Forecasting Social Cost of Carbon and Atmospheric Temperature Using the DICE 2016R2 Model

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Abstract

The Dynamic Integrated Climate-Economy (DICE) model is one of the three models that have been applied by governments to estimate the social cost of carbon (SCC) and atmospheric temperature. Results from running the DICE model play important roles in climate change decision-making across US states and other countries (Barrage, 2019). In this paper, I assume reforestation and estimate SCC and atmospheric temperature by modifying the DICE2R model. By comparing the results with the DICE2R model base run, I found that if governments restore all potential areas to plant trees with high mean annual increment, SCC will be lower about 100 dollars per tCO2 in 2100 and atmospheric temperature will increase only 2.054 degrees Celsius above the 1900 average in 2100.

Introduction

In 2015, the Paris Agreement of the United Nation Framework Convention on Climate Change was built to “strengthen the global response to the threat of climate change” by “holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, …..., making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development"(FCCC, 2015). It requires 196 countries to make their best efforts to reduce their carbon emissions through "nationally determined contributions" (NDCs). By collecting data from the Intergovernmental Panel on Climate Change (IPCC) report, Nordhaus(2016) claims climate changes and resource scarcity as the most natural constrains on long-term economic growth (Barrage, 2019). He assumes human beings are cutting down trees with a decreasing rate and estimates that the SCC is $30.7 per tCO2 in 2005 U.S. dollars in 2015 and projects the SCC will increase to 271.3 per tCO2 in 2005 U.S. dollars in 2100 by using his DICE model. He also estimates that the global temperature will exceed 3.5 degrees Celsius above the 1900 average in 2100 under decreasing deforestation assumption. In this paper, I estimate the social cost of carbon and atmospheric temperature under multiple reforestation situations. I also compare the results with the current deforestation situation to determine whether it is worth to take climate mitigation actions. I found that planting trees in restoration potential areas, SCC and atmospheric temperature is much lower than the results from deforestation assumption.

The social cost of carbon is the marginal cost of emitting an additional ton of carbon dioxide for economic growth. More precisely, it is the “change in the discounted value of the utility of consumption per unit of additional emissions, denominated in terms of current consumption" (2013, Nordhaus). It is currently estimated by Integrated Assessment Models (IAMs), including Nordhaus's Dynamic Integrated Climate and Economics (DICE) model and Tol's Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model (van Kooten, 2018). There are two main scenarios in the DICE 20162R model: the optimal scenario and the baseline scenario. In the optimal scenario, climate policy is optimized. The SCC is equal to the price of carbon. It is also equal to the marginal cost of carbon emissions reduction and the marginal benefit of abatement. The baseline scenario is a more realistic case. "Base" means "existing policies as of 2010" (Nordhaus, 2013). The SCC in the baseline scenario is the marginal damage of carbon emissions along with the current policy. Nordhaus (2013) demonstrates that "2010 policies were the equivalent of $1 per ton of CO2 global emissions reductions". To distinguish the baseline scenario and base run scenario showing later, my research only concerns the optimal scenario in the DICE 2016R2 model. It also represents the base run in my DICE model.

Nordhaus puts climate change as a natural constraint on a long-run economic growth model (Barrage, 2019). There are three components in Nordhaus's DICE 2016R2 model: the economic component, the ecosystem component, and the policy component. He introduces an (i) endogenous CO2 emissions from economic growth and (ii) carbon cycle and climate change in natural systems to a standard neoclassical (Ramsey-Cass-Koopmans) growth model (Barrage, 2019).

In this paper, I will use the DICE 20162R model to investigate three sections of the SCC In section A, I will begin by showing the economic growth model in the DICE2R model and reviewing equations in the DICE 20162R model. In section B, I will apply various values on the three critical scalars, including the rate of pure time preference (α), the elasticity of marginal utility of consumption (ε) and the equilibrium climate sensitivity (ECS) in the DICE 2016R2 model to show the sensitivity of SCC paths over periods since 2015. The choice of the rates used to discount future benefits and costs varies among economists. For example, economist Nicholas Stern employs α=0.1% and ε = 1 in the UK government's "Report on the Economics of Climate change". Since the present value of social welfare per capita is calculated over more than 100 years range, the SCC is sensitive to the value of scalars, such as elasticity of marginal utility of consumption, the initial rate of social time preference per year. These two parameter changes cause interest rate changes and further have an impact on SCC estimations. In section C, I will estimate the SCC using the DICE 20162R model with the assumption that each country in the Paris Agreement has been following NDCs to plant trees since 2015. I also assume governments adopt optimal climate policy that maximizes economic welfare "with full participation by all nations starting in 2010 and without climatic constraints" (Nordhaus, 2013). This will balance the present value of the costs of abatement and the present value of the benefits of abatement and lead to efficiency. Intuitively, the marginal emissions of CO2 into the atmosphere in a modified DICE model will reach the peaking sooner than in Nordhaus's base run. The atmospheric temperature will be lower than that in Nordhaus's base run and it will result in a lower social cost of carbon each period. That is, if governments plant costless trees on the restoration potential areas, low SCC are generated to achieve optimal social welfare.

The Theoretical Analysis of the DICE2R Model and Equations of the DICE 2016R2 Model

In the economy component, labour and capital are the basics to produce output and create economic growth. The amount of labour force is exogenous and proportional to the global population. It is a logistic equation where the initial value in 2015 is given. The amount of capital depends on economic growth, as well as the consequences of optimal consumption flows over time, from the previous period. Some of the output will be invested to be capital for the economic growth of the next period. The remaining is going to be consumed immediately. The DICE 20162R model assumes that social welfare is determined by the amount of consumption. This "generalized consumption" includes the traditional market goods (such as food and shelter) and non-market good sand services (such as leisure, health status, and environmental services) (Nordhaus, 2013). The more individuals consume, the more social welfare they get. In the economy component, to maximize social welfare throughout generations, individuals need to decide the optimal consumption and investment ratio for each period. If individuals consume too much output, they will get high social welfare but a low capital investment for the next period. If they invest too much output, they will get high investment but low social welfare. The rate of time preference and elasticity of the marginal utility consumption are the critical parameters to determine the value of social welfare as well. High values of the rate of pure time preference mean that individuals are optimistic about future economic development. They care more about the current social welfare of consumption than about the future social welfare of consumption. In the DICE 20162R model, Nordhaus assumes reducing carbon emissions is an urgent issue. Therefore, individuals value more about the current social welfares than the future social welfares and prefer to take mitigation actions right now. The high value of elasticity of marginal utility consumption means the consumption of the current generation is relatively significant than that of the future generation. That is, to prevent global warming, people prefer to consume output to reduce carbon emissions now rather than in the future. The rate of pure time preference adds to the growth rate of consumption weighted by the elasticity of the marginal utility of consumption is the Ramsey equation. It is an important tool to discount the cost of future disasters (Thureson, 2016).

To indicate climate process and economic growth influence each other, Nordhaus assumes that economic production needs not only labour and capital but also energy and land. The use of energy and decreasing deforestation cause carbon emissions. Oceans absorbed some amount of carbon emissions and the remaining part goes into the atmosphere. Carbon emissions accumulation causes global warming through increases in radiative forcing (Nordhaus, 2013). The temperature increasing will then have a damaging impact on the economy component. A critical parameter in the climate component is the equilibrium climate sensitivity (ECS). It is a measure of the equilibrium change in global surface temperature following a doubling of the atmospheric equivalent carbon dioxide (CO2) concentration (Meehl et al. 2007). Large ECS means a large temperature increase resulting from the concentration of CO2 doubles. Different values of the ECS have disparate impacts on damages of carbon emission and therefore on the estimates of SCC (van Kooten, 2018).

To deal with global warming, individuals can reduce carbon emissions caused by land-use change. The abatement cost is the amount of cost of economic output that individuals sacrifice to substitute carbon-based fuels (such as coal, and natural gas) with low carbon energy (such as wind power, solar power and nuclear power). Therefore, individuals spend the economy output not only on consumption and capital investment but also on the abatement. It depends on the emissions reduction rate. High emissions reduction rate indicates individuals pay less on consumptions and investment, but more abatement cost to reduce carbon emissions. It will slow down carbon accumulation in the atmosphere and global warming process. Fewer climate damages will accelerate economic growth and social welfare will improve. Therefore, to maximize the social welfare per capita from consumption subject to natural constraints, the individual needs to determine the value of three variables each period: consumption, investment and emissions reduction rate.

Next, I will list the specific equations of the DICE 20162R model. These equations are divided into three groups: the objective function, the economic relationships and the climate-emissions relationships (Nordhaus et al. 1992).

The model maximizes the social welfare function W. It is "the discounted sum of population-weighted utility of per capita consumption" (Nordhaus 2013). c(t) is consumption per capita. L(t) is labour and it is a logistic equation. It is proportional to the population.It follows the form L(t) = L(t-1)[1+g_L(t)], where g_L(t)= g_L(t-1)/(1+δ_L). The initial world population in 2015 is given at 7.4 billion. To reach the projection of United Nations' estimates in 2050, g_L(2015) is set as 13.4% per 5 years. The growth rate declines every 5 years and reaches to 10.5 billion in 2100. R(t) is the discount factor. ρ is the rate of pure time preference. The population-weighted utility function of consumption has a constant elasticity of marginal utility of consumption, α. "α represents the diminishing social valuations of consumption of different generations. If α is close to zero, then the consumptions are close substitutes, with a low aversion to inequality. If α is high, then the consumptions are highly differentiated, and this reflects the high inequality aversion" (Nordhaus, 2013).

$$W = \sum_{t=1}^{Tmax} U[c(t), L(t)]R(t) \quad (1)$$

$$R(t) = (1+\rho)^{-t} \quad (2)$$

$$U[c(t), L(t)] = L(t)\ [c(t)^{1-\alpha}/(1-\alpha) \quad (3)$$

In economic relationships, Q(t) is the gross output deducted by damages and abatement. Y(t) is the gross output and it is a Cobb-Douglas function of total factor productivity A(t), capital K(t) and labour L(t). Same as L(t), A(t) is also a logistic equation. Ω(t) is the function of economic damages D(t) caused by climate change T_{AT}(t). The DICE 20162R model assumes that it is “a quadratic function of temperature change and does not include sharp thresholds or tipping points” (Nordhaus, 2013). Λ(t) is the abatement costs and it is a power function of the emissions reduction rate μ(t). Abatement costs function is highly convex because the marginal cost of abatement increases more than linearly with emissions reduction rate increasing (Nordhaus, 2013).

$$Q(t) = \Omega(t)\,[1-\Lambda(t)]\,Y(t) \tag{4}$$

$$Y(t) = c(t) + I(t) \tag{5}$$

$$\Omega(t) = D(t)/[1+D(t)] \tag{6}$$

$$D(t) = \psi_1 T_{AT}(t) + \psi_2 [T_{AT}(t)]^2 \tag{7}$$

$$\Lambda(t) = \theta_1(t)\,\mu(t)^{\theta_2} \tag{8}$$

The next equation in the economic relationships is the total emission equation, E(t). It is equal to uncontrolled industrial emissions, gross output times a level of carbon intensity, reduced by emissions reduction rate, μ(t), plus emissions caused by land use or deforestation E_{Land} (t). The level of carbon intensity σ(t) is a logistics-type equation similar to that of technology and labour. Notice that E_{land}(t) is the important component to calculate the SCC because it is considered the main cause to global warming: Emissions caused land-use are exogenous and “are projected based on studies by other modelling groups and results from the Fifth Assessment of the IPCC" (Nordhaus, 2013). Part of the CO2 emissions ends up in the lower and upper oceans, and parts of it will stay in the atmosphere, causing global warming.

$$E(t) = \sigma(t)\,[1-\mu(t)]\,Y(t) + E_{land}(t) \tag{8}$$

Moving to climate – emissions relationships, three reservoirs carbon equations connect total emissions with the carbon cycles in ecosystems. These three reservoirs are the atmosphere M_{AT}, the upper oceans and biosphere M_{up}, and the lower oceans M_{LO}. φ_{ij} are the parameters representing the flows of carbon between three reservoirs.

$$M_{AT}(t) = E(t) + \varphi_{11}M_{AT}(t-1) + \varphi_{21}M_{up}(t-1) \tag{9}$$

$$M_{up}(t) = \varphi_{12}M_{AT}(t-1) + \varphi_{22}M_{up}(t-1) + \varphi_{32}M_{LO}(t-1) \tag{10}$$

$$M_{LO}(t) = \varphi_{23}M_{up}(t-1) + \varphi_{33}M_{LO}(t-1) \tag{11}$$

The carbon emissions accumulations in the atmosphere result in global warming through increasing radiative forcing. F(t) is the change in total radiative forcing caused by carbon emissions. $F_{EX}(t)$ is the exogenous part of radiative forcing change caused by other long-lived greenhouse gases and other factors.

$$F(t) = \eta\{log_2[M_{AT}(t)/M_{AT}(1750)]\} + F_{EX}(t) \tag{12}$$

Change of radiative forcing firstly increases the temperature of the atmosphere, which will increase the temperature of the upper ocean and biosphere leading to the warming of the lower ocean. T_{AT} is the atmospheric temperature and T_{LO} is the temperature of the lower ocean. Notice that the equilibrium climate sensitivity (ECS), $\Delta\, T_{AT}$, is a critical parameter to determine the temperature of the atmosphere and the lower ocean.

$$T_{AT}(t) = T_{AT}(t-1) + \xi_1\{F(t) - \xi_2 T_{AT}(t-1) - \xi_3[T_{AT}(t-1) - T_{LO}(t-1)]\} \quad (13)$$

$$T_{LO}(t) = T_{LO}(t-1) + \xi_4\{T_{AT}(t-1) - T_{LO}(t-1) \quad (14)$$

$$\Delta T_{AT} = \Delta F(t) / \xi_2 \quad (15)$$

The warming of the atmosphere will cause damages to economic output, which will again lead to the decision of consumption and capital investment. The DICE 20162R model forms the circular from carbon emissions in the economy to global warming to damages then closing the circle back to the economic component.

By using equations (1)-(15), software GAMS can solve the social welfare function W(t) incorporating various scalars and policy variables. Then we define the social cost of carbon at period t as SCC(t) (Nordhaus, 2014).

$$SCC(t) = -\ \frac{\partial W}{\partial E(t)} / \frac{\partial W}{\partial C(t)}$$

The numerator is the marginal impact of total emissions E(t) on welfare W. The denominator is the marginal impact of consumption C(t) on welfare W. Because the numerator and denominator change in every period, the SCC is time indexed (Nordhaus, 2014). The value of SCC is determined by the “power” of numerator and denominator. When the “power” of the marginal impact of total emissions on welfare is relatively large than the "power" of the marginal impact of consumption, SCC will be large. When CO2 emissions cause global warming, the damages of global warming will reduce economic production. Consumption, therefore, social welfare will be affected.

The Choices of Discounting Parameters

Next, I will show the results of SCC in the DICE 20162R model under different discounting parameters. The range of the ECS is 1.5°C – 4.5 °C. Nordhaus choose the value of the ECS of 3.1°C. He also set a value of elasticity of the marginal utility of consumption to be 1.45, and the value of rate of pure time preference to be 0.015. Stern takes the elasticity of marginal utility of consumption to be 1 and the rate of the pure time preference to be 0.001. Low Ramsey discount rate indicates we need to take action now to mitigate climate change. In table 1, I change the rate of pure time preference from 0.0015 (DICE) to 0.001 (*Stern Reviews*) and 0.03 (relatively high value than DICE value and *Stern Reviews* value), respectively. By running the DICE 2016R2 model, with ECS being 3.1°C and other parameters remaining the same, I get the values of the SCC at \$36.72/tCO2, \$295.15/tCO2 and \$9.64/tCO2 in 2020. The SCC with a relatively high discount rate is almost one-fourth of the SCC with Nordhaus's discounting rate. While the SCC of *Stern Reviews* is much higher than the SCC of the DICE 2016R2 model because of the low discounting rate. A low value of ECS indicates low SCC due to the small climate change.

Table 1: Estimated SCC (\$ / tCO2) by the DICE 2016R2 model under various discounting parameters, 2015-2100.

	ECS = 3.1°C			ECS = 2°C		
	Elasticity of the Marginal Utility of Consumption					
	1.45	1	2	1.45	1	2
	Rate of the Pure Time Preference					
Year	0.015	0.001	0.03	0.015	0.001	0.03
2015	30.70	252.62	8.41	17.14	144.33	8.04
2020	36.72	295.15	9.64	20.41	170.67	9.30
2030	51.17	376.15	13.22	28.19	220.71	12.62
2040	69.15	460.25	18.22	37.75	271.95	16.88
2050	91.04	554.77	24.68	49.27	326.91	22.08
2060	117.20	659.72	32.65	62.90	386.64	28.22
2070	147.99	772.46	42.23	78.80	452.37	35.31
2080	183.74	890.71	53.49	97.14	524.19	43.39
2090	224.75	1012.09	66.50	118.08	600.09	52.46
2100	271.32	1134.03	81.32	141.76	678.50	62.56

Table 2: Estimated atmospheric temperature (°C) by the DICE 2016R2 model under various discounting parameters, 2015-2100

	ECS = 3.1°C		ECS = 2°C	
	Elasticity of the Marginal Utility of Consumption			
	1.45	2	1.45	2
	Rate of the Pure Time Preference			
Year	0.015	0.03	0.015	0.03
2015	0.85	0.85	0.85	0.85
2020	1.016342	1.016342	0.960548	0.960547688
2030	1.353598	1.359773	1.191102	1.193419464
2040	1.694196	1.712366	1.42978	1.43606056
2050	2.033171	2.069941	1.671131	1.683451147
2060	2.364415	2.428397	1.909803	1.93116369
2070	2.681402	2.783309	2.14087	2.175097544
2080	2.977658	3.13021	2.360073	2.41165809
2090	3.246987	3.464912	2.563887	2.637899809
2100	3.483481	3.78371	2.749484	2.851557094

The Modified DICE2R Model

This section will begin with the assumption that 196 countries had been making their best efforts to reforest all restoration potential areas in order to reduce their carbon emissions through “nationally determined contributions” (NDCs) since 2015.I also assume the emissions caused by land use is zero. I change the emissions equation in the DICE 2016R2 model to presents the value of SCC under reforestation assumption. Recall that equation (8) total emissions is the sum of industrial emissions and emissions from land use. Emissions from land use is exogenous and results from the research of the IPCC. To show the reforestation impact, I will remove the emissions caused by land use and add the negative amount of emission absorbed by trees to the total emissions equation. The new total emissions equation E(t) is:

$$E(t) = \sigma(t)[1-\mu(t)]\, Y(t) - E_{tree}(t) \tag{16}$$

The first part of the E(t) is emissions from industry and E_{tree}(t) is the emissions removed by planting trees in all restoration potential areas on the earth. There is room for an extra 0.9 billion hectares outside cropland and urban can support trees and the global forest restoration target of IPCC of 1 billion hectares is “undoubtedly achievable under the current climate” (Bastin et al. 2019). Table 3 demonstrates the differences of the GAMS codes between the base run Nordhaus’ model under optimal policy and my reforestation assumptions.

Table 3: GAMS Code with two assumptions

	Deforestation (Base Run Nordhaus’ model)	Reforestation
Emissions of Trees	etree(t) = eland0* (1-deland)**(t.val-1);	etree(t)=5*tree0 *mai*0.2*0.001*(44/12)
Cumulative Emissions from Trees	cumetree("1") =0; loop(t,cumetree(t+1)=cumetree(t) +etree(t)/(44/12)	cumetree("1") =0; loop(t,cumetree(t+1)=cumetree(t) +etree(t)/(44/12)
Total Emissions	E(t)=EIND(t) + etree (t)	E(t)=EIND(t) - etree (t)
Cumulative Total Emissions in Atmosphere	CCATOT(t)= E =CCA (t) +cumetree(t)	CCATOT(t)= E =CCA (t) - cumetree(t)

1. Plant0 is the extra restoration potential areas on the earth and I employ the value of 900 billion ha and 1million ha.
2. mai is the average net annual increase in the yield (expressed in terms of volume per unit area) of living trees. I employ the value of 2.5, 5 and 10 depending on the species of forest-based on FOA statistics (2000).

Major Results for the Modified DICE 2016R2 Model

To compare the impact of deforestation and reforestation on SCC and temperature, it is very useful to show some major results under these two consumptions. Table 3 shows the six scenarios by applying different values of extra restoration potential areas and mean annual increment of trees.

Table 3: Six Scenarios with Different Value of Extra Restoration Potential Areas and Mean Annual Increment (MAI).

	mai=2.5	mai=5	mai=10
plant0=900	Scenario 1	Scenario 3	Scenario 5
plant0=1000	Scenario 2	Scenario 4	Scenario 6

Figure 1 shows the industrial emissions GTCO2 per year from 2015 to 2100. It compares the six reforestation scenarios with Nordhaus's Base run. The larger MAI and extra restoration potential areas, the more of industrial emissions GTCO2 emitted. Compared with the industrial emissions of base run, the industrial emissions of reforestation reach their peaking earlier and decline more slowly.

Figure 1: Industrial Emissions GTCO2 Per Year Comparison

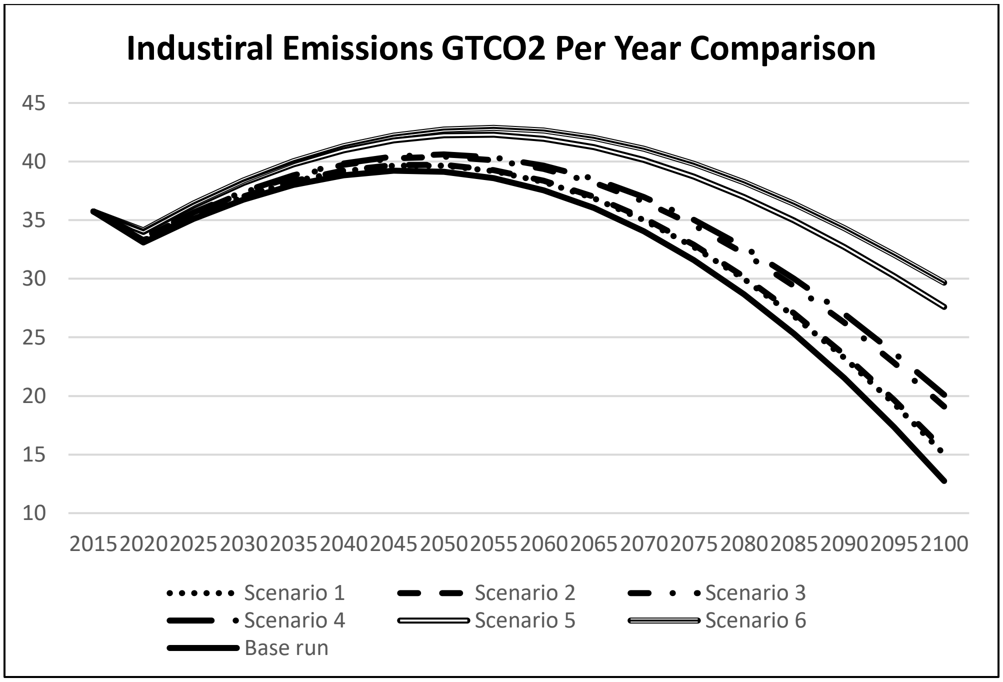

Table 1: Industrial Emissions GTCO2 Per Year Comparison

Industrial Emissions GTCO2 Per Year Comparison							
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Base run
2015	35.74038	35.74038	35.74038	35.74038	35.74038	35.74038	35.74038
2020	33.26457	33.2863	33.48317	33.53708	34.00404	34.1433	33.10147
2025	35.30594	35.33322	35.58168	35.64991	36.24108	36.41837	35.10588
2030	36.9985	37.03242	37.34285	37.42828	38.16729	38.38984	36.75452
2035	38.30474	38.34659	38.73106	38.83702	39.75073	40.02659	38.00894
2040	39.19517	39.24641	39.71882	39.84911	40.96745	41.30548	38.83876
2045	39.64774	39.71006	40.28621	40.44516	41.8012	42.21097	39.22102

2050	39.6472	39.7225	40.42038	40.61289	42.24305	42.73485	39.13948
2055	39.18444	39.27488	40.11495	40.34659	42.29095	42.87578	38.58389
2060	38.25585	38.36388	39.36944	39.64652	41.94935	42.639	37.54936
2065	36.86277	36.9912	38.18879	38.51849	41.22881	42.03591	36.03566
2070	35.01095	35.16296	36.58286	36.97339	40.14566	41.08374	34.04672
2075	32.71006	32.88927	34.56608	35.02677	38.7217	39.80532	31.59003
2080	29.97323	30.18379	32.15698	32.6985	36.98389	38.2287	28.67623
2085	26.81669	27.06332	29.37794	30.01245	34.96411	36.38694	25.31853
2090	23.2593	23.54739	26.2548	26.99615	32.69882	34.31773	21.53231
2095	19.32214	19.65784	22.81651	23.68042	30.22862	32.0629	17.33449
2100	15.02798	15.4183	19.09464	20.09891	27.59759	29.66765	12.7428

Figure 2 shows the comparison of atmospheric Concentration of carbon from 2015 to 2100. The two scenarios at the bottom decrease slightly at first, following the increment to the highest point and then decrease again because of the higher MAI. There is no doubt that the base run without emissions removal is on the top of the graph.

Figure 2: Atmospheric Concentration Carbon Comparison

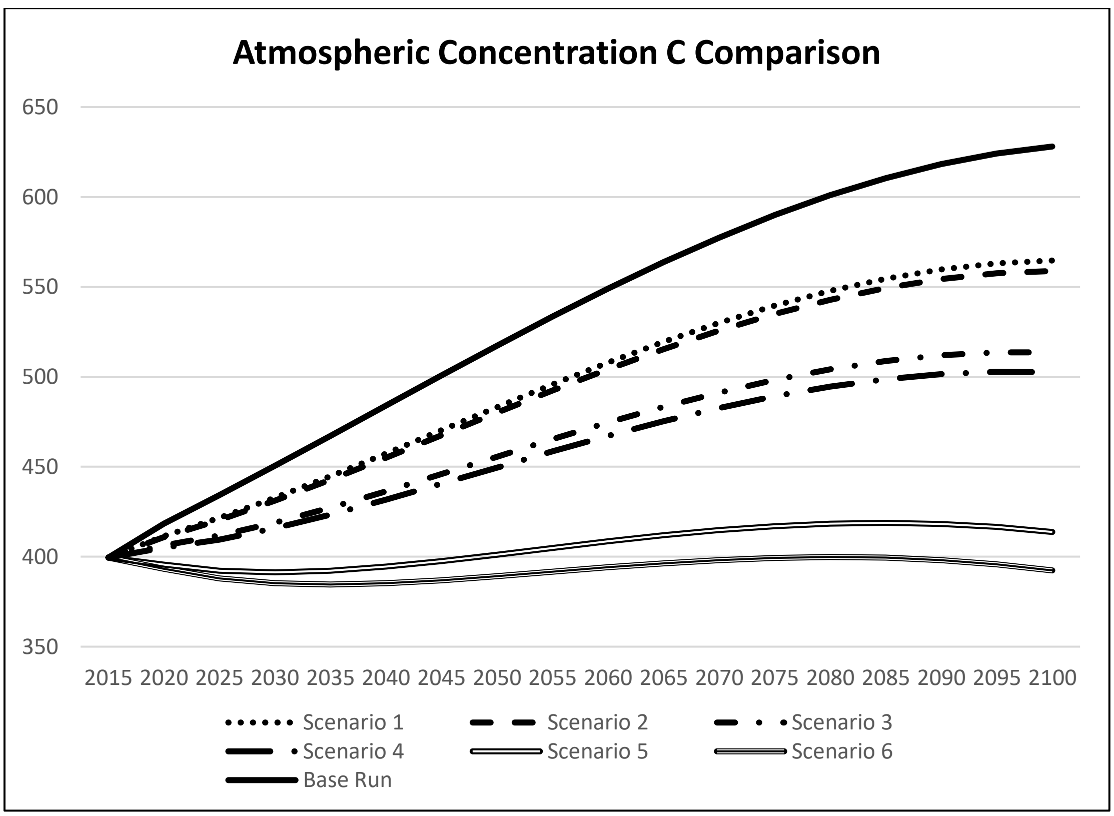

Table 2: Atmospheric Concentration Carbon Comparison

Atmospheric Concentration C Comparison							
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Base Run
2015	399.5305	399.5305	399.5305	399.5305	399.5305	399.5305	399.5305
2020	411.5182	410.9312	406.2355	405.0616	395.6702	393.3224	418.4657
2025	421.5208	420.4312	411.7294	409.557	392.2002	387.8754	434.2862
2030	432.7403	431.1981	418.8935	415.8239	391.3162	385.2208	450.5957
2035	444.8172	442.8582	427.2405	423.347	392.2777	384.5628	467.2408
2040	457.4379	455.0884	436.3727	431.7098	394.5205	385.3006	484.0483
2045	470.3204	467.6004	445.9535	440.5641	397.6009	386.9677	500.8314
2050	483.2049	480.1307	455.6896	449.6093	401.1596	389.1906	517.3948
2055	495.8488	492.4344	465.3195	458.5797	404.897	391.6617	533.5392
2060	508.0232	504.2813	474.6052	467.236	408.5577	394.1222	549.0639
2065	519.5108	515.4539	483.3286	475.3597	411.9204	396.3498	563.7697
2070	530.1053	525.7463	491.2882	482.7508	414.7912	398.1526	577.4606
2075	539.6108	534.9633	498.2976	489.2256	417.0006	399.3641	589.9457
2080	547.8422	542.9211	504.1855	494.6161	418.4008	399.8412	601.0401
2085	554.6251	549.4468	508.7951	498.7699	418.8655	399.4632	610.5663
2090	559.7961	554.3791	511.9845	501.5503	418.2893	398.1312	618.3551
2095	563.2034	557.5686	513.6271	502.8371	416.5885	395.7688	624.2455
2100	564.7072	558.8782	513.6125	502.5267	413.7013	392.3222	628.0858

Figure 3 shows the comparison of SCC under deforestation and reforestation assumption. SCC of base run is highest among these scenarios. It indicates that climate change cause severe damages and it is urgent to take actions to mitigate global warming. Contrast to base run, scenarios with large restoration potential areas and large MAI generate low SCC.

Figure 3: Social Cost of Carbon Comparison

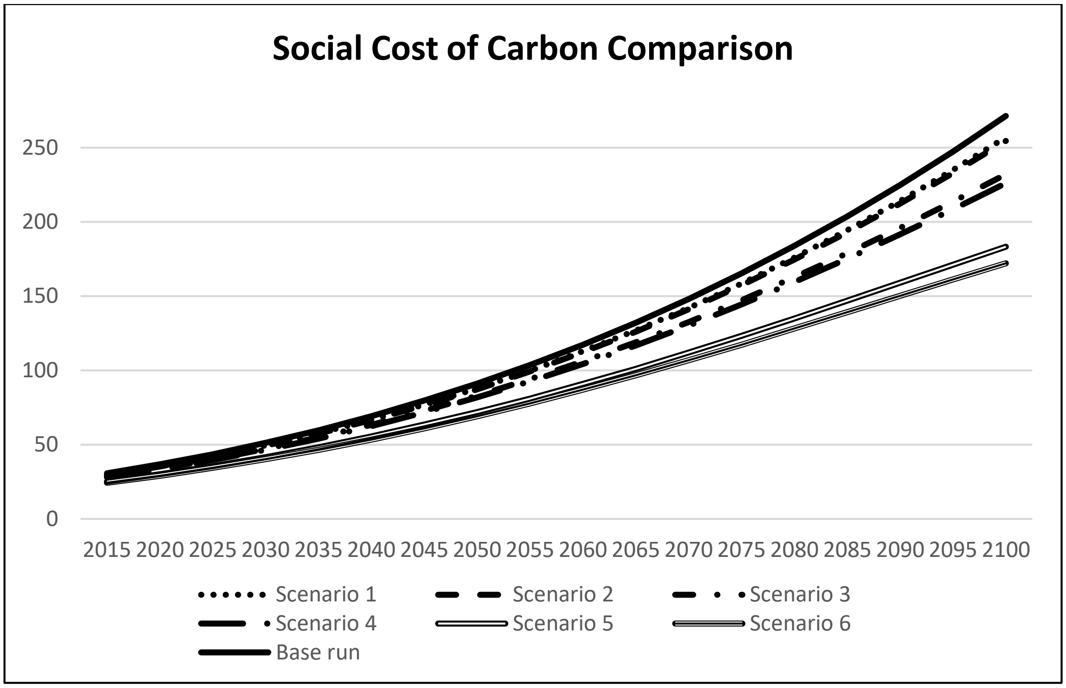

Table 3: Social Cost of Carbon Comparison

Social Cost of Carbon Comparison							
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Base run
2015	29.63031	29.49318	28.27025	27.94018	25.14803	24.34295	30.69666
2020	35.47342	35.3092	33.83536	33.43608	30.0535	29.07172	36.71755
2025	42.06638	41.86936	40.09191	39.6091	35.52096	34.3287	43.52635
2030	49.45368	49.21744	47.0768	46.4943	41.57306	40.13326	51.17016
2035	57.67923	57.3965	54.82498	54.12446	48.22915	46.5014	59.69617
2040	66.78591	66.44839	63.36858	62.52918	55.50363	53.44406	69.15162
2045	76.81512	76.41325	72.7361	71.73392	63.40451	60.96556	79.58351
2050	87.8063	87.32903	82.95157	81.7591	71.93194	69.06201	91.03845
2055	99.79651	99.23102	94.03371	92.61918	81.07683	77.7199	103.5624
2060	112.8199	112.1512	105.995	104.3216	90.8194	86.9146	117.2002
2065	126.9072	126.1179	118.8409	116.866	101.1277	96.6089	131.9958
2070	142.0853	141.155	132.5687	130.2427	111.9563	106.7516	147.9912
2075	158.3763	157.2813	147.1666	144.4321	123.2448	117.2761	165.227
2080	175.7978	174.5105	162.6126	159.4033	134.9162	128.0992	183.7418
2085	194.3617	192.85	178.8737	175.113	146.8763	139.1201	203.5722
2090	214.0746	212.3013	195.9054	191.5048	159.0129	150.2202	224.7541

2095	234.9381	232.86	213.6507	208.5091	171.1957	161.2634	247.3234
2100	256.9501	254.5172	232.041	226.043	183.2786	172.0991	271.3201

Figure 4 shows a comparison of atmospheric temperature of different scenarios. Consistent with the results of atmospheric concentration of carbon, temperature increment of base run is the highest, following that of the scenarios with low MAI. Scenario 5 and scenario 6 with high MAI increase only about 2 °C.

Figure 4: Atmospheric Temperature Comparison

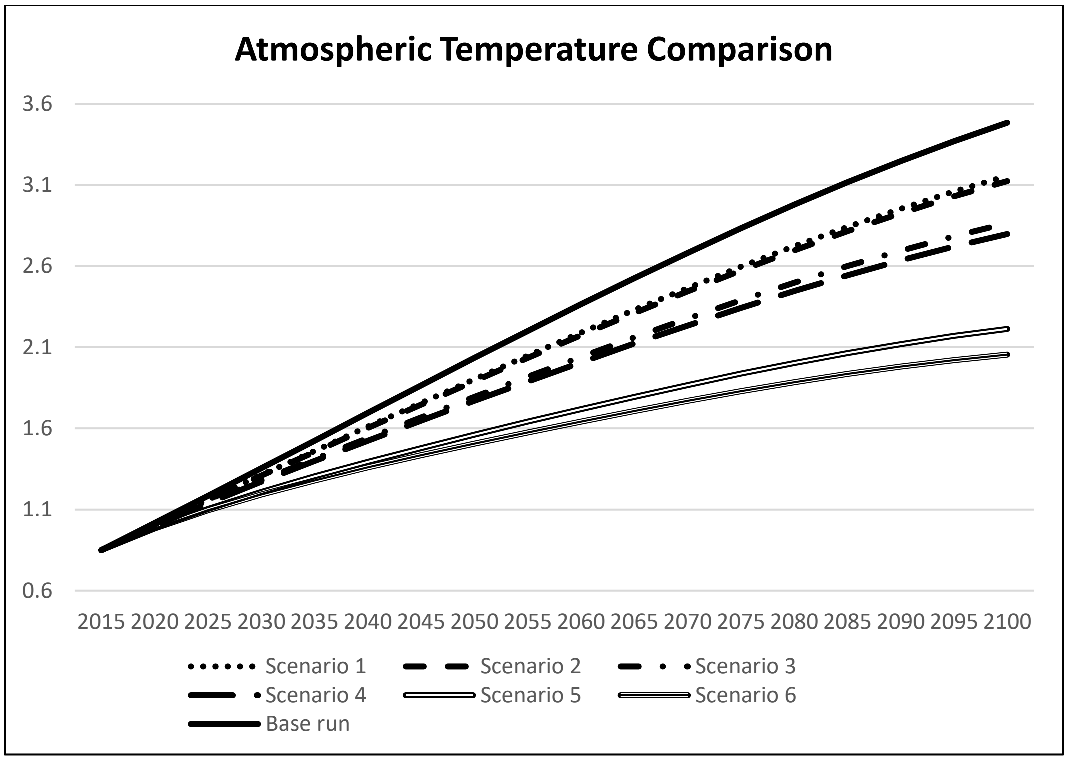

Table 4: Atmospheric Temperature Comparison

Atmospheric Temperature Comparison							
Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Base run
2015	0.85	0.85	0.85	0.85	0.85	0.85	0.85
2020	1.007406	1.006644	1.00051	0.998965	0.986444	0.983267	1.016342
2025	1.160595	1.158549	1.142038	1.137867	1.103838	1.09515	1.184309
2030	1.31134	1.307651	1.277802	1.27024	1.208147	1.192192	1.353598
2035	1.460654	1.455081	1.409891	1.39841	1.303583	1.279069	1.523753

2040	1.608989	1.601381	1.539557	1.523811	1.393033	1.359034	1.694196
2045	1.756387	1.746656	1.667436	1.647214	1.478389	1.434268	1.864251
2050	1.902596	1.890701	1.793715	1.768907	1.560793	1.506142	2.033171
2055	2.047153	2.033089	1.918255	1.888826	1.640829	1.575417	2.200164
2060	2.189455	2.173239	2.040681	2.006653	1.718667	1.6424	2.364415
2065	2.3288	2.310466	2.160459	2.121895	1.794168	1.707058	2.5251
2070	2.46443	2.444025	2.276943	2.233935	1.866974	1.76911	2.681402
2075	2.595553	2.573127	2.389415	2.342074	1.936567	1.828097	2.832516
2080	2.721359	2.696969	2.497113	2.445566	2.002321	1.883433	2.977658
2085	2.841035	2.814738	2.599252	2.543634	2.063539	1.934449	3.116063
2090	2.953768	2.92562	2.695035	2.63549	2.11948	1.980425	3.246987
2095	3.058748	3.028805	2.783663	2.720341	2.169386	2.020617	3.369699
2100	3.155166	3.123481	2.864337	2.797397	2.212496	2.054276	3.483481

Conclusion

My modified DICE2R model shows a new set of SCC and atmospheric temperatures by using the new assumption. The distinguishing features of my model are the following: First, it removes the deforestation assumption and replaces it with a reforestation assumption. By replacing with the reforestation assumption, I demonstrate how the exogenous CO2 emissions removal from planting costless trees contributes to damages and influence social welfares Second, it shows the impact of MAI on global warming and SCC results.

The most important results are the following. First, choices of ECS, marginal utility of consumption and rate of time preference impact the estimated SCC and atmospheric temperature. The lower the discounting rate, the higher SCC. High ECS leads to high estimated atmospheric temperature, therefore the SCC. Second, when we plant 900 million ha trees with high MAI on restoration potential areas, we will get the lowest estimated SCC for 2100. The estimated SCC for 2100 is $172.09 per tCO2 in 2005 U.S. dollars, which is about $100 lower than base run with deforestation assumption. The atmospheric temperature in that scenario will increase 2.05 degrees Celsius, which is about 1.5 degrees Celsius lower than base run with deforestation assumption.

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