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An Analysis of the DICE Model: The Impacts of Damage Function and Social Rate of Discount

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ABSTRACT

The DICE Model by Nordhaus aims to provide policy recommendations for pricing carbon. While the model is comprehensive and innovative, there are often concerns about its capability to reflect real-world situations. Despite a way to connect economic development to environmental activities, there have been critiques about the model's ability to deal with real world issues. This paper examines this aspect of the model by adjusting its key components: damage function and social rate of discount. We find that the model is very sensitive to these components and should be only used as a reference instead of a policy tool.

Key words: DICE Model; damage function; social rate of discount; social cost of carbon

SECTION 1. INTRODUCTION

Nordhaus' DICE model is based on an intertemporal, neoclassical growth (Ramsey-type) model, where a composite good is produced in six regions of the world with equal quality (see Nordhaus 2008, 2017). Since this good is a perfect substitute, we do not need to consider international trade explicitly. The production of the good leads to greenhouse gas emissions. The reduction of these emissions is costly because it implies a decrease in total factor productivity. Thus, the rate of CO_2-emissions reduction, along with consumption and investment, are the decision variables in the model. The decision variables are optimized intertemporally. The main new feature of the Nordhaus model is the consistent, (model-) endogenous consideration of climatic interactions.

The concentration of greenhouse gases in the atmosphere) hereafter only referred to as CO_2 emissions) increases with a time lag. The CO_2 concentration in the atmosphere decays with a defined dwelling time and gets absorbed by a carbon sink, which is assumed to be infinite. The concentration of greenhouse gases affects outgoing radiation from the atmosphere to space. The higher the CO_2 concentration, the higher the heat-trapping effect. This determines the development of temperature in the atmosphere and on the Earth's surface. The temperature increase on the surface and upper ocean levels is slowed down by heat released to the deep ocean. The difference in temperature between the two strata converges over time, since the absorption capacity of the deep ocean decreases with increasing temperature. In the long-term this leads to a temperature feedback into the atmosphere and this, in turn, serves to increase the effect of radiation. Therefore, assuming constant economic activity, the effect is self-reinforcing.

The damage from an increase in temperature enters the production function as a negative externality. Avoidance costs are incorporated in the production function. We have a feedback of the environmental condition on production. This kind of reaction is not specified for consumption, which means that the quality of the environment is not integrated in the utility function of the households.

The wealth function incorporates consumption preferences on a global level, assuming a diminishing marginal utility of consumption. An important feature is time preferences, since consumption today has an effect of consumption tomorrow. This affects investments in e.g. technology as well as the natural capital of the climate system in the form of a higher concentration of greenhouse gases. For instance, reductions in emissions are investments which increase the availability of natural capital, and therefore, increase the opportunity for future consumption.

The loss function of economic damage due to climate change is characterized by uncertainty. This will be discussed at a later point in this paper.

The objective function maximizes the present value of welfare over time, which requires specification of a discount rate. Consumption leads to production procedures that are described by a production function, with capital, labour and energy inputs. This in turn affects CO_2 emissions. The geophysical part of the DICE model includes a carbon cycle module (affected by CO_2 emissions), the accumulation of greenhouse gas and the resulting temperature change. Decision variables could be, inter alia, the rate of emission reductions or the tax on carbon, (Nordhaus, 2017).

The paper is organized as follows. In section 2, we review the key results of the latest version of the model. Section 3 is divided into two subsections. In section 3.1, we replace Nordhaus' damage function with the damage functions used by other economists, and analyze their impacts on the model results. In section 3.2, we proposed a new damage function and analyze its impacts on the results. Then, in section 4, we modify the model to calibrate the social discount system, as discussed by Boardman et al. (2008). Section 5 provides a brief conclusion.

SECTION 2. DICE 2016R

The most recent version of the DICE model was published in August 2017. Some of the model predictions are presented in Table 1. The recent versions of the DICE model explicitly include a backstop technology. Backstop technologies can replace all fossil fuels such as solar power or windmills. It also considers trees that remove carbon from the atmosphere or any other technology that might not yet be discovered. We assume the price of the backstop to be high in the beginning and then decrease over time due to carbon-saving technological developments.

Table 1: Extract of the resulting values (DICE-2016R)

Year	2015	2020	2025	2030	2035	2040	2045	2050	2060
Δ in atmospheric temperature	0.85	1.02	1.19	1.37	1.55	1.74	1.93	2.13	2.52
Carbon price ($2015/tCO$_2$)	2.00	2.21	2.44	2.69	2.97	3.28	3.62	4.00	4.88
Social cost of carbon	31.23	37.25	44.04	51.62	60.03	69.29	79.44	90.49	115.42

SECTION 3. THE DAMAGE FUNCTION

3.1. Background

Integrated Assessment Models (IAM) aim to inform policy makers about optimal emission pathways and recommend climate policies. Unfortunately, we do not know much about the damage function. Lacking an empirical foundation, economists are forced to make up a loss function that fits the parameter values of their model (e.g., Ackerman and Stanton 2012). Mostly, the loss function describes a negative relationship between the temperature increase (ΔT) and GDP. The DICE model incorporates this effect in two ways: through capital depreciation and though the growth of total factor productivity (TFP). Labour and TFP are exogenous in the DICE model. Temperature shocks consistently decrease GDP. Therefore, global warming has a compound effect on GDP. Temperature shocks can also lead to a reduction in the TFP due to the change in the environment for which the investments were meant. Shifting resources from R&D to prevent environmental threats can lower the growth of TFP. Both would affect the growth rate of GDP.

3.2. Some mathematics

The following is a mathematical derivation for the damage function. Let $a_t = 0.00511T_t$ and g_t be the growth rate of net GDP at time *t*. This is illustrated as:

$$GDP_1^{gross} = GDP_0^{net}(1+g_0) \qquad GDP_1^{net} = GDP_0^{net}(1+g_0-a_0)$$

$$GDP_2^{gross} = GDP_1^{net}(1+g_1) \qquad GDP_2^{net} = GDP_1^{net}(1+g_1-a_1)$$

$$\cdots \qquad \cdots$$

$$GDP_t^{gross} = GDP_{t-1}^{net}(1+g_{t-1}) \qquad GDP_t^{net} = GDP_{t-1}^{net}(1+g_{t-1}-a_{t-1})$$

The left-hand side and right-hand side are mathematical representations for gross GDP and net GDP, respectively. Gross GDP shows total GDP without the damages from temperature. In contrast, net GDP takes damages into consideration. They both start at time 0 which is taken to be 2018. The last lines are the recurrence formulas for time t. Both net and gross GDP at time t equal to net GDP from last period multiplied by its growth rate. Temperature reduces the growth rate by a_0, which is the increased temperature multiplied by its damage rate (-0.00511). As gross GDP falls when temperature rises, gross GDP at time t is based on net GDP from the last period (t–1) multiplied by the growth rate g_t.

The total damage is the difference between gross GDP and net GDP in the same period. The damage fraction or damage function shows the share of damage from gross GDP. Thus, the damage fraction is the total damage divided by gross GDP, which is given by:

$$damage_t = GDP_t^{gross} - GDP_t^{net} = GDP_{t-1}^{net}(1 + g_{t-1}) - GDP_{t-1}^{net} = GDP_{t-1}^{net}a_{t-1}$$

$$damagefraction_t = \frac{GDP_t^{gross} - GDP_{t-1}^{net}}{GDP_t^{gross}} = \frac{damage_t}{GDP_t^{gross}} = \frac{GDP_{t-1}^{net}}{GDP_t^{gross}}(0.00511 \times T_{t-1}) \ .$$

Nordhaus uses an inverse-quadratic damage function: $damage_t = GDP_t^{gross} \times damagefraction_t$, with the following damage fraction of GDP: $damagefraction_t = a_1T_t + a_2T_t^{a_3}$, where a_1 is the damage intercept, which Nordhaus sets to zero, and a_2 is the damage quadratic term set to 0.0028388 in the 2007 version, so a_3 =2. In his 2016 model, Nordhaus set a_2 to 0.00236. This shows that impact estimates have become less pessimistic over time. The recent value says that estimates increase by 0.23% of GDP per year.

Nordhaus (2008) states that, for an increase in temperature of 4°C, the global mean loss in GDP could be between one and five percent, following the 2007 IPCC report. However, the IPCC itself received these values from evaluations based on ‘other’ IAMs that, in turn, use self-chosen values themselves. The point is that these damage functions are not based on solid empirical evidence. The function should describe how the GDP decreases with increasing temperature.

Empirical data from Dell et al. (2012) supports the negative effect of increasing temperature on GDP growth. One explanation is that increased temperature would affect the ecosystem permanently – raising sea levels, increasing disease risks, reducing biodiversity, increasing extreme weather events, et cetera . Furthermore, we can expect that resources needed to lower the effect of global warming cannot be used for research or investments in other areas, and thereby reduce GDP growth.

Climate change policy is directly affected by the change in temperature. Different levels of damage determine the social cost of carbon (SCC). In order to evaluate the fit of the chosen damage function, we examine various functions for estimating the economic impact of climate change. In Table 2, we list different damage fractions to compare their effect on the SCC. Figure 1 captures these damage fractions graphically.

Table 2: Different damage fractions used in the literature

Specification	**Reference**
$0.00236 \times T_t^2$	Dice-2016R
$0.0019 \times T_t^2$	Nordhaus (2017)
$0.0071 \times T_t$	Hope (2006)
$0.12T_t + 0.16T_t^2$	Tol (2018)
$0.02e^{T_t - 0.02}$	Karp (2009)
$\frac{0.0102T_t^2}{1 + 0.0102T_t^2}$	Weitzman (2010)

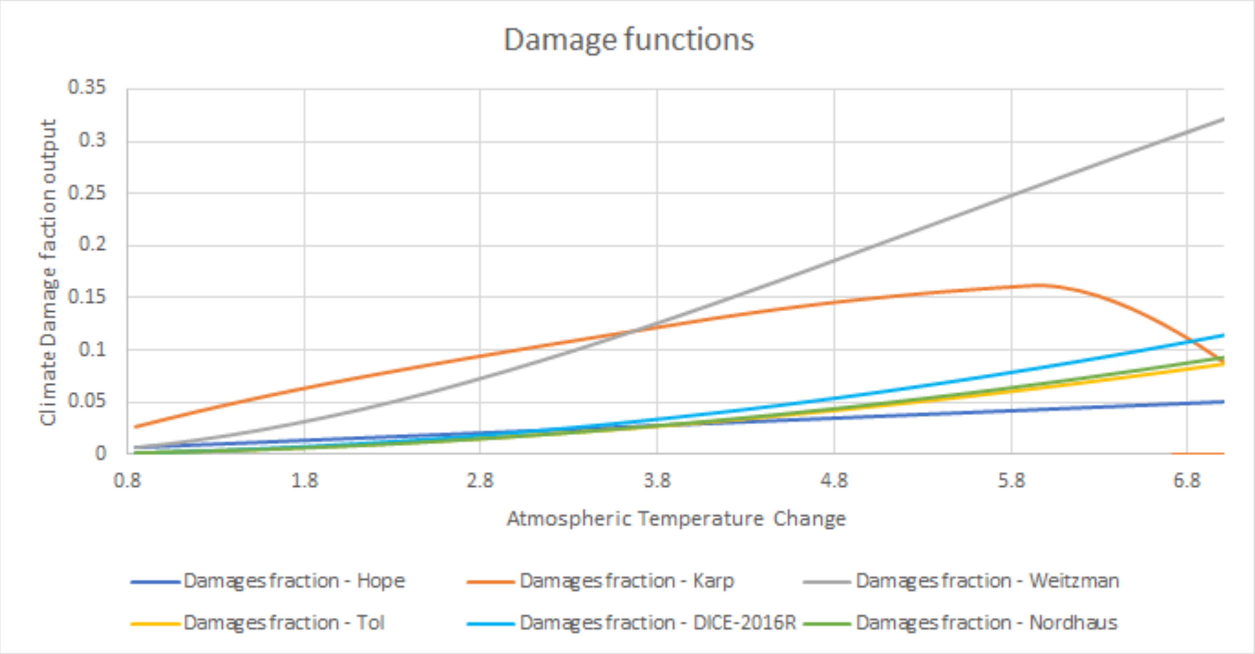

Figure 1. Different Damaged Fractions Plotted Against an Increase in Temperature of Atmosphere (Degrees C from 1900)

Figures 2 and 3 depict the development of the SCC over time, comparing the earlier specified damage functions. Especially, the damage function used by Karp (2009), but also that used by Weitzman, predict a quite sharp increase in the SCC. Since their predictions are more extreme and differ significantly from the other ones, Figure 3 zooms into lower SCC values. They all predict an increase in the cost, which can be explained by the compounding effect of an increase in temperature. Temperature shocks consistently decrease GDP. Therefore, global warming has a compound effect on GDP, which results in an increasing SCC and therefore a higher carbon tax.

It is obvious that the different damage fractions of GDP result in significantly different predictions of the development of the SCC. It might also be reasonable to have a negative SCC in the first years before it increases over time. Weitzman often uses that approach in his predictions.

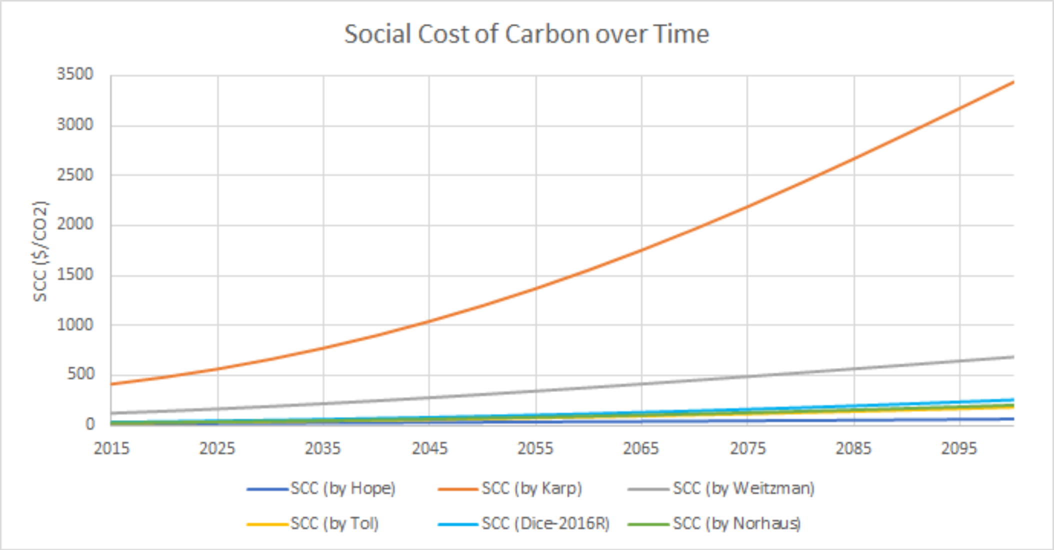

Figure 2. Development of the Social Cost of Carbon over Time with the Specified Damage Functions

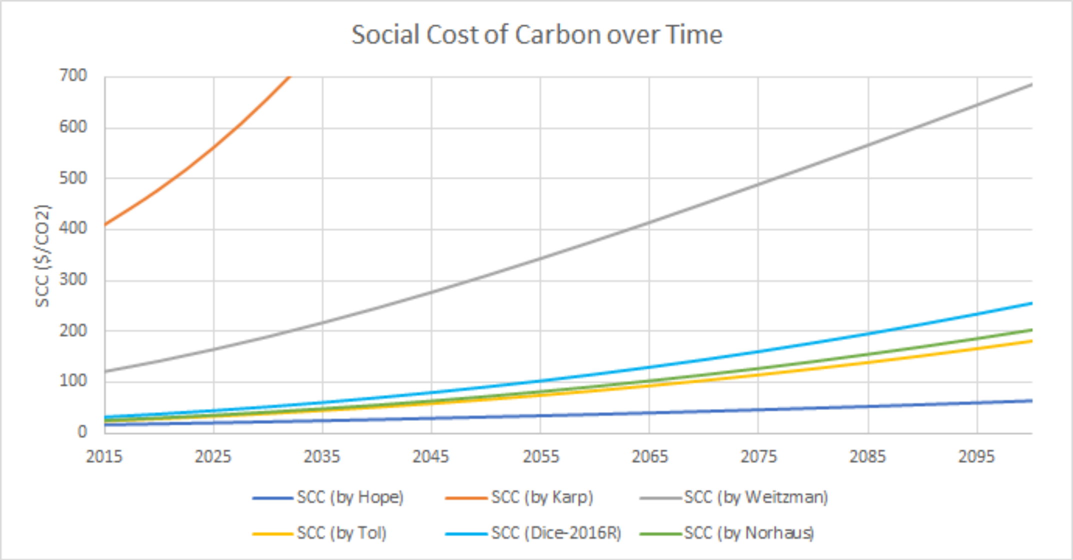

Figure 3. Development of Social Cost of Carbon Disregarding the Damage Function by Karp (2009) (zoomed in)

3.3 Changing the Damage function

Dell et al. (2012) found a significant effect of increasing temperature on the growth rates in poor countries and less strong effects in rich countries. Thus, they developed a two-region version of the DICE model. Based on results from Dell et al. (2012), we construct a new damage function. These authors applied econometrics to analyze how the temperature increase impaired GDP growth rates by groups – rich and poor countries. We choose time series data with 10 temperature lags from Dell et al. (2012; see also Moore & Diaz 2015). For every 1℃ temperature increase above the average, GDP growth drops by -1.171 percentage points for poor countries and -0.152 percentage point for rich countries.

Table 3. Impact of 1℃ in temperature on GDP growth.

Countries	GDP Growth Rate (percentage points)	Share of World GDP (2018)
Poor	-1.171	35%
Rich	-0.152	65%

Source: Dell et al. (2012) and World Bank (2018)

To apply reductions in the growth rate into the DICE model, Moore and Diaz (2015) constructed the two-region version of DICE 2013, while the base case DICE model regarded the world as one economy. Thus, our project aggregates the two rates to form an integrated, declining GDP growth rate for DICE 2016R.

One classification for countries is from World Bank database (2018); it includes low income, medium income, and high-income countries. To correspond with Dell et al.'s classification, we take low and medium-income countries as poor countries, and high-income as rich countries. Furthermore, poor (low and medium income) and rich (high income) countries shared 35% and 65% of total world GDP in 2018 as shown in Table 3. We multiply two shares with the reduced growth rate in GDP due to a temperature increase and aggregate them to find a global reduction in GDP of 0.00511 percentage points.

3.4. Results

Here, we focus on the short-term effects. As our damage function is based on data from econometrics estimation, it is possible that the long-term damage is not correctly estimated using past data. One hundred years (to 2095) is an arbitrary end-point for short-term analysis. The temperature change for two damage functions is provided in Figure 4. In the short-run, there is only a small difference between the two temperatures. The temperatures in the base model are slightly higher after year 2055. They both have upward trend and stop at around 4℃ by the end of this century.

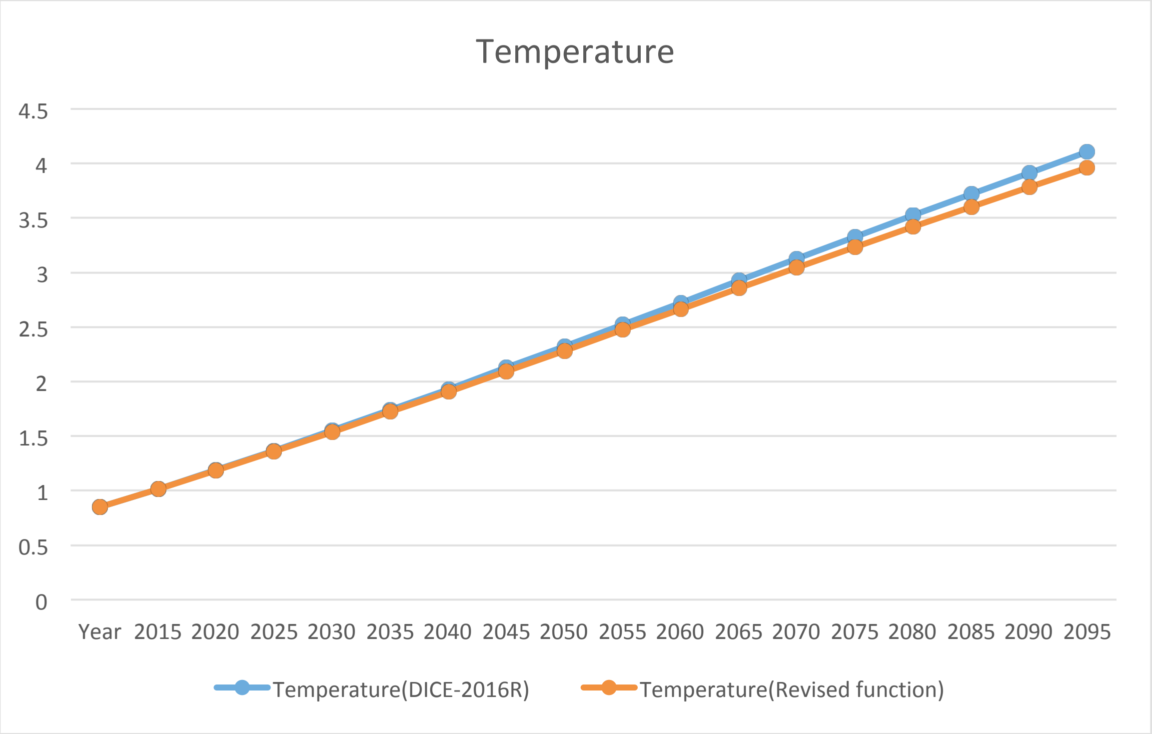

Figure 4. Temperature Change overtime

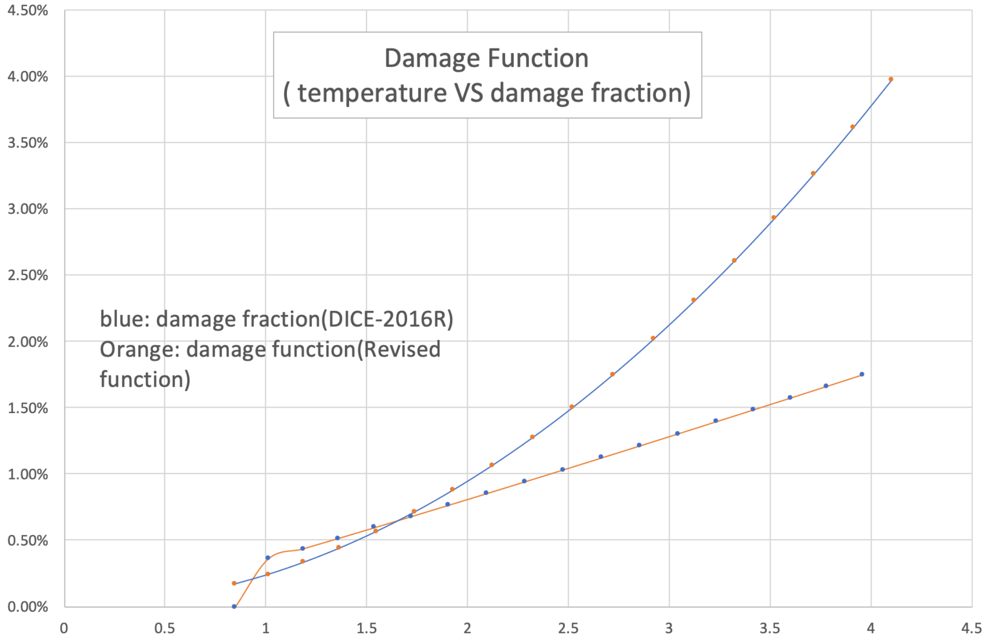

Figure 5. Damaged Fractions Plotted against an Increase in Mean Atmospheric Surface Temperature (Degrees C, Year 2015-2095)

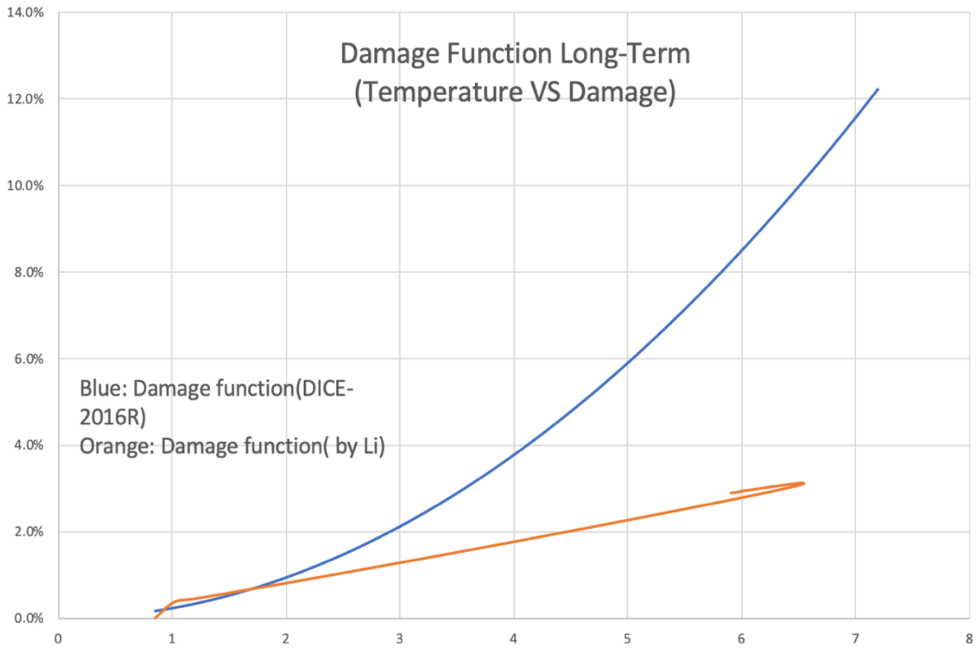

Figure 6. Damaged Fractions Plotted against an Increase in Mean Atmospheric Surface Temperature (Degrees C, Year 2015-2510)

Figures 5 and 6 are the damage function in short term (to 2095) and in long term (to 2510). The X-axis provides temperature changes and the Y-axis damage as a fraction of gross GDP. The blue line represents the base case DICE-2016R, and the orange line our new damage function. Although the two models have similar temperature increases (as discussed above), they represent significantly different damages as temperature goes up. Short-term and long-term damage functions have similar shape: DICE-2016R has quadratic function, while our function is almost linear and has much lower damage in the future compared with the base case. Interestingly, for the long run, there is a kink in our damage function line. This is because of the different GDP ratio. Even if they have the same temperature change, a larger the GDP ratio or greater GDP growth, the same rate of decline leads to more impacts on the economy in the next period.

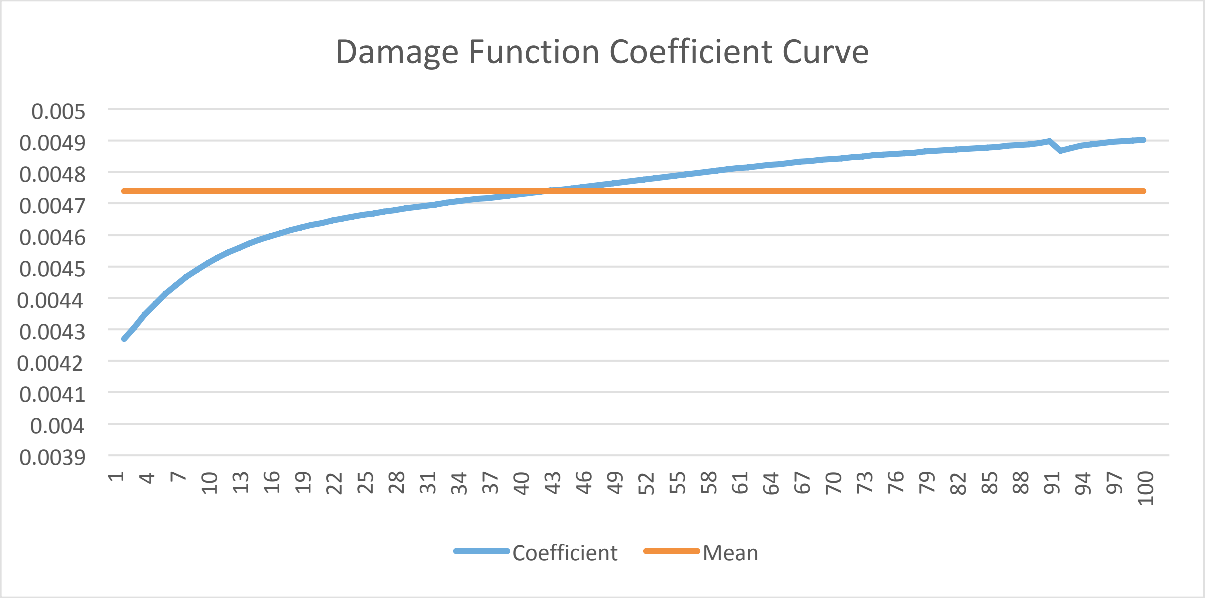

Figure 7. Damage Function Coefficient Changes overtime

Figure 7 illustrates the long-run damage function in more details. This curve represents $\frac{GDP_{t-1}^{net}}{GDP_t^{gross}} * 0.00511$, the coefficient of the damage function. In long term, the curve is concave until year 2460. The curvature is high in the first few centuries but then goes to almost linear afterwards. This indicates that damages from temperature grow faster in the beginning but stay at a constant growth rate by the end of 21st century. The average of the coefficient changes is 0.00473945. With the change of temperature, a linear relation is observed in the damage function. We could further simplify the damage function to: $damagefraction_t = 0.0047395 \times T_{t-1}$. This simplified version of the revised damage function is slightly smaller than Hope's (2006) damage function, which is linear with a coefficient 0.0071. Among those six damage-fraction functions in Table 2, our revised version predicted that the temperature has low damages to gross GDP.

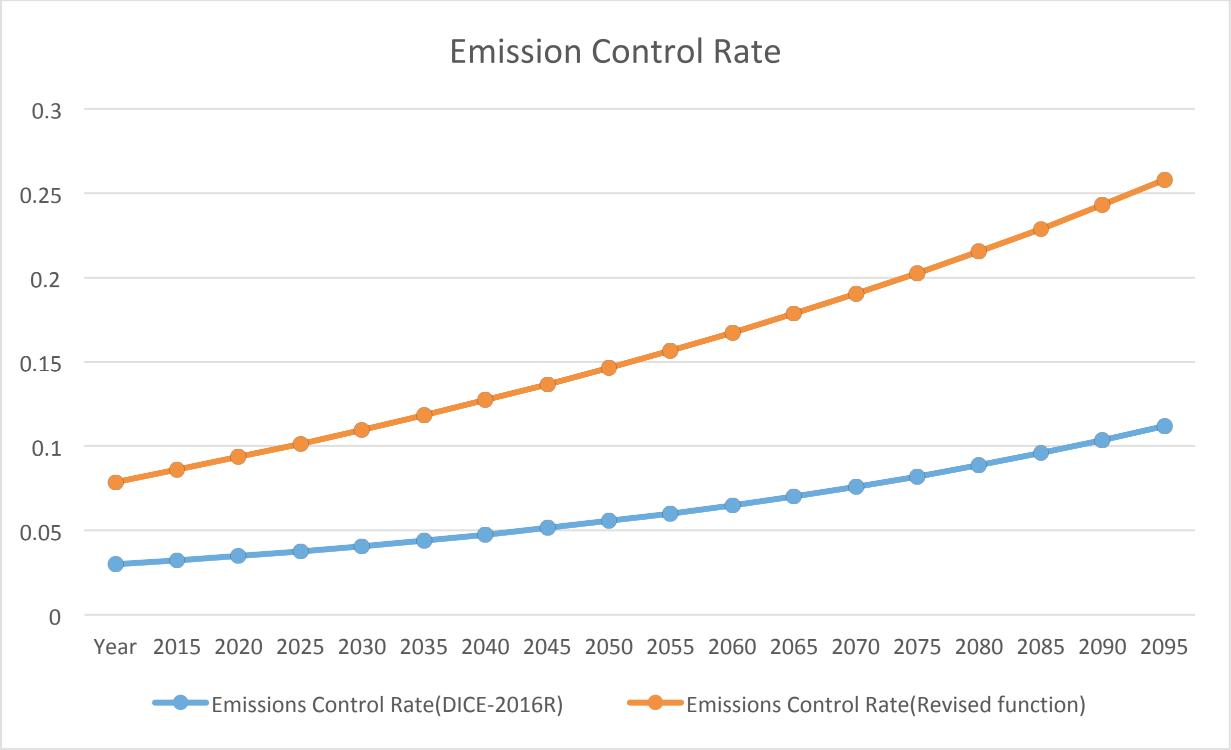

Figure 8. Emission control rate overtime

Our results indicate that gross and net GDP are similar in the short run and long run (see Figure 9), which means that our revised damage function does not have huge a impact on gross/net GDP compared with DICE-2016R. Based on the similar GDP output, the emission control rate and social cost of carbon should be inversely related, meaning that the higher the control, the lower will be the social cost (Figure 10).. Since the emission control rates for our damage function are 10% to 15% points higher than DICE-2016R, the social costs of carbon are lower. In other words, if emissions are more constrained while keeping GDP constant, the economy has less costs to compensate the damage caused by growing emissions of carbon dioxide or higher temperatures, or vice versa. Notwithstanding, the social cost of carbon in our model ends up at less than $50/tonne, which is quite small among the six DICE model results from section 3.1.

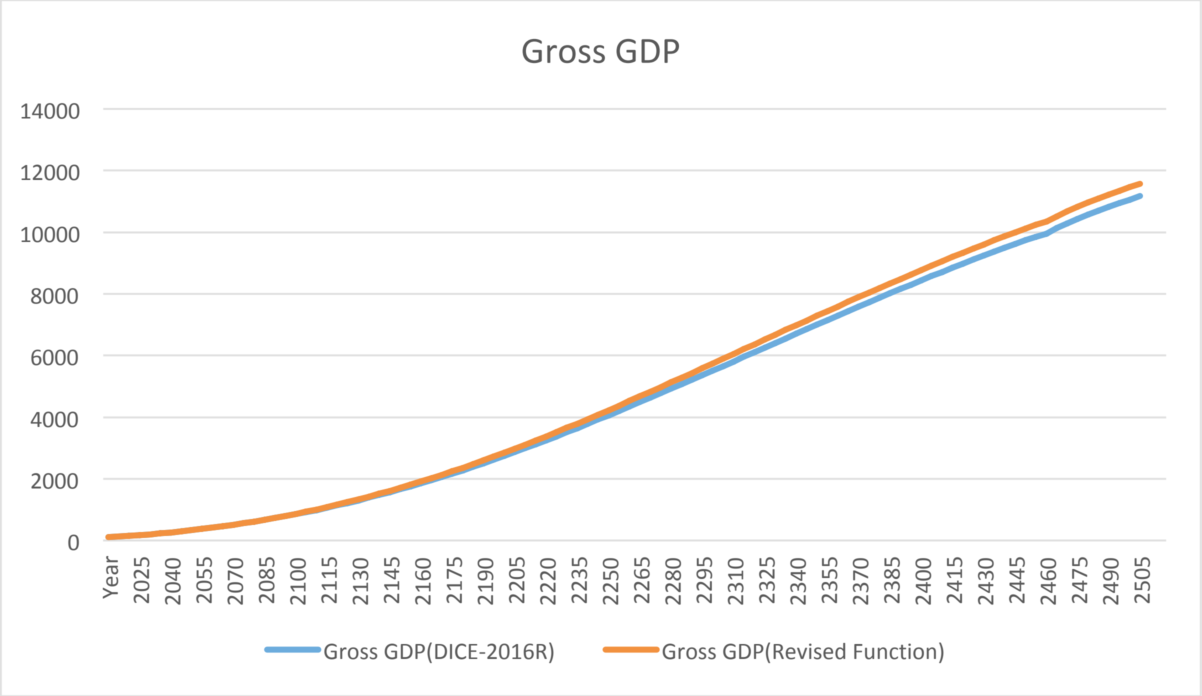

Figure 9. Gross GDP Change Overtime

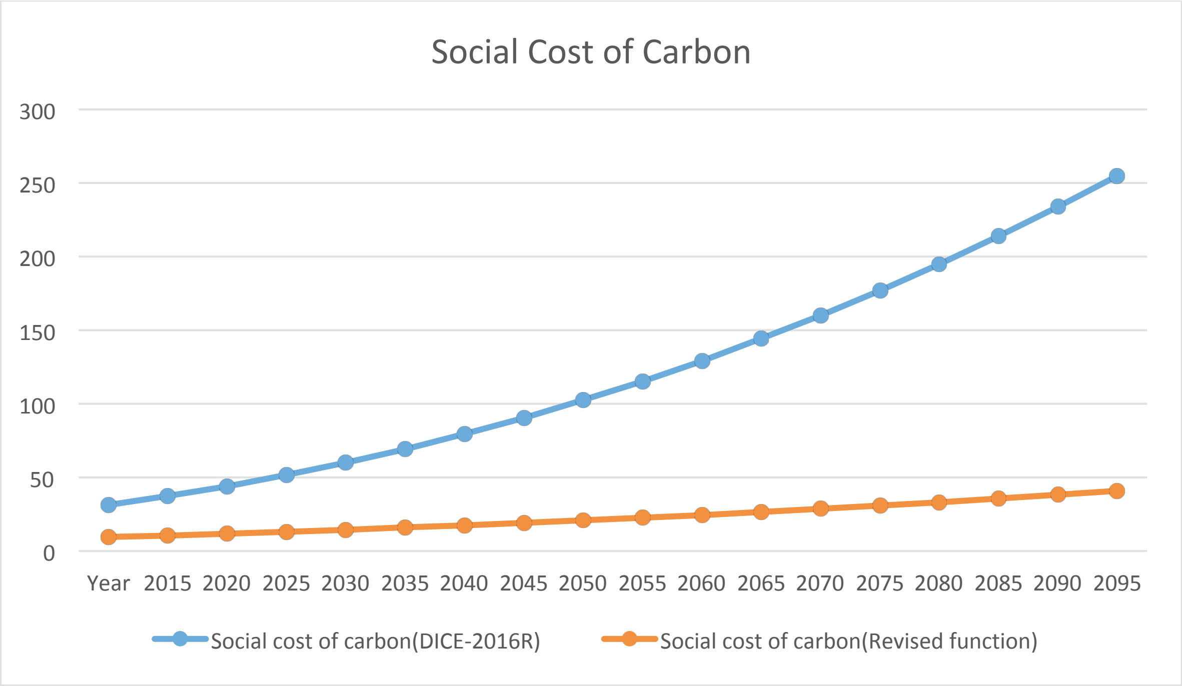

Figure 10. Social Cost of Carbon ($/tonne)

As the social cost of carbon is fully paid, the carbon tax is considered as compensation for externalities. We could compare the SCC from the DICE model with real world carbon taxes. For example, British Columbia has a carbon tax of $35/tonne ($2018) and the tax will increase

\$5/year to %50/tCO$_2$ (BCMF 2018, p. 75). Norway's carbon tax was \$52/tCO$_2$ (\$US2016) (World Bank 2016, p. 14). However, most countries do not apply a carbon tax or tax little for CO$_2$ emissions. Overall, it is possible that the worldwide carbon tax should not go beyond \$50/tonne as indicated in Figure 10, and then only near 2100.

A policy implication is that, with the base case damage function, higher compensation for damage is required than for the revised damage function, which might be an advantage for developing countries. With the base case, restrictions on emissions are lower (Figure 8), developing countries such as China and India that do not hold advanced technology require high emission industries to boost their economy. Thus, paying more tax later on is reasonable for developing countries. However, if the revised damage function is applied, economic development of poor countries will be limited in the beginning, as they face strict emission control rates. (Figure 8).

3.5. Change in the Damage function: Limitations

There are some limitations for our revised damage function model. First is the classification problem. The data from Dell et al. (2012) were based on data from World Development indicators (World Bank, 2007). These indicators classified the world into poor and rich countries. In our damage function, we use the dataset from 2018, which classifies the world into low, median, and high-income countries. This reclassification groups countries different than before, so that the results –0.005111 should not be a precise but, rather, a starting-point for the model.

The second problem is about econometric estimation. Since coefficient estimation depends on historical data, it is probable that some uncommon phenomena that did not appear in the past are not adequately taken into account. For instance, the damage function is almost linear as is the temperature increase in our model, which means damages are not enlarged when the temperature reaches a high level, such as above 5°C. We are not able to predict damages from extreme temperatures, since those temperature shocks never show up in the historical data. However, our damage function could be used to predict the short-term period, due to less uncertainty for temperature changes in that time. From Figure 5, our estimated damages are higher than for the base case when temperature changes are small (between 1 to 1.5°C). Since the current temperature increase is above the predicted temperature increase by Nordhaus, the damage in the base case is undervalued in contrast with real-world data. Therefore, the revised damage function is better for short-term prediction, while the DICE-2016R will be reasonable guess for long-term future.

Last but not least, there is a problem in the initial value for the damage function. Figures 5 and 6 show that the initial damage for a positive temperature increase is zero. This is caused by the setting of an initial value in GAMS. Nevertheless, starting with zero should not have huge influence on the future prediction, as our outputs are reasonable under the revised model circumstances.

SECTION 4. SOCIAL DISCOUNT RATE

4.1. Overview

The social discount rate (SDR) is a crucial component of public project valuation. In the DICE model, SDR is provided in the output file as the interest rate. The rate is calculated using the Ramsey formula:

$$SDR = \rho + (g \times \varepsilon)$$

where ρ represents the pure rate of time preference (PRTP), g represents the growth rate of per capita consumption, and ε represents (the absolute value of) the elasticity of marginal utility of consumption. When it comes to intergenerational projects, PRTP reflects how much the current generation cares about the next generation; and the elasticity of marginal utility of consumption reflects people's willingness to substitute their consumption across time.

A further explanation about the relationship between ε and the current rate of change in consumption can be developed with the following formula (Acemoglu 2011):

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\varepsilon(c(t))}(r(t) - \rho)$$

This equation defines the rate of change of per capita consumption as a function of the difference in r(t), the financial rate of return and the PRTP. This difference in return is scaled by the inverse of ε. If ε is greater than 1, people are less attracted by the rate difference. If ε is less than 1, people respond more rapidly to the rate difference.

There are various schools of thoughts about the value of SDR. The Treasury Board of Canada Secretariat published a cost-benefit analysis guide in 2007 and recommended a SDR of

8% and a PRTP of 3% (p. 37). Boardman et. al. (2008) argue that the above rates are too high and proposed their own system of discount rates for intergenerational projects (Table 4).

Table 4. Discount System by Boardman et al.

Year	Discount Rate
0-50	3.5%
51-100	2.5%
101-200	2.0%
Over 200	1.5%

Source: Adapted from Boardman et.al. (2008, p.28)

This series of SDRs declines over time, which implies that time distribution of income makes a larger difference the closer it is to the present. For instance, the value of \$100 today or two years from now feels different, but the value of \$100 in 50 or 51 years from now is not considered different from today's perspective. This is known as hyperbolic discounting.

The DICE Model implements $\rho=0.015$ and $\varepsilon=1.45$ and produces a series of declining SDRs starting from 5.09%. Since the consumption change in the model is not constant, we are unable to produce a fixed SDR over time. However, it is possible to adjust the values of PRTP and elasticity of marginal utility of consumption to produce a series with values similar to Boardman et al's system in all corresponding periods.

The discussion is organized as follows. We first explore the partial effect of PRTP and elasticity of marginal utility of consumption. Then we adjust the value of these parameters to calibrate the discount rate system in Table 4. After that, we compare our parameter values to the values used by other experts in empirical research. Finally, we compare the SCC under our scenario with the SCC from the DICE Model.

4.2. Results: Partial Effect of PRTP and Elasticity of Marginal Utility of Consumption

Though the Ramsay formula already indicates that both parameters have a positive relationship with the SDR, it is still important to consult the model to acquire more details about the relationship over time (i.e. whether the increase in SDR is constant, increases, or decline over time) and how this changes the SCC. Though the model is able to project up to 500 years from now, it makes intuitive sense to limit our projection to 2100, since, as we move into the future, the level of uncertainty raises. We show the change in SDR for the full time duration to get more information for our calibration. For SCC, we limit the time to 2100. Our results are provided in Figures 11 and 12.

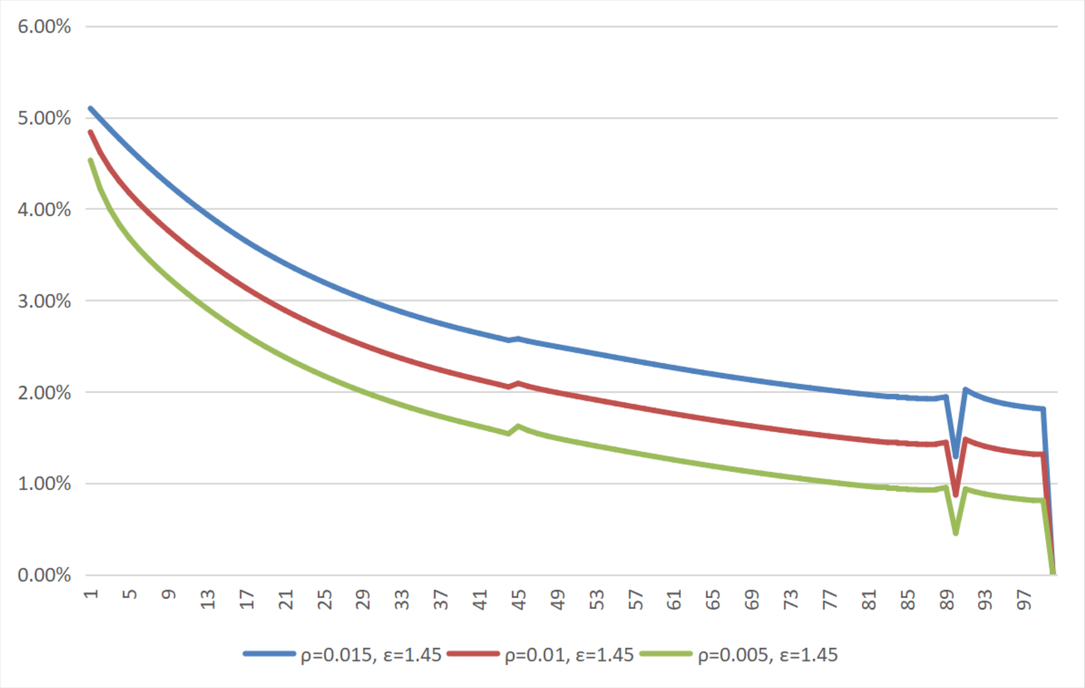

Figure 11. SDR with Different PRTPs

In Figure 11, we provide the path of SDR under three different PRTPs over time. All SDR curves decline over time and reach zero in the final period; this indicates the absence of discounting when there is no future. There are also two odd spots, one is a minor structural upshift around year 2235, and the other is a major structural break at year 2455; these shifts might be the result of the type of damage function Nordhaus selects.

In Figure 12, the projected SCC is plotted over time. The concave shape of the SCC curves is a result of the quadratic damage function. This means that the carbon leftover in the atmosphere will proceed into the next period and damage the atmosphere again.

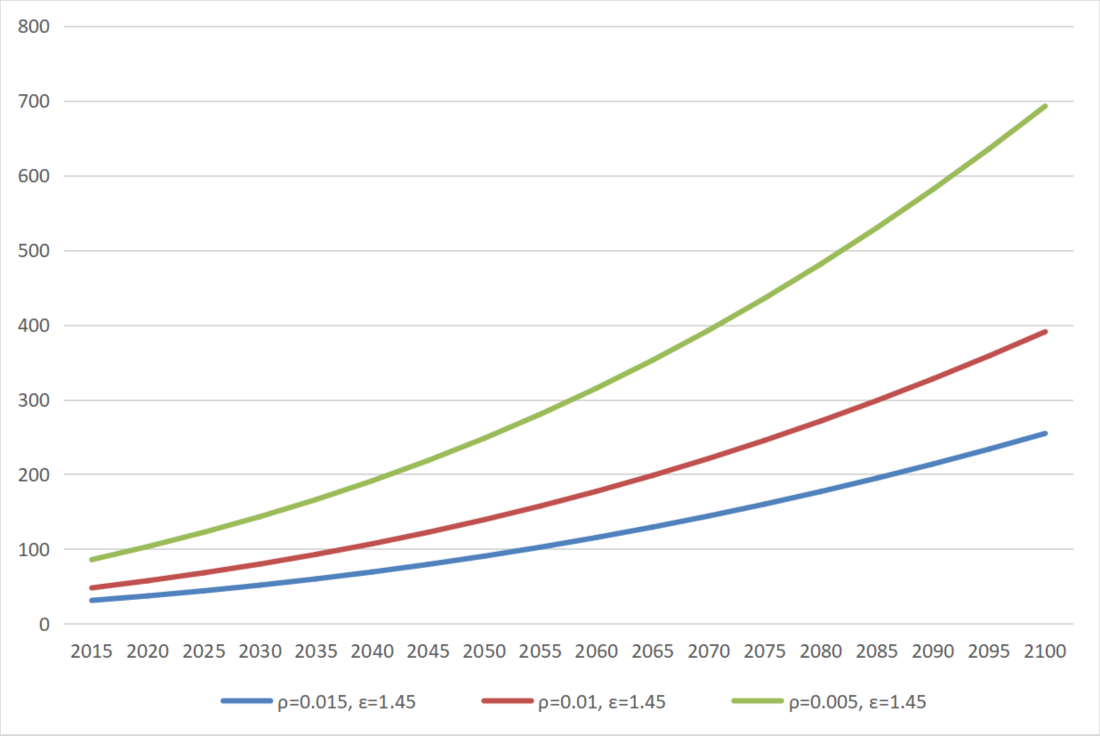

Figure 12. SCC by 2100 with Different PRTPs

According to both figures, a decrease in PRTP leads to a structural decrease in the SDR and a structural increase in the SCC. Intuitively, as people care more about the future generation, they place higher value on the cost of carbon, which incentivizes the government to collect a higher carbon tax.

Partial Effect of Elasticity of Marginal Utility of Consumption

The paths of SDR and SCC over time under five different values of the elasticity of marginal utility of consumption are provided in Figures 13 and 14. The partial effect of ε on SDR is positive but declines over time as opposed to the constant effect of ρ. Intuitively, as ρ declines, people are more willing to substitute consumption across time; in other words, they do not care too much about today's consumption versus tomorrow's consumption. The partial effect of ε is largest at the beginning and declines over time as people care less about the time distribution of income. As ε declines, SCC increases. This means that, as people's marginal utility of consumption becomes less elastic, they have greater incentive to move their consumption to the current period, leading to overuse of resources and increasing an SCC. Although a value of 1 is an important threshold value for elasticity in economic theories, we do not observe the partial effect of ε different as its value falls below 1.

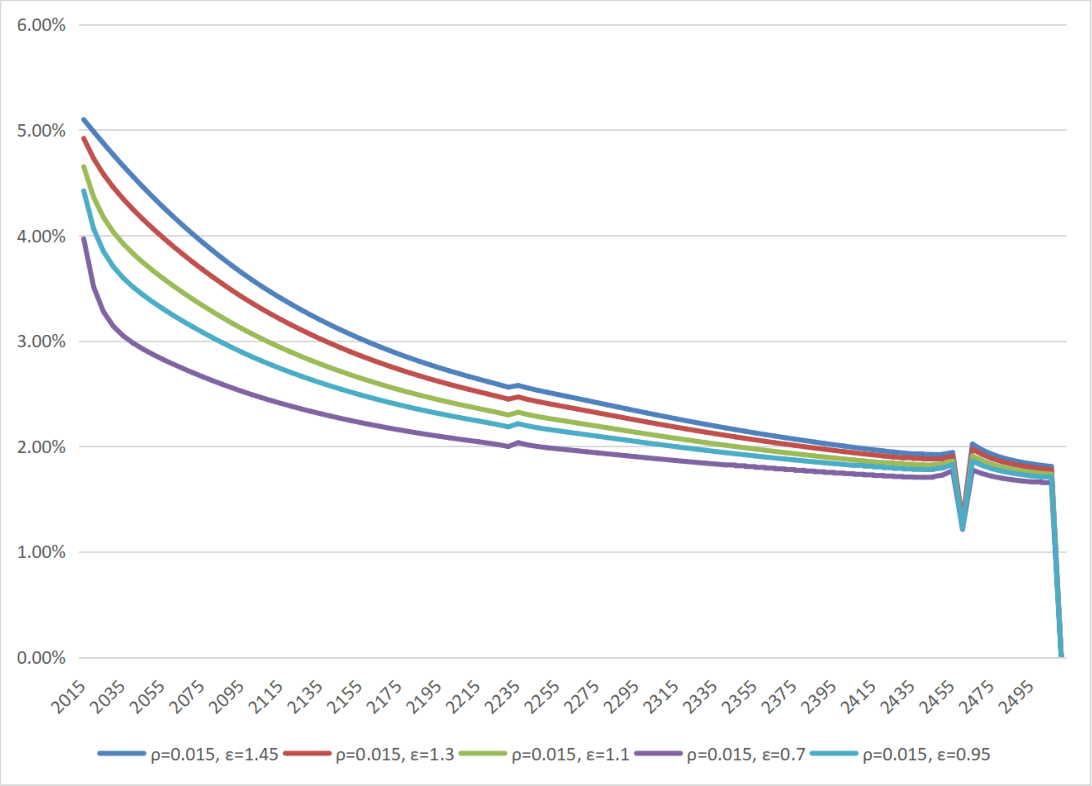

Figure 13. SDR with Different Elasticities

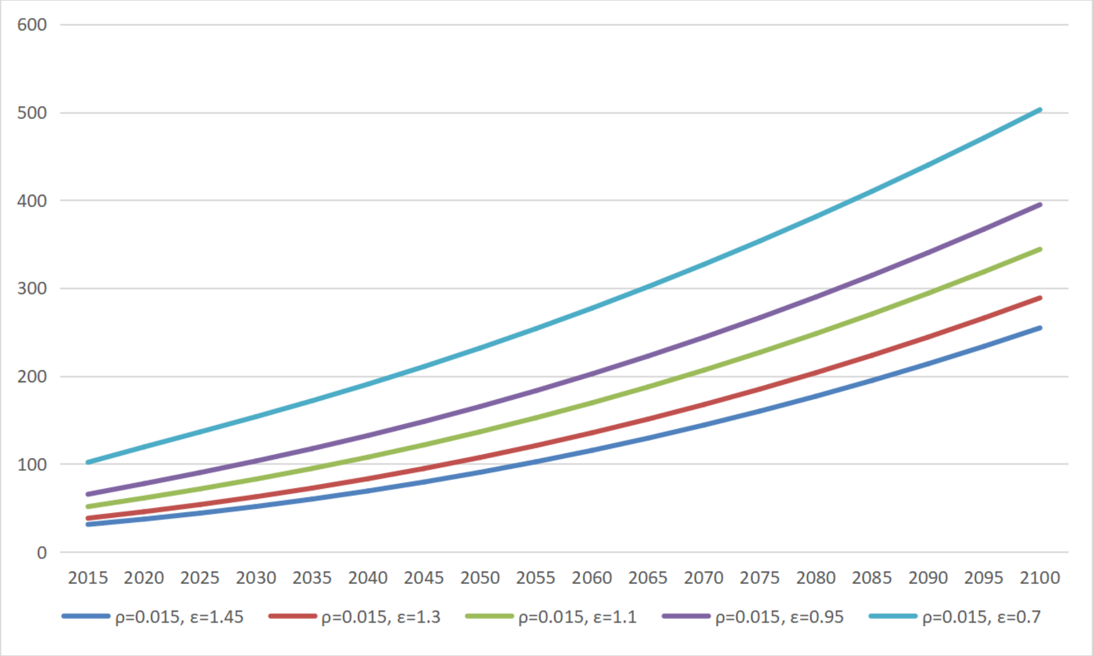

Figure 14. SCC by 2100 with Different Elasticities

4.3. Calibration

The DICE Model produces a series of declining interest rates starting from 5.099%. In order to calibrate the discount system in Table 4, we have to decrease PRTP or the elasticity of marginal utility of consumption, or both. Table 5 illustrates the steps and results of the calibration.

Table 5. Calibration Results

Period	1	50	100	200
Decrease PRTP Only				
ρ=0.015, ε=1.45 (original)	5.099%	4.184%	3.460%	2.663%
ρ=0, ε=1.45	4.032%	2.629%	1.918%	1.140%
Decrease elasticity holding PRTP=0				
ρ=0, ε=1.3	3.615%	2.344%	1.719%	1.022%
ρ=0, ε=1.25	3.444%	2.249%	1.653%	0.983%
Decrease elasticity Only				
ρ=0.015, ε=0.55	3.634%	2.505%	2.233%	1.937%
ρ=0.015, ε=0.5	3.509%	2.413%	2.166%	1.897%
Decrease both proportionally				
ρ=0.008, ε=0.7736	3.459%	2.206%	1.826%	1.410%
ρ=0.009, ε=0.8703	3.810%	2.488%	2.057%	1.588%

The first step is to decrease PRTP to its lower bound zero (otherwise it would violate the assumption that people prefer things sooner than later). Though we produce a lower series of SDR, their values are still far from the target. Then, we decrease ε holding PRTP equal to zero. We then produce two series with values close to the target for periods 1 to 50, but for periods 100 to 200, values are much lower. The third step is to decrease the elasticity of marginal utility of consumption only. We then produce two series with values close to the target at period 1 and 50, but higher than the target for periods 100 to 200. Recall that each period represents 5–years.

Since previous attempts failed to produce satisfactory results, we decided to decrease ρ and ε proportionally. This produces two series of SDR that are relatively close to target values. Using ρ=0.009 and ε=0.8703, SDRs start off slightly higher but SDR values are close to the target values the rest of the time (Table 5).

Comparison of parameter values

In this section, we compare our values of PRTP and the elasticity of marginal utility of consumption to the ones used by experts in leading climate policy evaluations (Table 6). There is a variation in the value selection of ρ. Stern and Cline (1992) assume people do not have strong time preference for ethical reasons, and Nordhaus (2007; 2008) assumes people are slightly self-interested and do take time seriously in valuations. The current calibration result falls within the range of the experts but is more on the side of Stern and Cline, assuming people have a time preference but do care about the future generation.

Table 6. Values of PRTP and Elasticity of Marginal Utility Consumption Comparison

Source	ρ	ε
Stern (2007)	0.1%	1.0
Cline (1992)	0.0%	1.5
Nordhaus (2007)	3.0%	1.0
Current Calibration	0.9%	0.8703

Source: Adapted from Goulder and Williams (2012, p.7)

As for the value selection of ε, all the experts select values that are at least 1, assuming individuals either don't care or are unwilling to substitute consumptions across time. The current calibration result does not reflect the same notion as that of the experts.

Comparison of SCC

According to Figure 15, the SCC under our scenario is higher than the original SCC of the DICE model over the time horizon, and the difference increases over time. The cost of per ton of CO2 at 2100 is about $300 under the original scenario and almost triple that under our scenario. We conclude that the SCC is sensitive to the social rate of discount, which is determined by the pure rate of discount and the elasticity of marginal utility of consumption. Since there is no agreement concerning the value of these parameters, one can simply manipulate the model result by selecting a set of ρ and ε that produces some desired result.

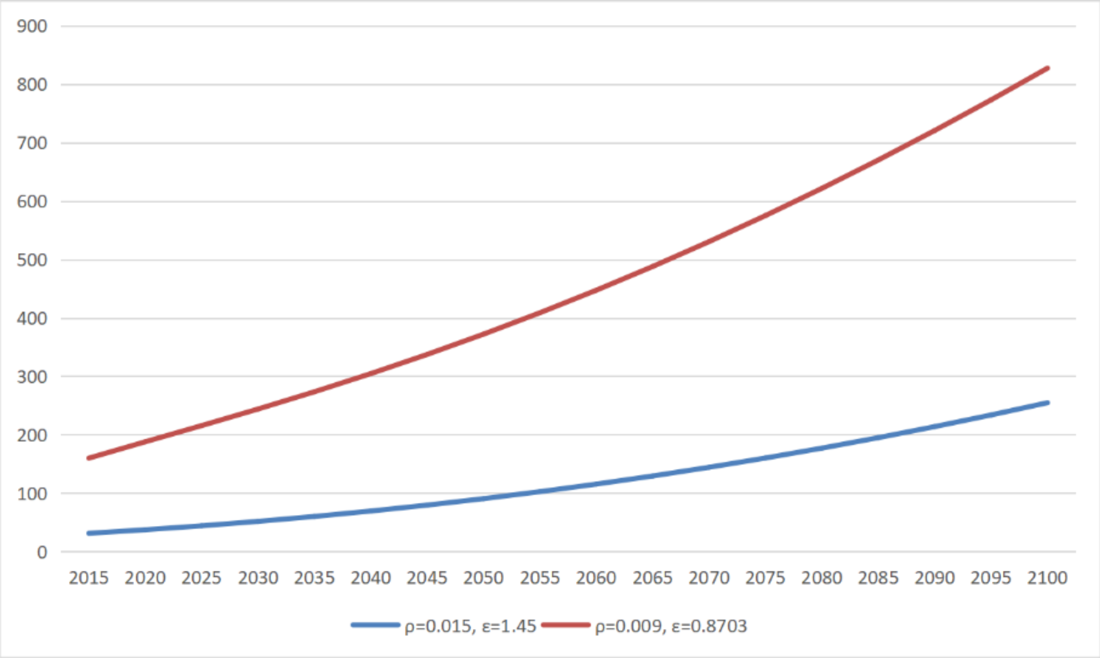

Figure 15. Social Cost of Carbon of DICE 2016R and My Calibration by 2100

SECTION 5. CONCLUSION

The DICE model is a convenient tool to compute how economic growth is affected by different predictions of climate change. It does not give an ultimate prediction since many assumptions have to be made and the model is based on a handful uncertain factors. Therefore, changes in one or more model parameters have significant effects on the resulting model predictions. The uncertainty incorporated in the assumptions might be seen as a distinct disadvantage of the model. However, the simplicity of the model allows the user to plug in a number of different values and compute quick results.

In our view, the model (and its current specified assumptions and values) should not be used for flawless future predictions, but rather as a tool to compare different policy effects against each other.

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