The Cost of Delaying to Invest: A Canadian Perspective

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Abstract

Canada has been warming twice as fast as the average global temperature, and is clearly highly susceptible to such opportunities and risks. The risks associated with climate change are frequently broken into three categories: physical; transition; and, liability.[1] The Office of Superintendent of Financial Institutions (OSFI) and the Bank of Canada are in the midst of a pilot project, along with a number of key Canadian financial institutions, to use climate-change scenarios relevant to Canada to better understand the transitional risks to the financial system with respect to a transition towards a low-carbon economy.[i] However, this leaves a void with respect to the physical risks associated with climate change for Canada, and the associated costs.

We fill this void by updating and extending to Canada, the ground-breaking Dynamic Integrated Climate and Economy (DICE) model developed by 2018 Nobel Laureate William Nordhaus, to create specific projections for various warming scenarios. Our results show that there are stark differences in the physical costs due to climate change under each of these scenarios, highlighting the importance of curbing climate change. For example, we find that an increase from 2°C to 3°C warming leads to additional physical damage by 2100 with a present value of $80.9 billion (CAD) in today's dollars, while this figure escalates to $184.4b under a 4°C scenario. Consistent with previous global DICE model studies, we find that 2050 and 2070 are inflection points. In particular, physical costs accelerate markedly around those dates under greater warming scenarios relative to our baseline 2 degree warming scenario. We compare the present value of climate damage under our Business as Usual (BAU) (5°C) warming scenario to those under a 2°C scenario, and relate the difference in these figures to the present value of undertaking annual investment to reduce greenhouse gas (GHG) emissions. The results suggest that the present value of the difference in damages is $10.1b to $45.4b larger than the present value of the required investments, depending on the length of required investment assumption employed. In other words, undertaking the required investments to reduce GHG emissions more than pays for itself in terms of avoided physical damage alone, and without taking into account the potential economic benefits of transitioning to a low-carbon economy.

Overall, our results provide important guidance for policymakers and other actors in the Canadian economy. We would note that our model does not specifically account for the faster warming rate of Canada, and as such, we would consider our cost estimates as being conservative.

Keywords: sustainable finance, climate change, climate-economy models

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[1] For example, refer to Office of Superintendent of Financial Institutions, "Navigating Uncertainty in Climate Change," January 2021, https://www.osfi-bsif.gc.ca/Eng/osfi-bsif/med/Pages/clmt-rsk_nr.aspx.

1. INTRODUCTION

Sustainable finance may be defined as the integration of sustainability considerations into all relevant business and financial decisions, coupled with the alignment of financial systems and services to promote long-term environmental and social sustainability along with economic prosperity. Sustainable finance considerations are quickly becoming mainstream as numerous organizations recognize the pressing need to address global climate change. In December 2020, more than 3,000 global investors controlling over $100US trillion were signatories of the UN-backed Principles for Responsible Investment, an increase of 20 times that of the 2006 figure (UN PRI, 2021).

Canada is no exception to this movement. In RIA's 2019 report, they show that $3.2 trillion in Canadian assets were managed in alignment with a "responsible" investment strategy, representing close to 2/3rds of Canada's investment industry. Further, announcements from the Bank of Canada (2020), OSFI (2021), and investment management companies like Black Rock (Fink, 2020; 2021), acknowledged the importance of climate change as a current challenge.

As a result of these developments, market participants are taking action, conducting research, and seeking policy guidance to reduce their risk as well as their impact on global climate change (Eccles and Klimenko, 2019). Investors, from institutional to retail, are shifting their holdings to exploit opportunities, mitigate their risk, and fund research to further the aim of transitioning the world to a low carbon, sustainable economy (Arabella Advisors, 2018). These groups need information that is reliable, consistent, and comparable to evaluate investment opportunities and risks.

Despite this growth and rise to prominence, the migration of our economies to low carbon sustainability is moving too slow. In 2018, the Intergovernmental Panel on Climate Change (IPCC) report stated that we are on pace to miss our target to limit our global temperature increase to 1.5°C above pre-industrial levels by 2100. Within the 2018 report, the expected global temperature increase by 2100 was expected to range from 1.5°C to 4.5°C, with a 3°C warming scenario being consistent with progress and commitments at the time. The 2021 IPCC report updated the expected global warming range to 2.5°C to 4°C, with 3°C again being the best estimate. The 2020 UN SDG (Sustainable Development Goals) report also underscored the need for quicker action from the global community. Finally, the Emissions Gap Report (2020) noted that several countries, including Canada, are not on track to attain net-zero by 2050, while also noting that there was a growing number of countries committing to this goal. The current trend, based on the Emissions Gap Report appears consistent with a 3°C global warming scenario, according to Nationally Determined Contributions (NDCs). Such a scenario would be particularly harmful to Canada, given its above average warming rate compared to the global average (CBC, 2019; BBC, 2019).

As a result of the potential damage cost by moving too slow, there is interest in examining the relationship between delaying required transition investment and the economic loss incurred by such delays. We posit that economic value is being sacrificed every day that action is not taken to mitigate the economic and ecological risks posed by climate change. While current economic models agree that losses will be unavoidable without change and investment, questions regarding how much value will be lost and how quickly remain. The New Climate Economy (2018) report indicates that in 2017, weather and climate-related events were responsible for thousands of deaths and an economic loss of $320 billion. In 2015, The Economic Intelligence Unit (EIU) of the Economist released a report entitled "The Cost of Inaction" wherein they discuss the value at risk from climate change. According to their study, the expected impact on global investable assets by 2100 under a five-degree warming scenario would result in a present value of losses worth US$18.4 trillion from a public-sector perspective. At a six-degree warming scenario this number jumps to US$43 trillion - 30% of the entire stock of the world's manageable assets.

With respect to the economic benefits of climate change mitigation strategies, these have been estimated as being as much as $12 trillion by 2030 in terms of market opportunity and 470 million new jobs, while the global economy is projected to be 10% larger by 2050 (Accounting for Sustainability, 2018). The New Climate Economy (NCE) (2018) report discusses an even greater economic benefit, citing a $26 trillion dollar direct economic benefit by the same timeframe compared to a business as usual approach.

Our study focuses on investigating the Canadian cost of delaying capital investment efforts to transition to a low carbon, sustainable economy. In the Emissions Gap Report (2020), Canada is one of 5 G20 countries projected to miss its Paris Climate Accord nationally determined contribution goal, with GHG emissions expected to be 15% above the goal by 2030 (Global News, 2019). We build on these findings, examining this relationship by conducting a study of the Canadian specific project economic growth using the DICE model (Nordhaus, 2016). The DICE model is notable for being widely used in a number of top publications in the field of economics and finance, such as Popp (2004) and Nordhaus (1993, 2014) among others. Nordhaus won a Nobel Prize for the contributions of this model to the academic field. From a policy perspective, the DICE model is notable as the model that the Environmental Protection Agency (EPA) uses to estimate the social cost of carbon.

Our study generates a unique data set by using Canadian macroeconomic inputs, applying them to the DICE model to project losses in gross domestic product (GDP), as a result of physical damages, for 2°C, 3°C, 4°C and 5°C warming scenarios across the years 2020-2100. The relationship between temperature and GDP is obviously negative, and shows a sharp decline over time, due to the increasing nature of climate damage at the temperature increases. This ultimately leads to specific inflection points, where action must have already been taken in order to avoid exponential growth in economic damage.

We find that 2030 is a critical date where the different scenarios begin to separate in their specific trajectories. We anticipate that a capital mobilization effort must have occurred by this point in order to avoid catastrophic acceleration of damages. As the relationship is still relatively linear by this point, these are the years when planning and execution are critical. The year 2050 is important, as this is the date where climate damages begin to compound to the point that the relationship takes on a decidedly more exponential shape. Finally, 2070 shows a shift to a much faster rate of climate damage acceleration. By 2070, our data shows that efforts have should have already been made to curb the impact of climate change on our economy. If not, our data shows the damages would be at their most destructive during the period of 2070-2100.

Our results show that the cost to the Canadian economy, compared to a 5°C, business as usual (BAU) warming scenario, ranges between $80.9 billion to $256 billion (CAD). These figures are consistent the Economist's Intelligence Unit's (2015) global projections, when scaled to Canada. The EIU report determines that the global cost of climate change by 2100 ranges from $4.2 trillion (USD) to $13.8 trillion for the private sector and $13.9 trillion to $43.0 trillion from the government. Taking Canada's 1.34% share of climate damage, based on Canada's share of global GDP, we would expect private sector climate damages valued at $56.3 billion to $184.9 billion (USD) or $75.3 billion to $247.3 billion (CAD) for the private sector and government respectively under a 2°C scenario, using an exchange rate of $1.33774 CAD/USD.

The Institute for Sustainable Finance's Capital Mobilization Plan (CMP) estimates that achieving Canada's Paris Agreement target of a 30 percent reduction in 2030 GHG emissions from 2005 levels would require an investment of $128b CAD over 10 years, or $12.8b annually. We compare these required annual investment figures, along with continued investment of $12.8b to 2100 and 2053, against our climate damage projections, and find the present value of such investments are less than the present value of the difference in climate damages under the 5°C BAU versus the 2°C warming scenario. We compare these figures, based on the assumption that making such investments would limit warming to 2°C, while committing no investments to transition would leave us on track for the BAU 5°C scenario. We recognize that Canadian only investment will not by itself limit future global and Canadian warming scenarios; but it does provide anecdotal evidence of the benefits associated with such investment, at least in terms of reduced physical costs.

Our results provide context to the cost of climate change under a variety of different climate change scenarios. If we continue to delay the necessary action of mitigating climate change, we will realize significant costs to our economy, which underscores the importance of taking action as quickly as possible. Additionally, as the CMP (2020) states "Given Canada's high GHG intensity, a more likely assumption is that these costs associated with climate change would be disproportionately larger than 1.34% of global costs for Canada." This implies that our climate damage projections fall on the conservative side, and the costs could be significantly larger.

Our pathway to 2030 must consist of effective planning and implementation in order to minimize our risk of proceeding toward more destructive climate damage projections. The CMP concludes that Canada requires an investment of $128 billion by 2030 to achieve its 2030 target.[4] Our results bolster the importance of this finding, showcasing that 2030 is a critical date to make these investments, which will require more robust action by 2050.

The remainder of this paper is organized as follows. Section 2 provides a review of the sustainable finance literature and the impacts of climate change on the economy, including studies from academia, policy-makers, and practitioners. Section 3 discusses the operating components of the DICE model that we adapt to make our climate projections for Canada from present day to 2100. Section 4 presents and discusses our results, and Section 5 concludes.

2. LITERATURE REVIEW

The economics of climate change have become increasingly important to academic, professional, and policy fields. There have been calls for global action to thwart the effects that climate change has on our growth and development (Stern, 2007; Stern and Stiglitz, 2017; Dietz et al., 2018). In response, models have been developed in attempts to quantify the physical damages of climate change (Nordhaus, 1993; 1999; 2013, 2016). The Economist Intelligence Unit modified Nordhaus' DICE model to project the global cost of climate change by 2100 to manageable assets and found that the value at risk

[4] More recent targets have been set at a 40-45% reduction by the current federal government: https://globalnews.ca/news/7779596/climate-change-emissions-targets-canada-2030-trudeau/.

was $4.2 trillion-$13.8 trillion in present value terms (USD) by 2100 depending on the amount of global warming.

Numerous jurisdictions have commissioned expert panels to produce reports with how best to direct their capital to take action against climate change risks (e.g., European Commission, 2018; Government of Canada, 2019). These reports have discussed a variety of actions, such as creating information repositories, providing capital investment, and investing in innovative technologies. Reports have also been published that advocate the manageable cost of mitigating climate change, the cost savings of immediate action, and the potential economic prosperity created by sustainable investment (CMP, 2020; New Climate Economy, 2018; Stern 2007; The Economist, 2015; and others).

The Canadian government's Paris Agreement commitment was to reduce GHG emissions by 30% of 2005 levels by 2030, before the federal government recently increased the reduction target to 40-45%. The required investment to achieve the 30% reduction was estimated at between $90 to $166 billion (CMP). This represents the estimated investment required to abate 789 million tonnes of GHG over this 10-year period. The New Climate Economy 2018 report estimated a projected benefit of $26 trillion (USD) of direct global economic gain within the next decade, should the world transition to sustainable, low-carbon economies. Presumably, by investing in this transition, Canada would experience a portion of these benefits while avoiding significant climate change costs.

The deadline for action on climate change, achieving net zero emissions, has been set at 2050 (IPCC, 2021). However, an important milestone is cutting emissions by 45-50 percent by 2030 (IPCC, 2018; MPRNews, 2019). Reaching net zero by 2050 is key in limiting our global temperature rise to 1.5°C above pre-industrial levels and beyond. But achieving this target may not be possible without robust action to limit our emissions by 40-60% by 2030 (IPCC, 2018; 2021). The IPCC (2018) report states that the action taken in by 2030 will determine our reliance on carbon dioxide removal (CDR) technologies to achieve our 2050 net zero goal. Petteri Taalas, the Secretary-General of the World Meteorological Organization (WMO) stated that global warming in excess of 1.5°C above pre-industrial will lead to the irreversible loss of the most fragile ecosystems, in addition to many crises for society (IPCC, 2018). Notably, the IPCC (2018) report projects that we are on track to reach a 3°C increase in global temperatures by 2100.

There exists a significant gap in available data to determine the economic costs to Canada should global warming progress beyond 1.5°C and into 3°C or even 4°C scenarios. These scenarios will have different impacts for the world (The Economist, 2015) and therefore Canada. Yet, to date, no model exist that examines the economic outcomes for Canada given the varying scenarios. Additionally, quantitative examination of climate damages through the years can provide insight into projecting true deadlines for climate change action. By utilizing the DICE model, we intend to create projections for Canadian-specific climate damages under 2°C, 3°C, 4°C, and business-as-usual (BAU) (5°C) warming scenarios, while also graphing the climate damages over each year from 2015-2100. We are not expected to reach 1.5°C by 2030-2052 (IPCC, 2018); therefore we consider a 2°C increase by 2100 as our baseline optimistic outcome and do not include a 1.5°C scenario in our analysis.

In addition to examining the relationship between the increase in global temperature and the associated economic costs, we also identify certain "tipping points" within the data, which indicate when temperature increases lead to significant economic damages, thus indicating deadlines for climate action. We produce macroeconomic data regarding climate change that will be useful to Canadian policy makers and experts in the field in determining and adjusting pathways forward. This addresses an important data gap, which should assist future research. While we apply the methodology to examine the costs of climate change to Canada, we note that the same approach could be used in a global context.

3. RESEARCH DESIGN

3.1 Temperature Adjustments

The DICE model uses a variety of parameter inputs and applies them to equations to determine economic and economically relevant outcomes. A necessary aspect to calibrating the DICE model to our particular needs is to adjust the model such that, by 2100, it reaches 2^{o}C, 3^{o}C, 4^{o}C, and 5^{o}C above pre-industrial levels. For our purposes, the temperature used for our projections is the increase in global temperatures, with our base model being 2^{o}C above preindustrial levels by 2100. The DICE model cannot elegantly differentiate between global temperature increases and that of temperature increases for a particular nation or region. Because of this, our model uses global projections of temperature increases and carbon output while applying these numbers to a Canadian economy. More succinctly, we modify the DICE model to project Canada's economic outcomes based on projections from the original model to Canada.

The atmospheric temperature in a given year is determined using the equation:

$$AT_n = AT_{n-1} + AS * \left(RF_n - \frac{DF}{ET}\right) * AT_{n-1} - CHL * (AT_{n-1} - LOT_{n-1}) \quad (1)$$

Where AT_n is the atmospheric temperature for a given year, AT_{n-1} is the atmospheric temperature for the previous year. AS is the "speed of adjustment parameter for atmospheric temperature". RF_n is the "total increase radiative forcing since preindustrial" for the given year, measured in Watts/m^2. DF is the Forcings at CO2 doubling and ET is the equilibrium temperature increase for CO2 doubling. CHL indicates the "coefficient of heat loss" from the atmosphere to the oceans, where heat loss is the amount of solar radiation that manages to escape the atmosphere into space. LOT_{n-1} is the "lower ocean temperature" in degrees Celsius above preindustrial for the previous year.

The baseline DICE model projects the world temperature at 0.85^{o}C above pre-industrial in 2015. The coefficient on heat loss is set at 0.088. We maintain the original DICE model's temperature sensitivity (referred to the "equilibrium temperature increase for CO2 doubling"), this means our model makes the assumption that Canada is equally affected by global warming as the rest of the world. The lower ocean temperature is set to 0.007 degrees Celsius above preindustrial for 2015. Ocean temperatures are important because they feed into heat loss, by acting as a heat sink.

We adjust the atmospheric temperature by adjusting the radiative forcings in Watts/m^2. Forcings are the difference between solar irradiance absorbed by the Earth and energy that is radiated back to space. Upward changes to these forcings increases the theoretical presence of greenhouse gases (GHG) in our model which has an upward influence on the temperature. For example, should our production of GHG remain at its present rate (3.6813 Watts/m^2) we would have an atmospheric temperature of 4.6^{o}C by 2100 in the original DICE model. We adjust these forcings downward from this starting point to reflect a 2^{o}C and 3^{o}C scenario. We also increase this value to reach 5^{o}C.

3.2 Climate Damage Modelling

Our main equation in this study is Equation 4, which provides annual estimates of climate damage. Equation 4 returns this result from the combination of "output (gross of abatement cost and climate damage)" from Equation 2, multiplied by "Total damage" which is calculated as a fraction of gross output from Equation 3. Intuitively, Equation 2 determines the GDP in CAD for the year by combining the population, productivity, and available capital, while Equation 3 generates the fraction of GDP lost as a result of the atmospheric temperature in a given year. When we multiply the products of these equations together in Equation 4, the result returned is the amount of GDP lost in CAD, in a given year, due to climate damage.

$$Output\ (Gross\ of\ abatement\ cost\ and\ climate\ damage)\ = TFP_n * K_n^{CS} * \frac{POP_n^{1-CS}}{1000} \quad (2)$$

$$Total\ damage\ (fraction\ of\ gross\ output) = AT_n * DT + (DT^2 * AT_n^{ED}) \quad (3)$$

$$Climate\ Damage = Output\ * Total\ damage \quad (4)$$

The "Output (Gross of abatement cost and climate damage)" is calculated from the model's Cobb-Douglas function which projects output as a function of capital, labor, and productivity. K_n is the capital investment in a given year and CS is the capital share. The capital investment is determined by Equation A-3, which is discussed in the Appendix. The original DICE model projects 0.300 as the capital share, and we leave this value unchanged. POP_n is the population in a given year. We use the Canadian specific population metrics for Equation A.11 of the Appendix, which is based on population projections from the Century Initiative (2020). Total damage as a function of gross output is calculated in equation 3, where ED is the exponent on damages. The exponent on damages is set to 2.0 in the original DICE model and we maintain this value. DT is the damage coefficient on temperature, which is set to the original DICE value of 0.0023600.

The inputs for these equations are acquired through a variety of other macroeconomic inputs and calculations. We have provided the details and explanations for these in the Appendix.

4. RESULTS

4.1 Scenario Development

The DICE model scenarios are generated by adjusting the atmospheric temperature via the radiative forcings in Watts/m^2 to generate the global temperature in year 2100. Figure 1 shows the yearly temperature projections corresponding to each scenario. Radiative forcings refer to the influence a particular factor has on the temperature of the Earth (Mann, 2016). The projections show significant differentiation by 2030, implying that significant action to reductions in GHG emissions by this date are strong indicators for increases in global temperature by 2100. The 2°C and 3°C scenarios illustrate significant differences starting in 2040, underscoring that it is likely that more robust action will need to be taken by 2050 to prevent a 3°C increase in global temperature by 2100. The 2018 IPCC report states that significant damage will occur to our most sensitive ecosystems beyond 1.5°C above pre-industrial levels. In all cases, we reach the 1.5°C above pre-industrial by 2040 or earlier. Figure 1 shows a linear increase in temperature with the only scenario that indicates a flattening of temperature increases being under a 2°C warming scenario.

INSERT FIGURE 1 HERE

Tables 1 and 2 show the radiative forcings increases since the preindustrial period for the World and Canada respectively, and projects that to 2100 for each climate scenario. The DICE model measures the impact of these factors on increasing temperatures. Our results in Table 1 show that the global Watts/m^2 is quite different for each temperature scenario. This is because the scenarios with less warming contain fewer GHG emissions and, therefore, much less positive radiative forcings values. Table 2 determines Canada's radiative forcings by scaling the values in Table 1 by 1.6%, the percentage of Canada's contribution to global GHG emissions (Boothe and Boudreault, 2016).

INSERT TABLE 1 HERE

INSERT TABLE 2 HERE

4.2 Projecting Damages and Impacts on Output Growth

Figure 2 shows the climate damages in billions $ (CAD) that are projected by the model using Equation 4. The projected damages show significant increases in climate damage values for higher 2100 temperatures. The costs of climate change damage grow in relatively linear fashion until 2050, at which time there is a stark increase. In all scenarios, by 2070 there is an exponential increase in climate damages. These years correspond to significant dates noted in the IPCC (2018) report, which discusses reaching net zero by 2050 and 2070 in their 1.5°C and 2.0°C warming projections respectively. Considering the IPCC (2018) our results illustrate the physical damage costs associated with delays in reaching net zero. Our results confirm that 2030 is an important date by which to take action in order to avoid a sharp increase in costs. This confirms the importance of setting and meeting ambitious near-term goals in reduction of emissions, with a target of net zero by 2050.

INSERT FIGURE 2 HERE

Table 3 shows the 2015-2100 climate damage estimates in 5 year increments. Columns 6-8 show the differences in climate damages for each global temperature increase (3°C, 4°C, or 5°C) compared to the 2°C base model. The bottom of Table 3 shows the total value of capital output lost due to climate change over the time period 2015 to 2100 for each climate scenario. Table 4 shows the same relationship with the dollar values discounted back to today using the discount rate of 5.58% as determined by the CMP (2020).

INSERT TABLE 3 HERE

INSERT TABLE 4 HERE

Examining the differences at the key dates outlined by the IPCC (2018) report, namely 2030, 2050, and 2070, there are distinct differences between each temperature scenario. In 2030, according to Table 3, the differences between the 3°C, 4°C, and 5°C scenarios when compared to the 2°C base scenario are $2.717, $6.158, $8.384 billion (CAD) respectively. In 2050, the difference in losses relative to the base case are $6.118, $14.323, $19.619 billion, and in 2070, the marginal losses are $11.423, $27.099, and $37.030 billion. There are stark differences between years and between scenarios, underlining the importance of immediate action to reduce our climate change to 2°C or below. For example, Table 4 shows that an increase from 2°C to 3°C warming leads to additional cumulative physical damages by 2100 with a present value of $80.9 billion (CAD) in today's dollars, while this figure escalates to $187.4b under a 4^{o}C scenario.

Figure 3 shows the deficit in Canada's yearly economic growth created by the increase in climate damages. The DICE model compares output growth as follows: $\left(\frac{Current\ Years\ Output}{Previous\ Years\ Output}\right)^{0.2-1}$, we take these values and convert the climate damage in billions into a percentage of the year's output: $\left(\left(\frac{climate\ damage\ \$}{current\ year\ output}\right) - 1\right) * 100$. This value is the percentage of output growth that is eliminated by climate damages.

In Figure 3, we examine the percentage of lost GDP each year from 2020 to 2100. The 5^{o}C scenario has the steepest slope with the greatest yearly reduction in GDP, a loss of $168b of the expected $525b GDP produced by Canada by year 2100 (a 31% reduction). The 2^{o}C scenario has a significantly reduced slope, an 11% reduction in GDP in 2100 (or $74.8b); although 2050-2055 shows a marked steepening. The 4^{o}C and 5^{o}C scenarios do not have noticeable slope changes from 2020 to 2100. We conclude that our findings show that action taken prior to 2050 is critical in reducing the value lost to climate damage. Unfortunately, even with robust action, significant negative changes in year-over-year losses are still likely around 2050 due to 1.5^{o}C of warming above pre-industrial being reached in even our most optimistic of cases.

INSERT FIGURE 3 HERE

Examining Figure 1 in conjunction with Figure 3 shows that 2050 corresponds roughly to where our 2^{o}C and 3^{o}C scenarios reach 1.5^{o}C of warming above pre-industrial. This is when the Secretary General of the WMO, Petteri Taalas, has stated that sensitive ecosystems would begin to be severely affected (IPCC, 2018). In Figure 1, we can see that this warming happens significantly earlier in the 4^{o}C and 5^{o}C scenarios, around 2025-2030, creating this steeper decline much earlier. The earlier temperature increase results in more severe climate damages over the long term, creating much more significant climate damages, which we observe in Figure 2. Underscoring the significance of immediate action, a delay which results in a movement from 2^{o}C to 3^{o}C by 2100 is shown to cost an additional $28.6b in GDP for that year.

4.3 Cost of Delaying Investment

Table 5 compares Canada's required annual investment to achieve its 2030 target according to the CMP (2020) to annual climate damage estimates. Column 2 shows the present value of the required annual investment proposed by the CMP with continual investment of $12.8b CAD per year to 2100, while Column 3 shows the present value of the annual investments if they are not required after 2053.[5] Columns 4 and 5 show the present value of climate damage over the same timeframe under the 2^{o}C and BAU 5^{o}C warming scenarios respectively. Finally, Column 6 shows the difference in the present value of climate damages between these two scenarios.

[5] In other words, if $12.8 per year investment reduces GHG emissions 30 percent over 10 years, then it could require another 20.33 years to reduce the other 70 percent of emissions to get to net zero.

INSERT TABLE 5 HERE

If we assume the required investments according to the CMP allows us to avoid a 5°C climate scenario, and instead realize a 2°C scenario, then we can compare the present value of these investments to the difference in damage under the BAU scenario versus the 2°C scenario. This provides us an estimate of the benefits, in terms of avoided physical costs, of making such investments. We note from Table 5 that the present value of total investments to 2100 is $239.21b, and is $203.96 if we assume such required investments cease in 2053. The present value of climate damage under a 2°C scenario is $351.50b versus $600.83b under the 5°C scenario, so the difference in damage is $249.33b, in today's dollars. The present value of the difference in damage is $10.12b larger than the present value of the required investments if we assume they are made until 2100, and it is $45.37b larger if the required investments cease in 2053.

The discussion above shows that investing $12.8b per year to address GHG emissions and reduce warming, creates an economic benefit if compared simply to the physical damage associated with greater warming. We note that this does not account for the costs associated with declining societal health outcomes, including the deaths and complications related to climate change. Also absent is the inclusion of the economic prosperity that investing in a low-carbon economy could provide, as discussed in the NCE (2018) for example. New jobs, energy independence, and technological synergies are potential positive benefits, to name just a few, that would make the transition to a low-carbon economy an even more attractive prospect.

5. **CONCLUSIONS**

Our study addresses important data gaps in the current literature, specifically a lack of actionable climate data from which to base climate projections and economic outcomes. By adapting the DICE model using Canadian inputs, we provide estimates of the economic damage associated with climate change from present day to 2100 under various warming scenarios. Our climate damage projections provide useful input for policy makers as well as the business sector to aid in planning a long-term strategy to mitigate against the most severe effects of global climate change.

We document a significant deterioration in outcomes beginning in 2050. We also show that significant transition strategies must be well in motion by 2030 in order for a 2°C warming scenario to be possible. The most costly years in terms of climate damage are between 2070 and 2100, and therefore taking action prior to this period is critical. We find that global climate change, even at 2°C is extremely costly; however, those costs are significantly magnified as the temperature increases to 3°C, 4°C, and 5°C scenarios. Our results for each scenario are consistent with those provided by The Economist in their 2015 report, if global climate damage estimates are scaled to Canada's share of global GDP. Our results support the Canadian Expert Panel (2019) among others that stress the need to take immediate and direct action against climate change to preserve our economic prosperity.

We confirm that there is a significant cost of delaying to invest in the transition to a low-carbon economy by 2030. We provide anecdotal evidence to this effect by comparing the present value of Canadian required annual investments according to the CMP (2020) to the present value of the difference in climate damage under a 5°C scenario versus under a BAU 5°C scenario. The results suggest that the present value of the difference in damages is $10.1b to $45.4b larger than the present value of the required investments, depending on the length of required investment assumption employed. In other words, undertaking the required investments to reduce GHG emissions more than pays for itself in terms of avoided physical damage alone, and without taking into account the potential economic benefits of transitioning to a low-carbon economy.

We note the following caveats with respect to our study. First, our Canadian adaptation of the DICE model assumes that global temperature increases affect Canada proportionately, whereas we know that Canada is warming faster than the rest of the world. This implies our model estimates of climate damages are likely conservative. Secondly, like the original DICE model, we estimate physical costs only, but do not account for associated transition costs. Finally, we do not incorporate benefits associated with mitigation. In other words, while we estimate the physical costs of climate change we do not estimate the economic benefits from investments in addressing climate change. As noted, these benefits have been estimated to be very significant. As a result, our model that estimates only physical costs, paints an incomplete picture of the total economic outcomes under each scenario. For example under a 2°C warming scenario, it is quite possible that Canada experiences significant additional economic growth in addition to the reduction in climate damage.

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Figure 1

Temperature (Degrees Celsius)

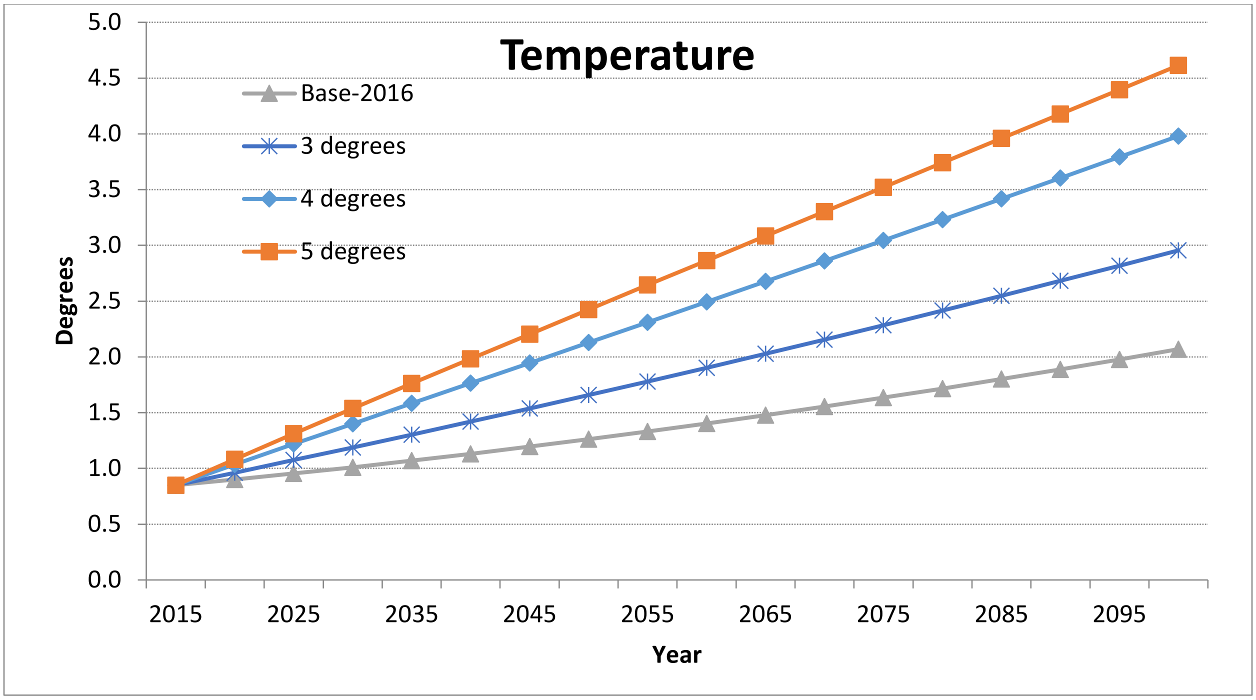

Figure 2

Climate Related Damage (billions CAD)

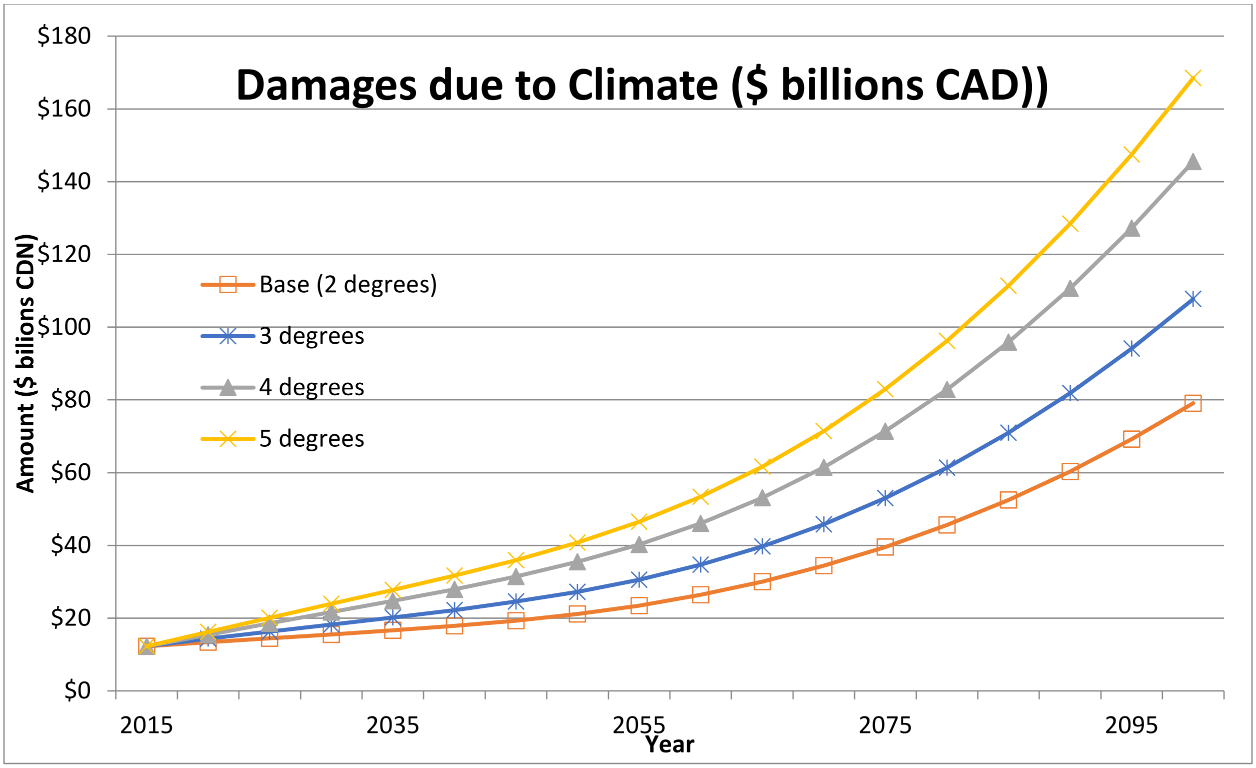

Figure 3

Output Growth – Climate Damage (expressed as a percentage of the current year's output)

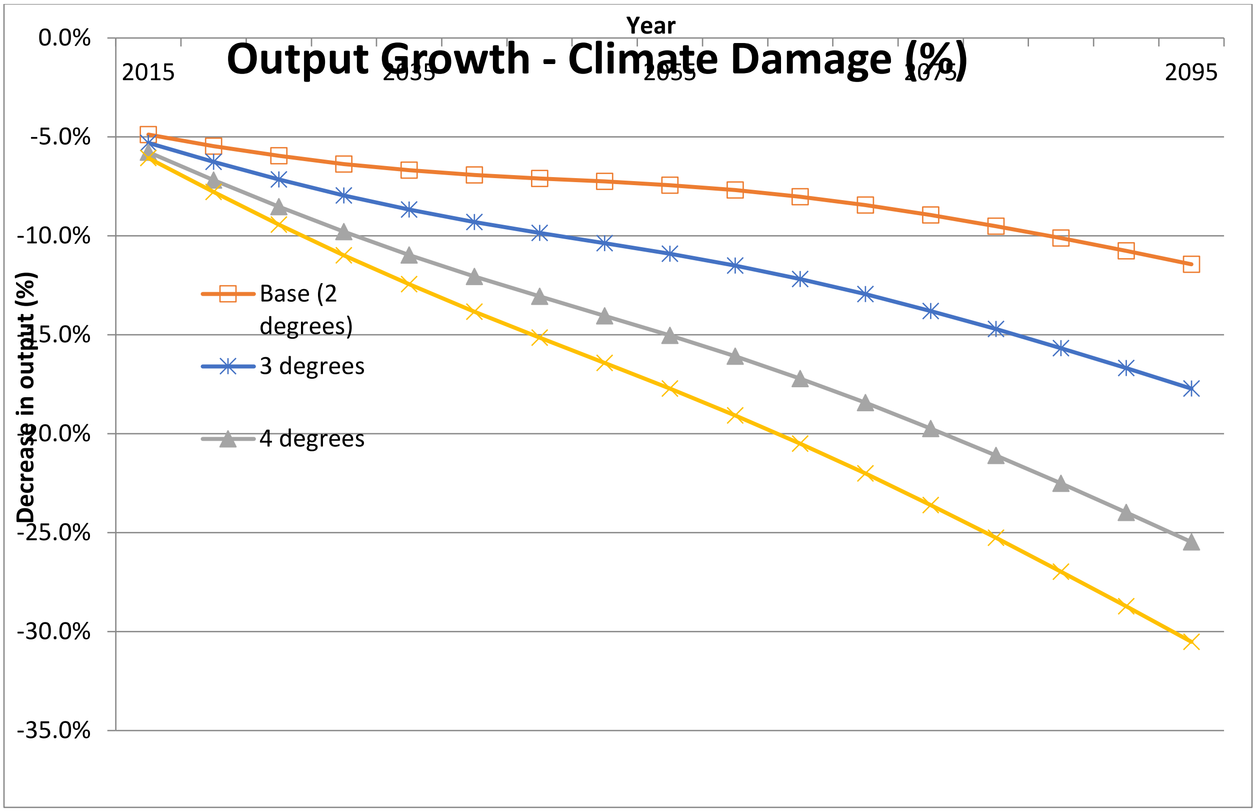

Table 1

Total increase in radiative forcing since preindustrial (Watts per square meter)

Year	2°C (Base)	3°C	4°C	5°C	3°C - Base	4°C - Base	5°C - Base
2015	0.553	1.193	1.967	2.463	0.634	1.413	1.910
2020	0.581	1.204	1.957	2.441	0.617	1.376	1.859
2025	0.610	1.221	1.961	2.435	0.606	1.351	1.826
2030	0.639	1.243	1.973	2.442	0.598	1.334	1.803
2035	0.668	1.267	1.991	2.456	0.593	1.323	1.788
2040	0.697	1.292	2.012	2.475	0.590	1.316	1.778
2045	0.726	1.319	2.037	2.497	0.588	1.311	1.771
2050	0.755	1.347	2.062	2.522	0.586	1.307	1.767
2055	0.785	1.375	2.089	2.548	0.585	1.305	1.763
2060	0.814	1.404	2.117	2.574	0.584	1.303	1.761
2065	0.843	1.432	2.144	2.602	0.583	1.301	1.758
2070	0.873	1.461	2.172	2.629	0.583	1.300	1.757
2075	0.902	1.490	2.200	2.657	0.582	1.298	1.755
2080	0.931	1.519	2.228	2.684	0.581	1.297	1.753
2085	0.961	1.547	2.256	2.712	0.581	1.296	1.751
2090	0.990	1.576	2.284	2.739	0.580	1.294	1.749
2095	1.019	1.605	2.312	2.766	0.579	1.293	1.747
2100	1.049	1.633	2.340	2.793	1.633	1.291	1.744

Notes: This table presents the yearly global increase in radiative forcing in W/m^2 (Watts per square meter) over the time period 2015 to 2100. This is determined using the equation: $s\ at\ CO2\ doubling * \frac{LOG(Atmospheric\ Concentration\ of\ carbon)}{LOG(2)+Exogenous\ Forcing}$. Columns 2-5 present the W/m^2 for each year in each temperature scenario. Columns 6-8 show the differences in W/m^2 for each global temperature increase (3,4, or 5 degrees) compared to the base model (2 degrees) .

Table 2

Total increase in radiative forcing since preindustrial (Watts per square meter)

Year	2°C	3°C	4°C	5°C	3°C - Base	4°C - Base	5°C - Base
2015	0.00885	0.01909	0.03147	0.03941	0.01015	0.02261	0.03056
2020	0.00930	0.01927	0.03132	0.03905	0.00988	0.02201	0.02975
2025	0.00976	0.01954	0.03137	0.03897	0.00969	0.02161	0.02921
2030	0.01022	0.01988	0.03156	0.03906	0.00957	0.02135	0.02885
2035	0.01068	0.02027	0.03185	0.03929	0.00949	0.02117	0.02861
2040	0.01115	0.02068	0.03220	0.03960	0.00944	0.02105	0.02845
2045	0.01161	0.02111	0.03259	0.03995	0.00940	0.02097	0.02834
2050	0.01208	0.02155	0.03300	0.04035	0.00938	0.02092	0.02827
2055	0.01255	0.02201	0.03343	0.04076	0.00936	0.02088	0.02821
2060	0.01302	0.02246	0.03387	0.04119	0.00935	0.02084	0.02817
2065	0.01349	0.02292	0.03431	0.04163	0.00933	0.02082	0.02814
2070	0.01396	0.02338	0.03476	0.04207	0.00932	0.02080	0.02810
2075	0.01443	0.02384	0.03520	0.04251	0.00931	0.02077	0.02807
2080	0.01490	0.02430	0.03565	0.04295	0.00930	0.02075	0.02804
2085	0.01537	0.02476	0.03610	0.04338	0.00929	0.02073	0.02801
2090	0.01584	0.02522	0.03655	0.04382	0.00928	0.02071	0.02798
2095	0.01631	0.02567	0.03699	0.04426	0.00927	0.02068	0.02795
2100	0.01678	0.02613	0.03743	0.04469	0.02613	0.02065	0.02791

Notes: This table presents Canada's yearly increase in radiative forcing in W/m^2 (Watts per square meter) over the time period 2015 to 2100. This is determined using the equation: $s\ at\ CO2\ doubling * \frac{LOG(Atmospheric\ Concentration\ of\ carbon)}{LOG(2)+Exogenous\ Forcing}$. We then scale this to 1.6% based on Canada's share of the global GHG emissions. Columns 2-5 present the W/m^2 for each year in each temperature scenario. Columns 6-8 show the differences in W/m^2 for each scenario's temperature increase (3,4, or 5 degrees) compared to the base model (2 degrees).

Table 3

Climate Damages ($ Billions CAD)

Year	2°C (Base)	3°C	4°C	5°C	3°C - Base	4°C - Base	5°C - Base
2015	12.252	12.252	12.252	12.252	0.000	0.000	0.000
2020	13.404	14.316	15.454	16.189	0.912	2.050	2.785
2025	14.483	16.311	18.604	20.085	1.827	4.120	5.602
2030	15.533	18.250	21.691	23.917	2.717	6.158	8.384
2035	16.620	20.190	24.769	27.734	3.570	8.149	11.114
2040	17.836	22.235	27.958	31.663	4.398	10.121	13.827
2045	19.298	24.529	31.442	35.914	5.231	12.144	16.616
2050	21.134	27.251	35.456	40.752	6.118	14.323	19.619
2055	23.465	30.585	40.250	46.469	7.120	16.786	23.004
2060	26.397	34.701	46.062	53.339	8.303	19.664	26.942
2065	30.016	39.739	53.089	61.595	9.723	23.072	31.579
2070	34.386	45.808	61.485	71.415	11.423	27.099	37.030
2075	39.558	52.992	71.365	82.930	13.434	31.806	43.372
2080	45.580	61.356	82.815	96.233	15.776	37.234	50.653
2085	52.495	70.956	95.902	111.392	18.461	43.406	58.896
2090	60.351	81.848	110.684	128.460	21.497	50.333	68.109
2095	69.196	94.083	127.214	147.480	24.887	58.018	78.284
2100	79.084	107.717	145.540	168.489	28.632	66.456	89.404
Total	**2772.779**	**3635.650**	**4794.569**	**5520.062**	**862.871**	**2021.790**	**2747.283**

Notes: This table presents the value of capital output lost due to climate change over the time period 2015 to 2100 in billions $ CAD. Our DICE model uses the equation: $Damage\ cofficent\ on\ temperature^2 * (World\ Atmospheric\ Temperature)^{exponent\ on\ damages}$ to determine the fraction of damages of gross output. The DICE model then multiplies this by the total capital output to get the value of climate damages. Columns 2-5 present the climate damage for each year. Columns 6-8 show the differences in climate damages for each global temperature increase (3,4, or 5 degrees) compared to the base model (2 degrees) .

Table 4

Climate Damages ($ Billions CAD, 2020 values)

Year	2°C (Base)	3°C	4°C	5°C	3°C - Base	4°C - Base	5°C - Base
2015	16.073	16.073	16.073	16.073	0.000	0.000	0.000
2020	13.404	14.316	15.454	16.189	0.912	2.050	2.785
2025	11.040	12.433	14.180	15.310	1.393	3.141	4.270
2030	9.025	10.603	12.603	13.896	1.578	3.578	4.871
2035	7.361	8.942	10.969	12.282	1.581	3.609	4.922
2040	6.021	7.506	9.438	10.689	1.485	3.417	4.668
2045	4.966	6.312	8.090	9.241	1.346	3.125	4.275
2050	4.145	5.345	6.954	7.993	1.200	2.809	3.848
2055	3.508	4.572	6.017	6.947	1.064	2.509	3.439
2060	3.008	3.954	5.249	6.078	0.946	2.241	3.070
2065	2.607	3.452	4.611	5.350	0.845	2.004	2.743
2070	2.277	3.033	4.071	4.728	0.756	1.794	2.452
2075	1.996	2.674	3.602	4.185	0.678	1.605	2.189
2080	1.753	2.360	3.186	3.702	0.607	1.432	1.949
2085	1.539	2.081	2.812	3.266	0.541	1.273	1.727
2090	1.349	1.829	2.474	2.871	0.480	1.125	1.522
2095	1.179	1.603	2.167	2.513	0.424	0.988	1.334
2100	1.027	1.399	1.890	2.188	0.372	0.863	1.161
Total	**426.385**	**507.238**	**613.760**	**681.933**	**80.853**	**187.375**	**255.548**

Notes: This table presents the value of capital output lost due to climate change over the time period 2015 to 2100 in 2020 billions $ CAD. Our DICE model uses the equation: $Damage\ cofficent\ on\ temperature^2 * (World\ Atmospheric\ Temperature)^{exponent\ on\ damages}$ to determine the fraction of damages of gross output. The DICE model then multiplies this by the total capital output to get the value of climate damages. Columns 2-5 present the climate damage for each year. Columns 6-8 show the differences in climate damages for each global temperature increase (3,4, or 5 degrees) compared to the base model (2 degrees).

Table 5

Comparison of the Present Value of Required Investments versus Projected Climate Damages

(billions CAD)

Year	*CMP Investment*	*CMP Investment to 2053*	*2°C Climate Damages*	*5°C Climate Damages*	*Difference between 5°C- 2°C*
2020	12.80	12.80	13.40	16.19	2.78
2025	9.76	9.76	11.04	15.31	4.27
2030	7.44	7.44	9.03	13.90	4.87
2035	5.67	5.67	7.36	12.28	4.92
2040	4.32	4.32	6.02	10.69	4.67
2045	3.29	3.29	4.97	9.24	4.28
2050	2.51	2.51	4.14	7.99	3.85
2055	1.91		3.51	6.95	3.44
2060	1.46		3.01	6.08	3.07
2065	1.11		2.61	5.35	2.74
2070	0.85		2.28	4.73	2.45
2075	0.65		2.00	4.19	2.19
2080	0.49		1.75	3.70	1.95
2085	0.38		1.54	3.27	1.73
2090	0.29		1.35	2.87	1.52
2095	0.22		1.18	2.51	1.33
2100	0.17		1.03	2.19	1.16
Total	**239.21**	**203.96**	**351.50**	**600.83**	**249.33**

Notes: This table shows the present value of required annual investment amounts according to the CMP (2020) and projected climate damages, with all amounts discounted at an annual rate of 5.58%. The last row for each column indicates the total present value in today's CAD amounts.

APPENDIX

Canadian Macroeconomic Variables

Equation 4 requires a variety of Canadian macroeconomic inputs. The determination of variables such as Total Factor Productivity and Capital, as well as Gross Investment, to name a few are critical to the accurate calculation of climate damage.

TFP_n is the total factor productivity for the year being examined. The Canadian specific value for total factor productivity used in our calculations is set to the 2015 value, 0.9857 (Feenstra et al., 2021). ga_n is the growth rate of productivity, which is based on the growth and decline rates of technology per half decade. The original DICE model sets the growth (GRT) and decline rate (DRT) for technology per half decade at 0.0760 and 0.0050, we maintain these values in our projections.

$$TFP_n = \frac{TFP_{n-1}}{1-ga_n} \tag{A.1}$$

$$ga_n = e^{(-DRT*5*(n-1)*GRT)} \tag{A.2}$$

K_n is the Canadian capital investment, we follow the EIU (2015) report which uses Financial Stability Bureau (FSB) (2015) reports ratios for manageable assets. In Canada, 66% of the financial assets are considered manageable according to the 2015 FSB report. StatsCanada shows the total value of Canadian financial assets to be $31.5 trillion (CAD) at the end of 2018. We use $20.8 trillion (CAD) as our initial capital, which is 66% of the total value. The capital in a given year is subject to the prior year's capital and the Gross Investment (GI) as well as the depreciation rate (Dp). The depreciation rate is set at .100 in the original DICE model and we maintain this rate for our projections.

$$K_n = K_{n-1} * (1 - Dp)^{Year-(Year-5)} + GI^{Year-(Year-5)} \tag{A.3}$$

Gross Investment is determined by adding the Net Output (NO) and the Savings Rate (SR). Net Output (NO) is "net of abatement and damages", determined by taking Output Gross of Abatement (OAD) costs and climate damage and subtracting both the climate damage and abatement cost. We get the Savings Rate from StatsCan (21.05%) and we maintain this value for all years.

$$GI = SR * NO \tag{A.4}$$

$$NO = OAD - Abatement\ Cost \tag{A.5}$$

$$OAD = Output - Climate\ Damage \tag{A.6}$$

Abatement Cost is a function of the Abatement Cost Function Coefficient (ACF), the Emissions Control Rate (ECR), and the Exponent of Control Cost Function (ECC). The ECC is set at 2.600 by the DICE model.

$$Abatement\ Cost = ACF * ECR^{ECC} * 1^{1-ECC} \tag{A.7}$$

The ACF is a function of the Backstop Carbon Price, the sigma industrial (σ_n), and the Emissions Control Cost Function. The sigma is calculated every 5 years, using a growth rate and applying it to the period before. The DICE model sets the growth rate at -0.015. The sigma value is meant to represent the energy cost at the industrial level. In a more intuitive context, as technology and industry becomes more efficient, this value should decrease and the abatement cost should also decline.

$$ACF = BSP * \frac{\sigma_n}{\frac{ECC}{1000}} \quad (A.8)$$

$$\sigma_n = \sigma_{n-1}\wedge\left(GRS * \left(n - (n-5)\right)\right) \quad (A.9)$$

The ECR is set as the minimum (MIN) function of Carbon price (per ton of CO2, plus hotelling rent), the backstop price of CO2 (BSP) (in $1000 per ton), and the ECC. The backstop price is set by the DICE model and a decline rate of 0.025 is applied per half decade. The carbon price per tonne of CO2 is set within the DICE model.

$$ECR = MIN\left(\left(\frac{CP}{BSP}\right)^{\frac{1}{ECC}-1}, 1\right) \quad (A.10)$$

POP_n is the population each year from 2015 to 2100 in 5 year increments. We use the 2015 Canadian population (35.7 million, StatsCan (2015)) as our starting population and calibrate the DICE models population growth formula to match the Century Initiative (2020) data, which projects that the Canadian population will expand to 100 million by 2100. The Canadian population projection is used to calculate the output of Canada’s economy, as well as its climate damages, while the world population present in the original DICE model is used to calculate the world’s carbon production and intensity as well as the global temperature increase. Through this, we are examining the effect that the world’s warming has on Canada’s economy.

$$POP_n = POP_{n-1} * \left(\frac{Asymptotic}{POP_{n-1}}\right) * parameter_{2050} \quad (A.11)$$

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[i] OSFI (2020), “Bank of Canada and OSFI launch pilot project on climate risk scenarios,” https://www.osfi-bsif.gc.ca/Eng/osfi-bsif/med/Pages/20201116-nr.aspx.