2120

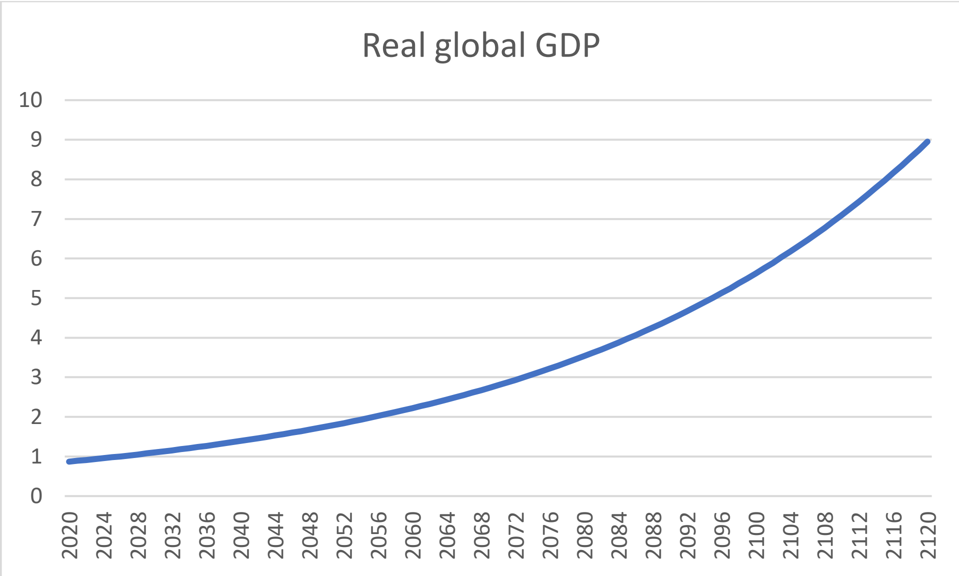


Figure 1 presents the projected (steady) growth in real global GDP during 2020-2120 – starting from 0.87 x 10^{14} in 2020 US $ in 2020 to 8.952 x 10^{14} in 2020 US $ in 2120. The average annual growth rate of real global GDP is 2.4%.

Box 1

Two Properties of the Cobb-Douglas production function

Constant returns to scale

The production function of eq. (1) exhibits constant returns to scale, because α and $(1-\alpha)$ add up to 1. This means that if we increase *L* by 10% and simultaneously raise *K* by 10%, then real GDP *y* will increase by 10% as well:

$$a \times (1.1 \times L)^{(1-\alpha)} \times (1.1 \times K)^{\alpha} = 1.1 \times a \times L^{(1-\alpha)} \times K^{\alpha} = 1.1 \times y$$

Capital income share $\boldsymbol{\alpha}$ and labour income share $(\mathbf{1}-\boldsymbol{\alpha})$

Global real GDP is (by definition) equal to the sum of wages (labour income) and profits (capital income), or $y = w \times L + \pi \times K$, where *w* = the real wage and π = the real profit rate. Dividing both sides of this equation by *y*, we get: $1 = \frac{w \times L}{y} + \frac{\pi \times K}{y}$, or the labour income share + the capital income share = 1.

We have seen in Week 2 that profit maximisation (using a constant-returns-to-scale production function) by firms leads to the following demand functions for labour, $L = \frac{(1-\alpha) \times y}{w}$, and for capital goods (machines) $K = \frac{\alpha \times y}{\pi}$.

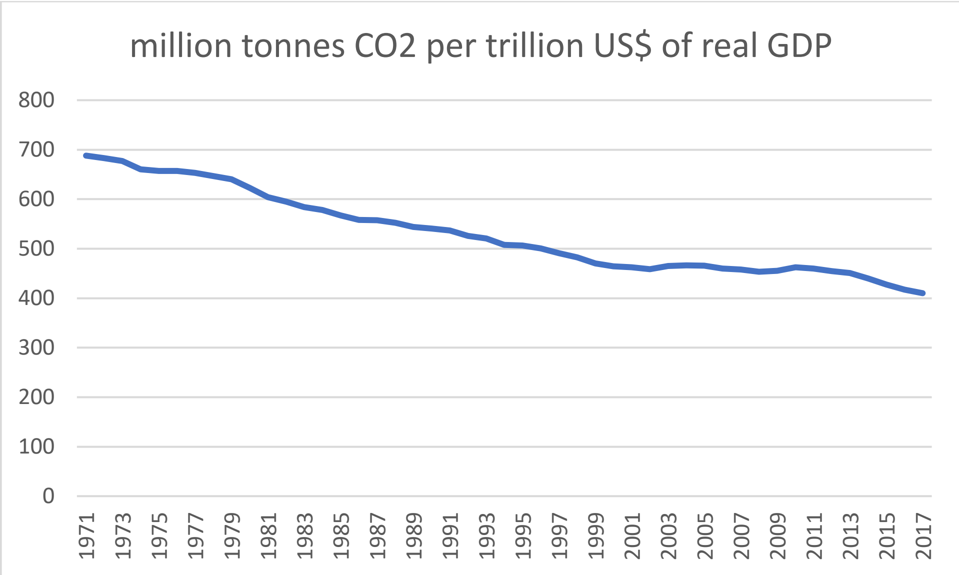
Solving the first expression for $(1-\alpha) = \frac{w \times L}{y} =$ the labour income share; and solving the second expression for $\alpha = \frac{\pi \times K}{y} =$ the capital income share. This means that in the neoclassical model, the exponents of the constant-returns-to-scale Cobb-Douglas production can be interpreted as the labour income share and the capital income share. Income distribution is constant, therefore, in the neoclassical growth model.

A simplified economy-climate-economy module

Steady income growth (as in Figure 1) will require energy (electricity) and will cause greenhouse gas (GHG) emissions. Data of the *International Energy Agency* (IEA) show that during the 1970s, the world economy was emitting around 650 million tonnes of CO_{2eq} per 1 trillion US$ of real GDP. Carbon intensity declined over time by 1.12% per year during 1971-2017 (see Figure 2). Carbon emissions are now (2020) around 410 million tonnes of CO_{2eq} per 1 trillion US$ of world GDP.

Figure 2

Carbon emissions per trillion of 2010 US $ of world GDP (1971-2017)



Source: IEA (2019), *CO2 Emissions from Fuel Combustion*.

Our climate-economy-climate module takes a number of simplifying shortcuts. The real model specifications are more complicated, nuanced and more based in climate science. But our module works as an approximation. To start, we assume that the annual flow of global GHG emissions is a linear proportional function of global real GDP as follows:

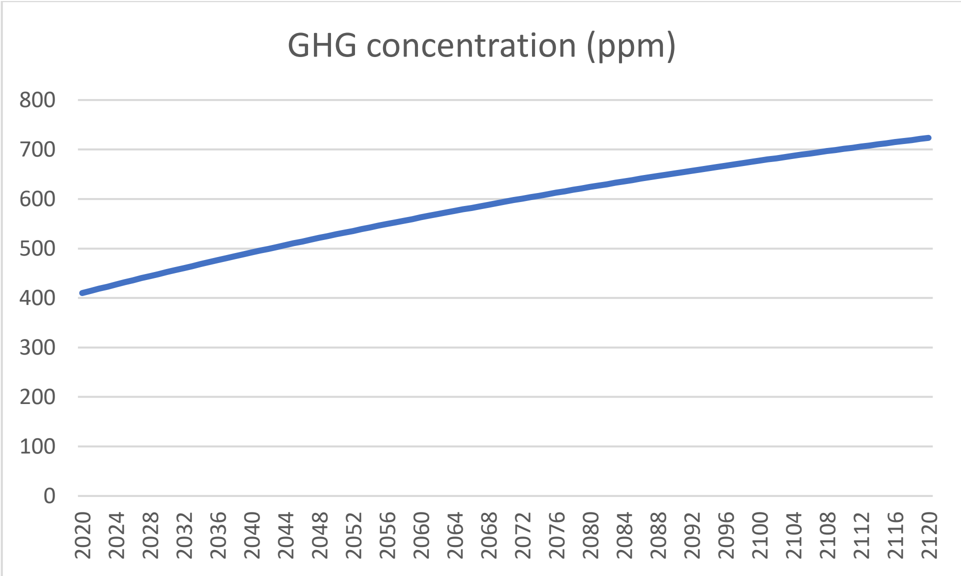
(9) $$CO_{2eq-t} = (1 - 0.03)^t \times 40 \times y_t$$

where CO_{2eq-t} = annual GHG emissions (in $GtCO_{2eq}$ in year t. We further assume that the rate of decarbonisation of economic activity is 3% per annum. The annual flow of carbon emissions increases the already existing stock of GHG emissions in the atmosphere ($stockCO_{2eq-t}$). As a result, the atmospheric concentration of GHG emissions $concCO_{2eq-t}$ increases as follows:

(10) $$concCO_{2eq-t} = 10.000 \times (stockCO_{2eq-t} + CO_{2eq-t})/7926829$$

The atmospheric concentration of GHG is 410 ppm (parts per million) in 2020. With the economic growth given in Figure 1, the concentration of GHG in the atmosphere increases to 724 ppm in 2120 – as is illustrated in Figure 3.

Figure 3
GHG concentration in our growth scenario



Climate scientists warn that this would be a disaster. Climate economists such as Nordhaus beg to disagree.

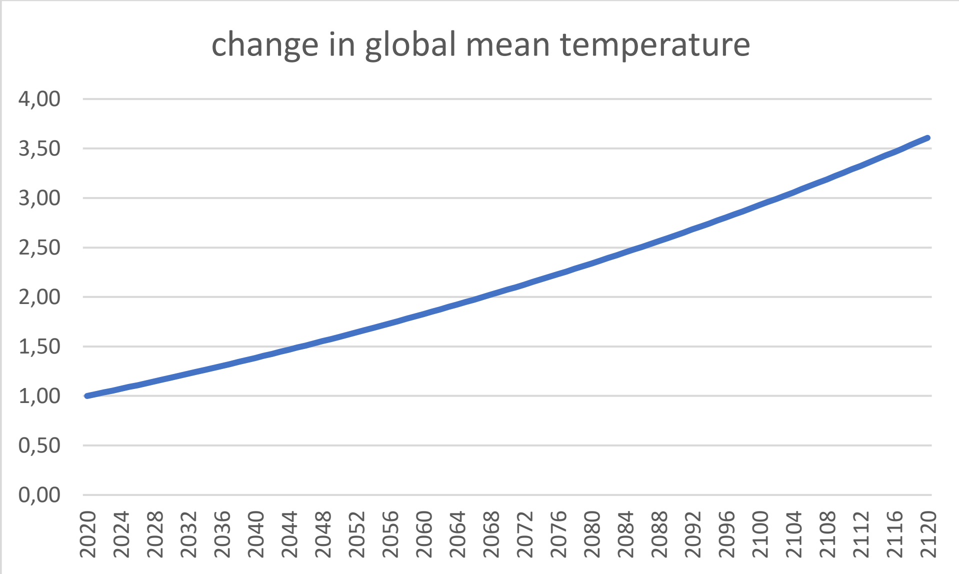
The concentration of GHGs in the atmosphere determines the change in the global mean temperature (above the mean temperature in pre-industrial times) as follows:

(11) $$\Delta T = 0.0024 \times (1 + 0.007176)^{t} \times concCO_{2eq-t}$$

In 2020, the global mean temperature is already 1°C higher than the mean temperature in the pre-industrial period (before 1800). In our base-line growth scenario, real global GDP increases by 2.4% per year during the next century – this growth generates $GtCO_{2eq}$ 2520 of additional atmospheric pollution and raises concentration of GHG in the atmosphere to 724 ppm in 2120. The global mean temperature is then projected to increase by 3.6 °C in above the mean temperature in the pre-industrial period in 2120 (see Figure 4).

Climate scientists and earth systems scientist think it likely that any increase in global mean temperature in excess of 2 °C will lead to dangerous, unstoppable and cumulative global warming; some argue that the risk of dangerous climate change becomes already unacceptably high in case global warming exceeds 1.5 °C (relative to pre-industrial times). In our base-line scenario, we will cross the threshold of 1.5 °C already in 2046 and the softer threshold of 2°C in 2067. (This suggests our time window to prevent dangerous warming is only 26 year, and perhaps 47 years). This brings us to the question of climate damage.

Figure 4
Increase in global mean temperature (in °C)



Climate damage

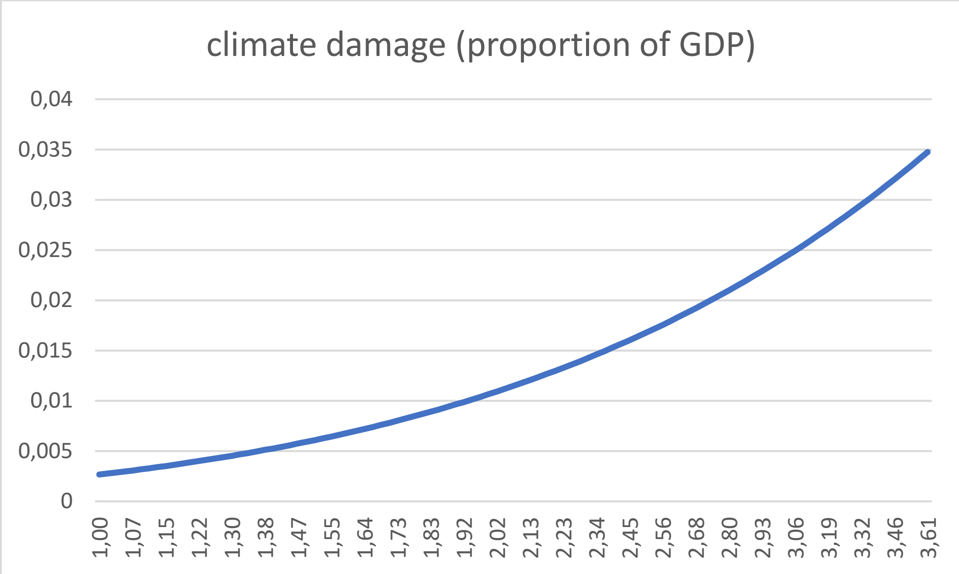
There is agreement that a rising global mean temperature will be associated with economic damages – due to considerable losses of agricultural land and output, damage due to a higher frequency of extreme-weather events, higher costs of healthcare (following the greater spread of diseases), higher cost of air-conditioning & cooling, devastation due to the rise of ocean-water levels, the cost of relocating communities living in coastal areas, etc. Climate-economy modellers such as Nordhaus attempt to account for these climate damages by including a climate-damage function; this is the climate-damage function of Nordhaus' DICE model, which expresses damage *D* (as a proportion of global real GDP) as a quadratic function of the increase in global mean temperature (above the pre-industrial mean):

(12) $$D = 0.00267 \times (\Delta\mathrm{T})^2$$

Figure 5 presents the (slowly, but steadily growing) climate damage as a proportion of global real GDP in the base-line scenario. In 2020, global warming damage is less than 0.3% of GDP; this amounts to US$ 232 billion. In 2120, with an increase in global mean temperature of 3.6 °C (above the pre-1800 mean), climate damage constitutes 3.5% of a much higher global real GDP; in constant 2020 prices, the damage is $ 31.1 trillion.

The climate damage function used by Nordhaus has been criticized as being a mathematical fiction that has little to do the real world. From eq. (12), it follows that 2°C of warming will only reduce global economic output – GDP – by 1 percent, and 4°C warming would cut real global GDP by just 4.2 percent. This is simply not realistic and it conflicts with all climate science warnings. We will use an alternative climate damage function below.

Figure 5
Climate damage (proportion of GDP) caused by higher temperature in the baseline 2020-2120



Discounting the future

The projected global warming damage in the year 2120 is \$ 31.1 trillion in constant 2020 prices – which is huge, even catastrophic, when compared to the size of global real GDP in 2020 which is \$ 87 trillion. Most economists will argue that this comparison is incorrect: if we want to find out the 'true magnitude' of the dollar damage in 2120, we must ask the question how much money we should have set aside today (in 2020) in order to be able to compensate for the damage of \$ 31.1 trillion in 2120. The answer depends on by how much we expect our savings today to grow in size over time as a result of the process of interest-rate compounding. After all, commercial banks will use our savings (or loanable funds) 'productively' by lending it to firms which invest and generate returns. This way, because financial capital is made productive, we earn a return on our wealth.

Let us assume that we set aside, for the next 100 years, \$ f dollars in a commercial bank account against a real interest rate of (say) 4%. Clearly, our wealth will have grown by 4% in 2021 ($= (1+0.04)\times f$), by 8.16% in 2022 ($= (1+0.04)\times(1+0.04)\times f = 1.0816\times f$)), and by 12.5% in 2023 ($= (1+0.04)\times(1+0.04)\times(1+0.04)\times f = (1+0.04)^3\times f = 1.125\times f$)). Each year, we receive 4% interest on f as well as on the interest we received in earlier years. It should be straightforward to see that after a century, our savings f (deposited in 2020 against an interest rate of 4%) have grown to a value of $(1+0.04)^{100}\times f$ (in constant 2020 prices).

We have deposited \$ f dollars in a commercial bank account against a real interest rate of 4% to pay for the climate damage of $\$31.1\text{ trillion}$ (in constant 2020 prices) in 2120. This means we can write: $(1+0.04)^{100}\times f = \$31.1\text{ trillion}$. This gives the following result:

$$f = \frac{1}{(1+0.04)^{100}} \times 31.1 = \frac{31.1}{50.505} = \$\ 0.616 \text{ trillion.}$$

Note that to discount the value of the future climate damage we have used a social discount rate δ of 4% ($\delta = 0.04$) – which is the social discount rate used in the DICE model by Nordhaus. The expression $\frac{1}{(1+0.04)^{100}} = 0.0198$ is called the discount factor, which 'converts' a future value into a present value. It can be defined in general terms as:

discount factor = $\frac{1}{(1+\delta)^{t}}$, where $\delta =$ social discount rate and t = time period

Accordingly, if in 2020 we set aside \$ 0.616 trillion (or just 0.7% of global real GDP in 2020) against a real interest rate of 4%, we will have accumulated \$31.1 trillion (in constant 2020 prices) by the time we reach 2120. Hence, to insure ourselves against the climate damage occurring in the year 2120, we have to set aside an 'insurance fee' of only \$0.616 trillion now (in 2020).

Discounting has nothing to do with accounting for inflation. All values, present and future, are expressed in constant US\$ of 2020; the social discount rate is the real social discount rate. Inflation plays no role in this long-run analysis; we have already accounted for inflation here. We still need to discount future values, however. By discounting we recognise the time value of money, *i.e.* the fact that even if we do not invest the money, but deposit it in a bank account, it will earn a return (an interest rate). Hence, we should compare the returns of one particular way of spending the money to at least one alternative way of using it – the low-risk, safe opportunity which gives us safe returns even when we are not doing anything.

In the jargon of economists, \$0.616 trillion constitutes the present value (PV) in 2020 of the future value (FV) of climate damage worth \$31.1 trillion (in 2020 US dollars) in 2120, discounted using a real social rate of discount of 4%. If one wants to compare future dollar damages, one has to transform their future values into present values – using a social discount rate, deliberately and consciously chosen for this purpose. In **Box 2** we explain the use of discounting and in **Box 3** we consider the choice of the social discount rate in greater detail.

If we discount the future value of the projected climate damage in the year 2120 (using a discount rate of 4%), we can do the same for climate damage in all the years during 2020-2120. For instance, the future value of climate damage in 2119 is estimated to amount to \$29.8 trillion (in 2020 US dollars). In present value *PV*, the 2119 climate damage becomes:

$$PV(\mathrm{cd}_{2119}) = \frac{1}{(1+0.04)^{99}} \times 29.8 = 0.020592 \times 29.8 = \$0.613 \text{ trillion}$$

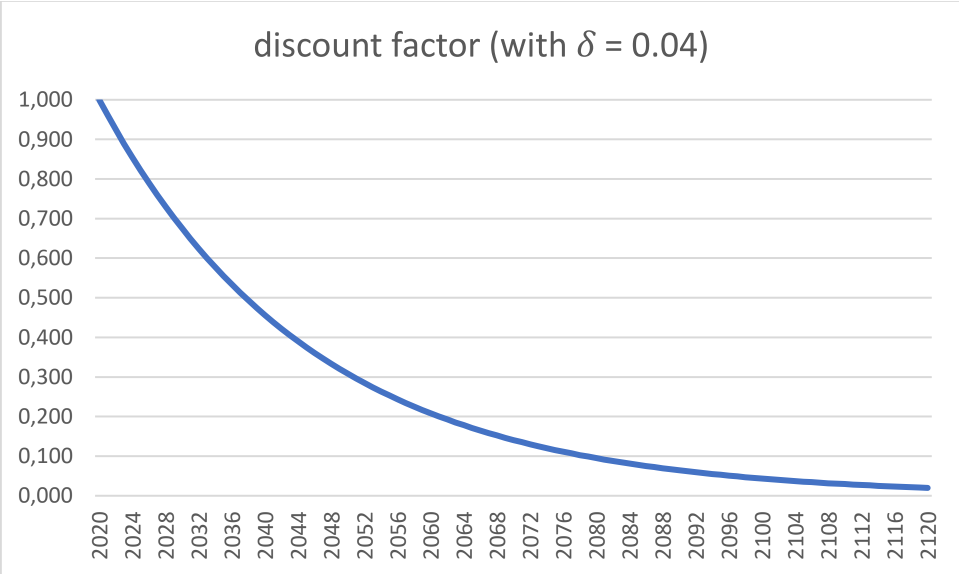
The discount factor (assuming $\delta = 0.04$) for the year 2119 is: $\frac{1}{(1+0.04)^{99}} = 0.020592$. This shows that the present value (in 2020) of climate damage in 2119 is only 2% of its future value.

Let us finally consider the future value of climate damage in the year 2068, which is \$ 2.92 trillion (in 2020 US dollars) or almost 10% of the future damage value in 2119. Converted into present (2020) value *PV*, the damage in 2068 amounts to:

$$PV(\mathrm{cd}_{2068}) = \frac{1}{(1+0.04)^{48}} \times 2.92 = 0.152195 \times 2.92 = \$\ 0.445 \text{ trillion.}$$

The discount factor (assuming $\delta = 0.04$) for the year 2068 is: $\frac{1}{(1+0.04)^{48}} = 0.152195$ or 15%. The discount factor (assuming $\delta = 0.04$) appears in Figure 6 for the period 2020-2120. The discount factor in the base-year 2020 (t = 0) is equal to 1; the discount factor declines to less than 0.5 in 2038 (t = 18) and less than 0.1 in 2079 (t = 59). This shows we are quite strongly discounting the future if we assume (as Nordhaus does) that $\delta = 0.04$.

Figure 6



Cumulatively, the present value of all future damages of global warming during the next century, discounted using a social discount rate of 4%, is:

(13) $$PV^{4\%}_{global\ warming\ 2020-2120} = \sum_{t=2020}^{t=2120} \frac{FV_t}{(1+0.04)^t} = \$\ 44.7 \text{ trillion.}$$

We have to compare this cumulative present value of climate damage with the cumulative present value of all future GDP during 2020-2120, which is:

(14) $$PV^{4\%}_{real\ GDP\ 2020-2120} = \sum_{t=2020}^{t=2120} \frac{FV_t}{(1+0.04)^t} = \$\ 4421.2 \text{ trillion.}$$

Box 2

Discounting: an exercise in opportunity costing

Discounting is a method to compare the returns to a particular planned investment to the returns of an alternative usage of a given (fixed) amount of investable resources. The alternative investment opportunity is generally chosen to be a 'safe' low-risk project which will generate safe and predictable returns. Let us consider the following example. The city council of a major Dutch town is planning to invest € 10 million in building a new bridge across the river which separates the city's northern and southern parts. Economic experts have estimated that this investment will be good for the urban economy and will generate additional income in the next 10 years (which is the policy horizon). The experts' projection of the costs and (growth) benefits (in constant prices) of building this bridge are as follows:

year	0	1	2	3	4	5	6	7	8	9	10
€ m.	-10	0.5	0.5	0.95	0.98	1	1	1.5	2	2	2.6

The (net) income (at constant prices) earned by this project is € 3.03 million, so the investment looks worthwhile indeed. But careful! Since we will be spending public (tax-payers') money, we have to be cautious and compare the return to this particular usage of funds to the return to a credible, low-risk alternative. This we do by discounting, *i.e.* by choosing a social discount rate which we use to convert the future income streams in to present values. Let us assume that the discount rate is 0.06 or 6%, which (we assume) is the interest rate the city council can earn if it invests the money in government bonds. The future value in year *t* is converted by multiplying it with the discount factor $\frac{1}{(1+\delta)^t}$ where $\delta =$ social discount rate and *t* = time period. We obtain the following results:

year	0	1	2	3	4	5	6	7	8	9	10
discount factor	1.000	0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558
PV	-10	0.47	0.44	0.80	0.78	0.75	0.70	1.00	1.25	1.18	1.45

The sum of all present values (of future values associated with our investment) is called the Net Present Value (NPV) of the project. In our example, NPV = $-$€ 1.17 million, when assuming $\delta = 0.06$. The negative NPV does **not mean** that the bridge-building project is making losses; we have seen (above) that this is not the case, as the city is projected to gain € 6.95 million in additional income from the project. The negative NPV indicates instead that investing €10 million in building the bridge is inferior (in terms of returns) to investing the money in (low-risk) government bonds, yielding 6% of interest. The net income gain (in present values) of the safe alternative is higher than that of the (risky) bridge-building project.

(Box 2 is continued on the next page)

Box 2 (continued)

The NPV is calculated using a preselected social discount rate. If we select a lower discount rate, say $\delta = 0.01$, the NPV of the same project increases. In the example, the NPV = + € 2.17 million, when $\delta = 0.01$. The positive NPV indicates that the bridge-building project generates greater benefits (in present value) than the low-risk alternative of buying bonds with an interest rate of only 1%. You can yourself calculate the NPV based on $\delta = 0.01$.

If we chose $\delta = 0.04$, the NPV ≈ 0. This means that the returns to the bridge-building project (in present value terms) are the same as the returns of investing in bonds which pay an interest rate of 4%. The discount rate for which the NPV = 0, is called the ***internal rate of return*** (*irr*) of the project. We can calculate the *irr*. It follows that if our chosen discount rate $\delta > irr$ → NPV < 0; if we select $\delta < irr$ → NPV > 0; and if we choose $\delta = irr$ → NPV = 0.

Finally, we highlight two critical properties of the social discounting of the future values of global warming damage. Both properties follow from the fact that the damages due to climate change will be very large in the relatively far-off future – say around the year 2100 (or 80 years from now).

- for the same social discount rate δ, the discount factor will become exponentially smaller the higher is *t* (*i.e.*, the more far-off in future the damage happens). Suppose $\delta = 0.03$, then €1 of damage occurring in 2030 will be worth $\frac{1}{(1+0.3)^{10}} = 0.74$ eurocents in present value of 2020; the margin of discount is 26%. €1 of damage occurring in 2070 will be worth $\frac{1}{(1+0.3)^{50}} = 0.23$ eurocents in present value of 2020. And the present value of €1 of damage occurring in 2120 (a century from now) will be worth $\frac{1}{(1+0.3)^{100}} = 0.05$ eurocents in present value of 2020; the margin of discount is 95%. Climate damage in the far-off future thus becomes trivialised. The higher the social discount rate, the more we discriminate against future generations.
- the higher is the social discount rate δ, the lower is the present value of climate damage in a given year *t*. Suppose climate damage in 2100 is estimated to equal € 50 trillion (which is more than half of today's global GDP). If $\delta = 0.01$, the present value of this damage is (still) € 22.6 trillion, but if $\delta = 0.04$, it is just € 2.2 trillion; and if $\delta = 0.06$, only € 500 billion of present value remains (or 1% of the original future cost of € 50 trillion).

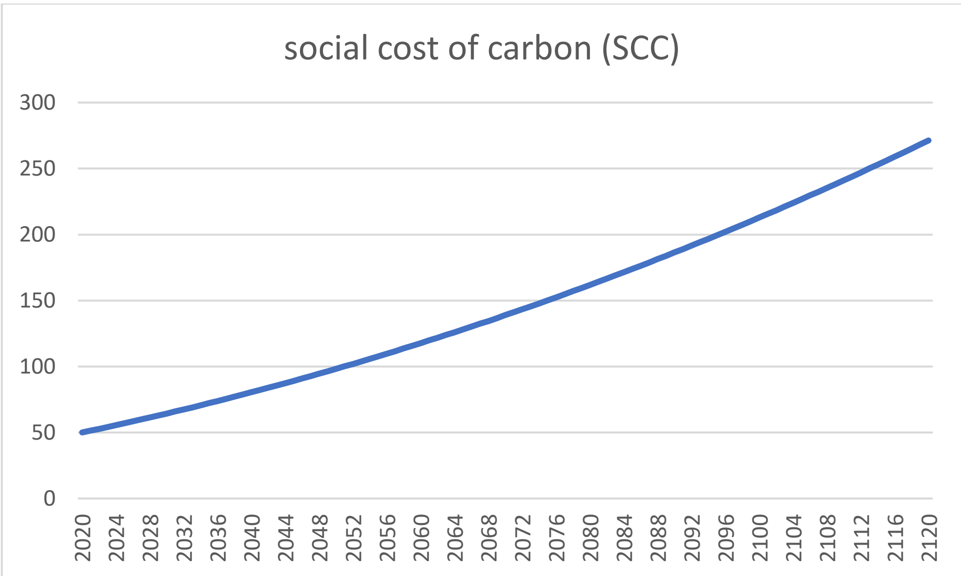
The choice of the social discount rate is all important. In Box 3 we review the debate on the choice of δ.

It follows that the present value of 100-years of climate damage – estimated by our model – constitutes only 1% of the present value of a century of global real GDP (using a social discount rate of 4%). This would mean that the economic damage due to global warming is quite small and therefore relatively easy to 'insure against': if we set aside 1% of our real income in each year during the next century, and earn compound interest on our deposit, we will be able to pay for the economic costs of global warming – following the logic of this model. If we accept these costs, there is no need for climate change mitigation – reducing carbon emissions to slow down global warming – because we will be able to bear the climate damage, if we allow the economy to grow and our wealth (savings) to bear fruit (in the form of interest earning).

However, if we prefer to lower the cost of (future) global warming, the (in theory) 'efficient' manner to do so, is to internalize the value of climate damage in the costs of production and thus in the price system. That is, producers and consumers should pay for the climate damage, which is the collateral damage of global economic growth, by including the damage value in costs and prices. This will mean that production costs and prices will be higher – which in turn will motivate firms and households to reduce their GHG emissions (which now have a price) by innovation and technological progress (in the case of firms) and by changing consumption in favour of lower-carbon items (in the case of households).

Figure 7

The social cost of carbon (US $ per tonne of CO_{2eq}), $\delta = 0.04$



To internalize the (future) value of climate damages, climate economists including Nordhaus, estimate the (annual) social cost of carbon (SCC). The social cost of carbon is defined as the present value of the future global warming damage in year *t* per tonne of CO_{2eq} emissions in year *t*. This implies that the SCC depends on the choice of the social discount rate (as we shall see below). For now, we continue to assume that $\delta = 0.04$. Figure 7 presents the SCC for our base-line growth scenario. The SCC is around \$50 per tonne of CO_{2eq} in 2020 and it gradually increases to \$100 per tonne of CO_{2eq} in 2051, \$213 per tonne of CO_{2eq} in 2100 and \$271 per tonne of CO_{2eq} in 2120 (assuming – to repeat – that $\delta = 0.04$). The SCC should be included in the costs and prices of carbon-intensive goods and services – for instance, by means of a global carbon tax per kWh of electricity.

In 2017, GHG emissions were 0.0002 tonne of CO_{2eq} per kWh of electricity. Using this ratio, a SCC of \$50 per tonne of CO_{2eq} in 2020 will raise the electricity price by \$ 0.01 per kWh in 2020; a SCC of \$100 per tonne of CO_{2eq} in 2051 will increase the electricity price by \$0.02; a SCC of \$213 per tonne of CO_{2eq} in 2100 will raise the kWh electricity price by \$0.04; and finally a SCC of \$271 per tonne of CO_{2eq} in 2120 raises the electricity by just \$0.05. This shows that the internalization of the present values of climate damages (using a social discount rate of 4%) will increase (electricity) prices by only a few cents. It is hard to believe that producers and consumers will change their behaviour and become more carbon-efficient in response to really small price rises (due to the imposition of a global carbon tax of 1 to 5 dollar-cents per kWh).

Our neoclassical climate-economy model is a simplification of actual neoclassical climate-economy models such as the DICE model, but it captures the essence of these models and it is able to reproduce (rather accurately) the general (policy) findings of these models.

Box 3

The choice of the social discount rate

There exists a large literature in economics on the problem how to choose the social discount rate. It is fair to say that this literature is inconclusive: there is no agreement on the criteria to select the social discount rate δ. Basically, there are two – opposing – schools of thought.

The 1st school is called the **prescriptive approach** which argues that δ should be based on ethical principles such as *inter-generational equity* (we do not discriminate against future generations) and/or the *precautionary principle* (we want to avoid low-probability-but-catastrophic-events and, in general, insure against dangerous outcomes). The best-known example of this approach is T*he Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge (2007). The Stern Committee sets $\delta = 0.01$ (1%) on ethical grounds. The prescriptive approach is taken by ecological economists and climate-change activists as well.

The 2nd school is the **descriptive approach** which argues that δ should be inferred from attempts to (*a*) elicit social preferences using stated preference methods; or (*b*) to elicit social preferences from decisions in financial markets regarding long-term (bond) interest rates. Nordhaus takes this approach. He bases his choice of $\delta = 0.04$ (4%) on the empirical finding that historical long-term returns to stock market investment, real estate investment and land investment are about 4%. Since we have the opportunity to invest our money in the stock market, in real estate or in land and earn 4% on average, so Nordhaus' argument goes, we should discount future values using 4% as the social discount rate.

Nordhaus ignores the fact that dangerous global warming will wipe out these historical returns, as coastal real estate becomes flooded, farm land gets eroded by high temperatures and water shortages, and share prices of firms will fall because of the economic crisis triggered by global warming. Past performance is no guarantee for future returns, in other words. In the worst case, there is no alternative usage of funds and hence no basis for opportunity costing (= discounting).

The present value of future climate damage will be considerably higher when using $\delta = 0.01$ instead of $\delta = 0.04$ – when using exactly the same IAM (see the discussion below).

To summarize our discussion:

- the neoclassical model of economic growth, (global) real GDP growth depends exclusively on supply-side drivers, including exogenous technological progress (TFP growth), exogenous labour-force growth and the propensity to save. Demand does not matter for long-run growth nor does income distribution play a role (see Box 1).

- all savings are automatically invested (arguably, through the operation of a loanable funds market) – an increase in the propensity to save will raise long-run growth, because higher savings lead to higher investment.
- economic growth results in GHG emissions which accumulate in the atmosphere. Higher atmospheric CO_{2eq} concentrations will raise the global mean temperature (above its pre-industrial mean).
- a higher global mean temperature causes damage to the economy. The damage (as a proportion of real GDP) is modelled as a simple quadratic function of the change in the global mean temperature. The damage function is deterministic: it does not account for the multiple risks and deep uncertainties concerning the possibility of 'dangerous runaway warming' or the collapse of the climate system into 'Hothouse Earth'.
- all future values (at constant 2020 prices) of real GDP and climate damages are discounted, using a social discount rate to convert them into present values. The choice of the social discount rate is an exogenous choice by the modeller. With a positive social discount rate, future values are turned into smaller present values by applying a discount factor which declines over time (Figure 6). Discounting is an exercise in opportunity costing, because the social discount rate reflects the annual (real) return to an alternative use of the resources (see Boxes 2 and 3).
- the annualised present value of global warming damage (due to carbon emissions) is expressed in terms of the social cost of carbon (SCC) – see Figure 7. The social cost of carbon is defined as the present value of the future global warming damage in year t per tonne of CO_{2eq} emissions in year t. The SCC should be internalised in the cost and price system of the economy (for instance, by means of a global carbon which exactly reflects the SCC).

A critique of neoclassical climate economics (and DICE in particular)

We briefly highlight the following problems with the neoclassical approach to global warming:

1. The 'all-important' choice of the social discount rate.
2. The (deterministic) specification of the damage function and the neglect of risk and uncertainty concerning the non-zero probability of dangerous warming, climate tipping points and catastrophe.
3. The pre-Keynesian loanable-funds approach to savings and investment which creates a false trade-off between 'consumption today' versus 'consumption tomorrow'.

The choice of the social discount rate

As already explained above and in Box 3, there is no consensus on the social discount rate. Nordhaus uses a social discount rate of around 4%, arguing that this reflects the opportunity cost of investing climate-change mitigation, since 4% is the historical rate of return on investing in assets such as stocks, land, and real estate. Nordhaus' assumption is fundamentally flawed in the face of the non-zero probability of disastrous run-away global warming, due to which all asset markets would collapse. Nordhaus' approach is backward-looking, not (rationally) forward-looking – and it ignores the existence of low-probability-catastrophic warming, a point stressed by climate science. In the face of a non-zero probability that increases in atmospheric concentration of carbon will cause catastrophic warming, the rational approach is the precautionary approach: we should err on the side of caution and avoid that (small-probability) outcome. This means that meaningful climate-change mitigation and decarbonisation are required in order to reduce global GHG emissions so as to stay within the remaining global carbon budget (consistent with global warming of 1.5°C). If we adopt this line of reasoning, the economic assessments by IAMs such as DICE are not needed, nor are they helpful in any meaningful sense.

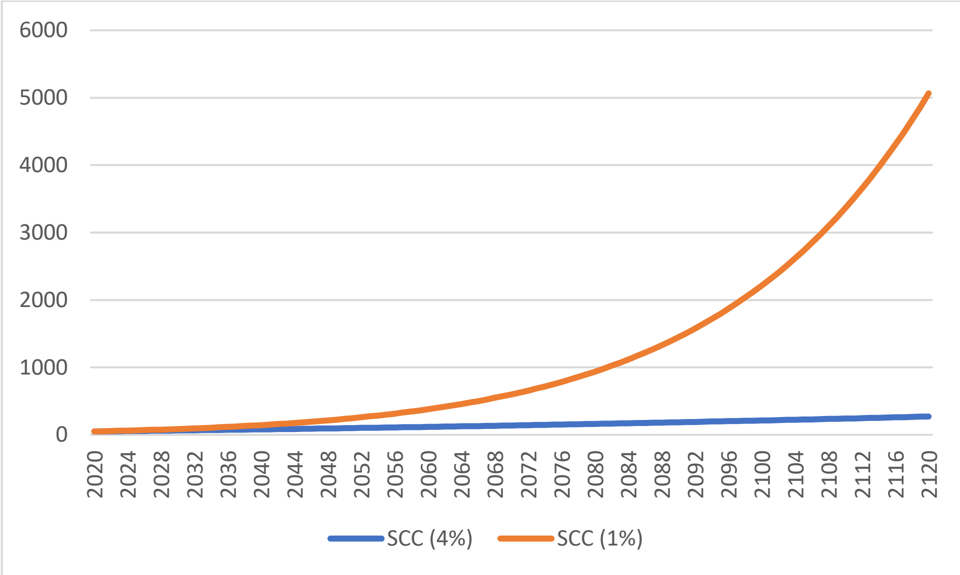
Discounting also becomes meaningless if there is no longer a safe alternative investment opportunity which generate a positive rate of return. It appears unlikely that historical rates of return of 4% can be sustained in the scourging conditions of Hothouse Earth. As there may well be no alternative profitable investment opportunity left, discounting has lost its rationale.

Finally, if one decides on ethical grounds that the social discount rate should be low, say 1% (as was done by the Stern Committee, see Box 3), then this choice of the social discount rate will have a significant impact on the SCC also in our neoclassical growth model.

The SCC (calculated using $\delta = 0.01$) is compared to the SCC (calculated assuming $\delta = 0.04$, as in Figure 4). The difference is easy to see. With $\delta = 0.01$, the SCC rises from US$ 50 per tonne of CO_{2eq} in 2020 to US$ 101 per tonne of CO_{2eq} in 2033, and further to US$ 2214 per tonne of CO_{2eq} in the year 2100 (compared to US$ 213 per tonne of CO_{2eq} with a social discount rate of 4%). The carbon tax (imposed to internalise the SCC) has to be much higher – and climate mitigation policy will have a real bite. The lower social discount rate gives greater weight to future damages – and discriminates less against the interest of future generations, while slowing warming by the imposition of a much higher carbon tax.

Figure 8

The social cost of carbon (US $ per tonne of CO_{2eq}), $\delta = 0.04$ and $\delta = 0.01$



A more realistic climate damage function (with a climate tipping point)

The climate damage function used in the DICE model is unrealistic for at least two reasons.

First, the DICE climate damage function (eq. (12)) does not reflect basic climate science, which highlights the self-reinforcing (cumulative) nature of global warming and the existence of climate tipping points. Nordhaus' quadratic damage function (shown in Figure 5) assumes that there are no discontinuities, and therefore no points at which the relationship implied by the function simply breaks down. Hence, in the DICE model, there are no temperature levels that set off catastrophic breakdown in the economy by triggering fundamental qualitative shifts in the climate—such as melting the icecaps, stopping the Gulf Stream, or turning El Nino from a temporary phenomenon into a permanent one – as argued by Steve Keen in the video lecture.

Second, the DICE climate damage function underestimates the likely economic damages of global warming as well as the risks and deep uncertainties associated with these negative impacts. Nordhaus reiterated his benign view of future climate damage in a 2017 paper, "Revisiting the social cost of carbon":

> "Including all factors, the final estimate is that the damages are 2.1% of global income at a 3 °C warming, and 8.5% of income at a 6 °C warming.
>
> (Nordhaus, 2017 #5559, p. 1519).

The 8.5% in global real GDP decline that Nordhaus predicts from a 6°C increase in average global temperature would take 130 years. Spread over more than a century, that 8.5% fall would mean a decline in GDP growth of less than 0.1% per year. At the accuracy with which change in GDP is measured, that's little better than a rounding error. We should all just sit back and enjoy the extra warmth – as Steve Keen summarizes Nordhaus' findings.

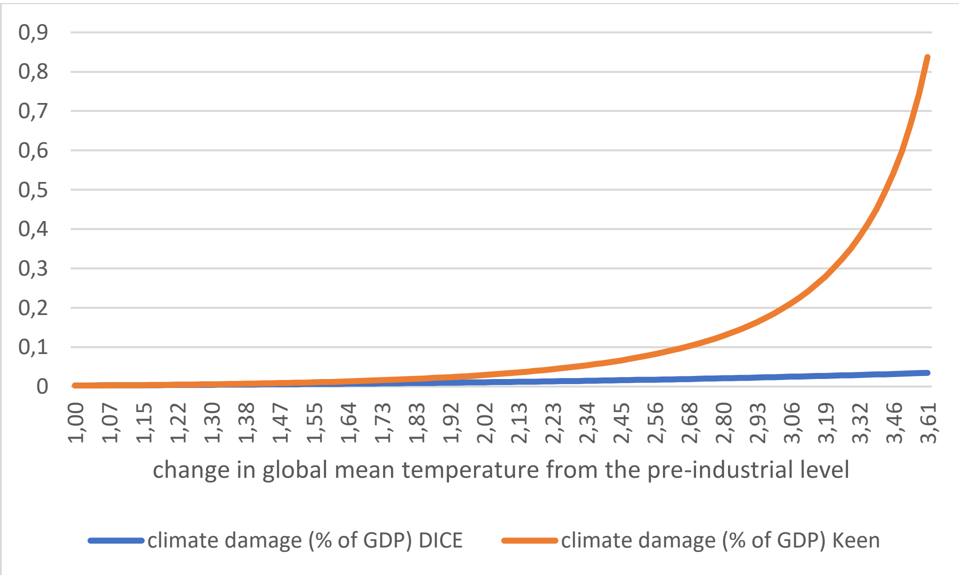
Following Steve Keen, we can define an alternative climate damage function with a climate tipping point (at 4°C) as follows:

$$D = \frac{-0.007 \times (\Delta T)^3}{\Delta T - 4} \tag{15}$$

We have used this climate damage function (instead of the DICE damage function, eq. (12)) to estimate future climate damages. At $\Delta T = 1.5$°C, which the level of warming that the IPCC wants policy-makers to set as a maximum, the damage according to DICE will be 0.6% of global real GDP, but it will be 1% of real GDP according to eq. (15). The difference becomes larger the more the global mean temperature increases. At $\Delta T = 3$°C, the damage according to DICE will be only 2.4% of global real GDP, but it will be almost 20% of real GDP according to eq. (15). This is more than 8 times as high. This alone is enough to reject outright Nordhaus' assurances about the manageability of climate change.

The SCC will be much higher when estimated using eq. (15). To illustrate: in 2050, the SCC is US$ 98 per tonne of CO_{2eq} according to DICE, but US$ 228 per tonne of CO_{2eq} according to eq. (15).

Figure 9
Nordhaus' Damage Function versus one based on a 4-degree tipping point function
(proportion of real GDP)



The false trade-off between consuming today versus consuming tomorrow

The neoclassical growth model used by Nordhaus is based on the assumption that banks need (prior) saving (deposited by households) before they are capable of originating loans to investing firms. This is the loanable-funds approach, at the heart of the neoclassical model (as we saw in Week 2).

The ‘loanable-funds’ banking system creates an intertemporal trade-off (or a conflict) between the present generation and future generations of people. The more the present generation saves (and hence invests) today, the lower will be its consumption (remember that $c = (1 - \sigma) \times y$) and ‘welfare’ today, but the more the economy grows and the higher can be consumption and welfare of future generations.

The intertemporal trade-off also applies to climate policy. The more resources we (the present generation) put aside to reduce GHG emissions and slow down warming, the lower will be our consumption and welfare. The fruits of our efforts (and savings) will accrue to the future generations who will enjoy a better climate and lower climate damages. In this logic, the social planner has to balance the interests of the present generation and of all future generations; the choice of the social discount rate is of critical importance to balancing the interests of the present versus the future generations.

A social discount rate of (say) 4% favours the present folks and discriminates against all future generations, especially those in the far-off future. The justification for a social discount rate of 4% is that we let the global economy grow, so that in 100 years, the average person has become much richer than the average person today – and therefore in a better position to pay for the (constantly growing) climate damages. The justification is spurious in view of the unrealistic climate damage function used in models such as DICE.

A social discount rate of (say) 1% is chosen to reduce the discrimination of future generations and give greater weight to future climate pain. While this position has a more convincing justification on ethical grounds, it is still based on a fallacious conflict or trade-off.

After all, since commercial banks are money-creating institutions, there is no need for the prior mobilisation savings. We can now invest in climate-change mitigation and deep decarbonisation, because this can be pre-financed by credit (new money). There is no inter-temporal trade-off to navigate and no solid economic reason to postpone or slow down effective climate action.

Two final concerns

The paper by Schröder and Storm looks at the issue of the decoupling of economic growth and GHG emissions. Is it possible to grow our economy while reducing carbon emissions? In this discussion, the paper uses two analytical frameworks which are useful when thinking about the economics of global warming:

- the Kaya identity is an instructive device for analysing the linkage (or decoupling) of growth and CO2 emissions. It decomposes global CO_2 emissions (in million tonnes), denoted by C, into measurable 'drivers' directly relevant to climate and energy policy:

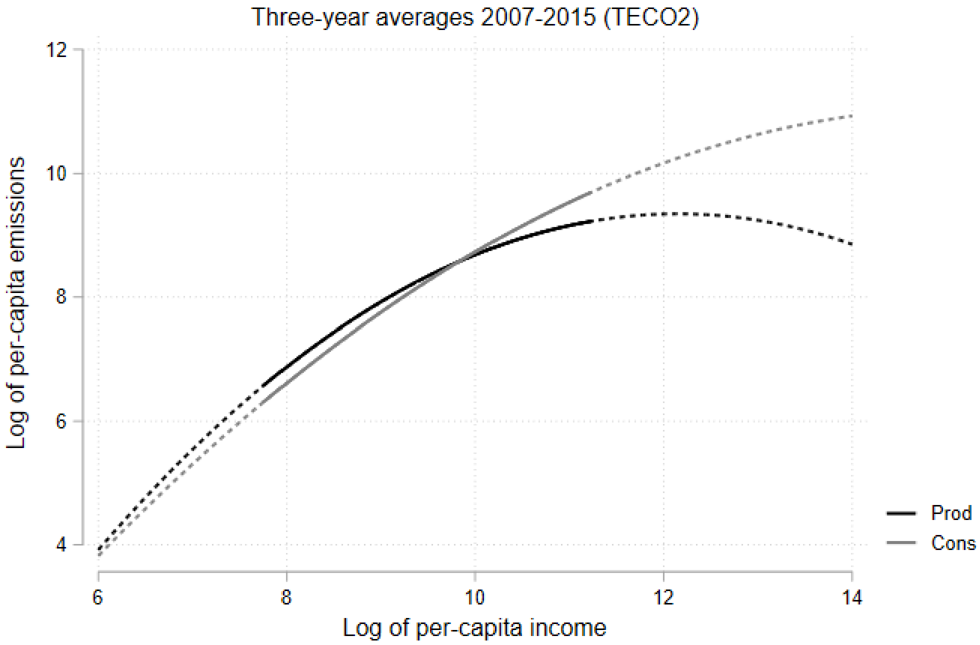
$$C = P \times \left(\frac{Y}{P}\right) \times \left(\frac{C}{E}\right) \times \left(\frac{E}{Y}\right) = P \times y \times c \times e$$

  where *P* = world population (billions of persons), *Y* = world GDP (in constant U.S. dollars), *E* = total primary energy supply or TPES (in PJ), *y* = global per-capita income (in constant U.S. dollars), *c* = *C/*E = carbon intensity of primary energy supply, or CO_2 emissions per TPES, and *e* = *E/Y* = energy intensity of GDP. The paper uses the Kaya identity (in growth rates) to assess the extent of decoupling during 1970-2017.

- the carbon Kuznets-curve (CKC): the CKC is based on the following quadratic relationship between CO_2 emissions per person *cop* and per-capita real GDP y:

$$\ln(cop) = \beta_0 + \beta_1 \ln y + \beta_2 (\ln (y))^2$$

  The shape of the CKC is an inverse-U (see the figure below). At low levels of per-capita income, per capita carbon emissions are low; this is the situation in low-income countries, where average consumption levels are low and the manufacturing sector is small. At higher per person income levels, emissions per capita are higher; this is the case in the newly-industrialising countries where living standards are rising and becoming more carbon-intensive, and where industrialisation is happening (e.g. China); at the highest per-capita income levels (in the OECD countries), emissions per person are lower; this has two reasons: decarbonisation of production and consumption; and the fact that these countries did outsource and offshore their manufacturing activities. Per-person carbon emissions peak at $y = \exp\left(-\frac{\hat{\beta}_1}{2\hat{\beta}_2}\right)$. Empirical evidence on the CKC based on production-based and consumption-based emissions appears in the article.



The End of EPA143A

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The End of the World as We Know It:

https://www.youtube.com/watch?v=JsxavPANO8s