

Climate Denial and the Costs of Optimal Climate Change Policy

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1. Introduction

Global warming is a negative externality, imposing the cost of climate damage on society. Uncorrected, this externality will have numerous negative consequences for future generations, such as sea level rise, increased drought, and increased frequency of severe weather events. Among the main contributors to global warming is carbon dioxide (CO₂), for which there is no private sector market price. Agents emit as if the marginal social cost of CO₂ emissions is zero, and the externality is imposed on society. Providing agents with the proper price signal, will lead them to internalize the cost of emissions. With the cost of emissions internalized, and thus incorporated into the return to capital, agents will allocate resources efficiently.

When the externality is treated as external, an agent making investment decisions does not account for the societal cost of his emissions. The returns to conventional capital investments are overstated because the damages to future productivity from capital accumulation are ignored. Agents believe that individual emissions have no effect on global warming. Thus, they overinvest in conventional capital, and under-invest in climate capital (mitigation). If agents were receiving the correct price signal, the social cost of emissions would be implicitly included in the inter-temporal maximization problem.

The result of receiving the correct price signal is that agents are able to internalize the externality. This directly alters the agent's optimal allocation of resources. Internalization of the costs of emission induces a shift in investment expenditure towards mitigation. The agent is now aware of the deleterious effects of over accumulating capital stock on the path of global warming. Returns to mitigation will be higher than investing in traditional capital stock, and so the agent will choose an efficient mix of mitigation, investment, and consumption. There may even be extra output not used for investment, which can instead be consumed. In this way, it may be possible to increase the consumption of all generations by inducing agents to internalize the costs of carbon emissions.

The amount of resources the current generation should devote to averting climate change has been under intense scrutiny. Rezai (2011) noted that much of the climate-economy modelling literature shows an intergenerational sacrifice must be made in order to implement effective climate policy. Current generations must be willing to sacrifice consumption in order to invest in mitigating the effects of climate change. While it is true current generations must invest in mitigation in order to avert climate change, Rezai (2011) showed that reducing consumption in order to do so may not be necessary. Contrary to much of the past literature, when the baseline scenario is modelled correctly, costs for the current generation may be negligible, and there may actually be benefits for all generations.

Modelling the path of the economy and global climate in Integrated Assessment Models (IAM's) involves designing scenarios, which mimic the real world as closely as possible. These scenarios will always be a simplified version of the real world, but they help to shed light on different policy options. In particular, IAM's allow us to examine the costs and benefits from climate policy. Results from high-profile IAM's such as Nordhaus's DICE Model (2008) show an intergenerational sacrifice must be made when implementing optimal policy. This is largely due to the poor specification of a baseline scenario.¹ To reconcile these inconsistencies, Rezai (2011) built upon and challenged previous modelling efforts, showing that the choice of baseline has a large impact on the intergenerational aspects of climate policy. He argued that the Constrained Optimal (COPT) baseline path used in earlier analysis is unrealistic and theoretically inconsistent. To reconcile these theoretical weaknesses, he proposed a new baseline he calls Business as Usual (BAU).

BAU as proposed by Rezai (2011) consists of a representative agent who is aware climate change is occurring, but views his individual contribution as negligible. The time path of aggregate emissions is correctly anticipated, while production related emissions are treated as inconsequential. The agent perceives a

¹ In the 2013 version of DICE, the model is solved without damages, and then the planner's choices are carried over to a second maximization where damages are present. This is similar to the procedure used in past versions of DICE.

zero marginal cost of emissions, and so the return to capital is thought to be higher than it actually is.

While this has the desirable property of keeping the externality external, it does not provide an explanation as to why the agent ignores individual emissions. In a purely mathematical sense it is because costs of emission are not incorporated into the agents' problem. This a mechanical choice, based on the underlying model structure, but it goes against the notion of "common sense". BAU provides a mathematical method for consistently estimating the current state of affairs, but it relies on assumptions that are not entirely realistic. I argue that if agents are aware of the damages caused by carbon emissions, it is not rational for them to assume no part in creating those damages.

Exactly why agents ignore damages is puzzling, but perhaps there is a free-rider incentive. It could be the case that the choice of climate policy can be represented by the classic prisoners dilemma. Everyone could be made better off by cooperation, and from the model specification the agents know this.² However, it is still a valid strategy for any individual agent to free ride, and enjoy the costless benefits resulting from mitigation performed by other agents. If it is a dominant strategy for one agent, the same applies to the others, and so the cooperative outcome will never arise.

Although free riding is a possible explanation, it is not perfect, as it relies on agents failing to communicate to explain the lack of cooperation in mitigation. All agents know that working together to reduce emission will yield benefits for everyone. They also know that every other agent faces the same incentive to free ride. However, if everyone chooses the free rider path, there is no longer any incentive to free ride, because the benefits of other agents mitigation are non-existent. If only there was communication among agents, the cooperative outcome would be within grasp. It is because of this that using free riding as an explanation for the results of BAU is unsatisfactory. A rational agent would certainly find a way

² In BAU, using the FOC method, the agent is fully aware of the time path of aggregate emissions, and the effects those emissions have on the environment.

to communicate with the others, and work together to reach the cooperative outcome.

Explaining the BAU outcome using a free rider argument is not appropriate, so perhaps other lines of reasoning should be explored. It could be the case that agents simply do not believe that climate change is occurring. This would explain the non-cooperative outcome seen in BAU, as agents would not communicate to solve a problem they do not think exists. If agents truly do not believe they have any effect on the outcome of climate change, they are in “climate denial” (CD). Climate denial is the alternative baseline I propose to analyze the costs of climate policy

When an agent is in climate denial, he sees only the costs associated with mitigation, while believing there are no benefits. Thus, the damage function does not update the level of damages as the atmospheric temperature increases. The perceived return to capital in this scenario is much above the actual level, and agents plan to accumulate a very large stock of capital. This results in higher long-run consumption and output than optimal.³ When using CD as a baseline, the climate sacrifice is present in every period after the first; where consumption is marginally below that seen in OPT.⁴

The remainder of this paper is structured as follows: Section 2 details the theoretical differences between the modelling scenarios mentioned above. Sections 3 and 4 present the structure of the model, and the results of the simulations, respectively. Section 5 compares those results to that of Rezai (2011), and Rezai et al. (2012). Section 6 proposes a new procedure for estimating the climate denial scenario. Some concluding remarks are provided in Section 7.

³ These are the findings from an open-loop solution, where future decisions are made in the first period and are not revised.

⁴ Consumption under Optimal Policy (OPT) is 0.2% higher than CD in the first period. Exactly why this occurs is explored in Section 5.

2. Modelling Scenarios

The results from Rezai (2011) reveal the following relationships between the different policy scenarios.

Optimal Policy (OPT)

The Optimal Policy scenario can be viewed as one in which the social planner has all the necessary information to implement an efficient allocation of resources. He is aware climate change is occurring, and he has a mitigation instrument available to him. The correct price signal indicating the true cost of emissions is received, which allows the planner to make an optimal decision regarding investment in physical capital and mitigation. Since the planner has the correct price signal and mitigation instrument available, the externality is completely internalized, and corrected for.

Constrained Optimal (COPT)

Under the constrained optimal scenario, agents face the same set of information as in the OPT scenario. They correctly predict the time path of emissions, and are aware of their contribution to emissions. COPT differs from OPT in one key aspect; the mitigation instrument is not made available. If it were available, agents would invest in mitigation, but its level is exogenously constrained to be equal to zero.

In this scenario the externality has been partially internalized. Thus, the agent makes his investment decisions taking into account the private and social costs of emissions, but cannot choose positive levels of mitigation. Lower levels of investment in conventional capital are chosen, relative to BAU and OPT, as the agent is aware of the effects conventional capital accumulation has on future productivity. The agents' choice of consumption in the initial periods is higher because less investment in capital is undertaken. The climate sacrifice applies. Thirty years into

the horizon, due to the decrease in capital stock and damages to the climate, consumption in COPT falls below OPT levels indefinitely.

Business as Usual (BAU)

Under BAU, agents are aware of climate change, but do not believe they are affecting the outcome; the agent is able to correctly identify the time path of emissions but denies any individual contribution to those emissions. In this scenario, the externality is treated as external. The agent miscalculates the return on conventional capital, as they fail to account for damages to future productivity resulting from climate change. They overinvest in conventional capital and underinvest in climate capital. Consumption is initially lower than in OPT because agents are investing a larger portion of net output in the capital stock. However, consumption grows rapidly due to excess capital accumulation, and exceeds consumption in OPT for a short time. This is short lived, as massive damages from the rapid accumulation of capital without mitigation, reduce usable output and consumption in BAU. If the optimal policy were in place to correct the return on conventional capital, agents would shift expenditure from investment in conventional capital, to mitigation and consumption.

Climate Denial (CD)

The definition of BAU above attempts to capture features of the real world, but gives agents more credit than they deserve. If an agent were able to correctly anticipate the time path of emissions, then why would they invest zero in mitigation? If the agent can correctly identify the time path of emissions, then it is not reasonable to expect them to invest nothing in mitigation. Correctly identifying the time path of emissions mean that they are able to track their own emission as well as all other agents, which would logically result in mitigation, if the instrument were available.

It is possible there is a free-rider effect, in that, every agent is waiting for someone else to start reducing emissions. When nobody is mitigating, there is no

incentive for any agents to do so, because an individual contribution to climate change is very small. Since everyone is waiting on the other agents to move first, no mitigation ever actually happens. As discussed above, this view is not appropriate, due to the assumptions about how agents make their decisions.

In order to offer an alternative explanation of observed behaviour, I propose a baseline in which agents deny the existence of climate change. The agent not only denies their individual contribution to climate change, but also that climate change is even occurring. This results in the externality being kept external, as well as justifying the zero mitigation seen in the BAU baseline. Section 3.3 details the differences between the model structure in BAU and CD.

3. Model

3.1 Structural Equations

I present a model based on Nordhaus's DICE Model, borrowing components from both the 1994 and 2013 versions. The problem is solved for 60, 5-year periods, for a total horizon of 300 years, starting in 2010. The structural equations of the model are as follows:

Gross output in any period, t , is given by the familiar Cobb-Douglas production function;

$$Q_t = A_t(K_t^\alpha L_t^{1-\alpha}) \tag{1}$$

where A_t is the exogenous level of total factor productivity, K_t is capital, and L_t is labour. Both A_t and L_t exhibit exogenous growth as defined in Nordhaus and Sztorc (2013). Growth is assumed to be exponential but at a diminishing rate.

Capital evolves according to the Ramsey structure:

$$K_{t+1} = (1 - \delta)\Delta K_t + I_t \quad (P_t^K) \quad (2)$$

where K_t is the capital stock, δ is the yearly depreciation rate, Δ is the period duration (five years in the present model), I_t is investment in physical capital, and P_t^K is the shadow value of capital.⁵

The model is subject to the budget constraint:

$$Y_t = C_t + I_t \quad (P_t^Y) \quad (3)$$

where Y_t is net output, C_t is consumption, and I_t is investment.

Net output is given by:

$$Y_t = Q_t DAM_t \quad (P_t^Y) \quad (4)$$

DAM_t is damages at time t . It includes reductions in gross output from costs related to emissions reductions, as well as damages due to an increase in the temperature of the atmosphere, TAT_t . DAM_t is given by;

$$DAM_t = \left[1 - \beta_1 MIU_t^{\beta_2} \right] / [1 + (\beta_3/9)(TAT_t^2)] \quad (P_t^{DAM}) \quad (5)$$

where MIU_t is the fraction of emissions abated through “end of pipe” methods⁶, and β_1 , β_2 , and β_3 are parameters (listed in Table 1).

⁵ The variable in brackets after an equation is its corresponding shadow value.

⁶ There is no functional specification for mitigation, it is assumed to happen “at the tail pipe”, or perhaps through alternative fuel/energy.

The model follows the climate sector specifications as laid out in DICE 2013. Carbon moves through three reservoirs: the atmosphere, the upper ocean and biosphere, and the lower ocean. The mass of carbon in the atmosphere, the upper ocean and biosphere, and the lower ocean are given by MAT_t , MU_t , and ML_t , respectively. The amount of carbon in the atmosphere, MAT_t , drives a radiative forcing equation, $FORC_t$, which in turn affects the change in the average atmospheric temperature, TAT_t .⁷ The change in atmospheric temperature shares a relationship with the temperature change of the lower oceans, TLO_t . The relationships between these variables are defined by the following equations:

$$MAT_{t+1} = E_t + \theta_{11}MAT_t + \theta_{21}MU_t \quad (P_t^{MAT}) \quad (7)$$

$$MU_{t+1} = \theta_{12}MAT_t + \theta_{22}MU_t + \theta_{32}ML_t \quad (P_t^{MU}) \quad (8)$$

$$ML_t = \theta_{23}MU_{t-1} + \theta_{33}ML_{t-1} \quad (P_t^{ML}) \quad (9)$$

$$F_t = \eta \left[\frac{\log MAT_t}{588} \right] / \log(2) + FX_t \quad (P_t^{FORC}) \quad (10)$$

$$TAT_t = TAT_{t-1} + C_1 \left[F_t - \frac{\eta}{\gamma} TAT_{t-1} - C_3 (TAT_{t-1} - TLO_{t-1}) \right] \quad (P_t^{TAT}) \quad (11)$$

$$TLO_t = TLO_{t-1} + C_4 [TAT_{t-1} - TLO_{t-1}] \quad (P_t^{TLO}) \quad (12)$$

FX_t is exogenous forcing from other GHG's, aerosols, ozone, and albedo changes. E_t is total emissions, which is the sum of industrial emissions, $EIND_t$, and exogenous emissions resulting from deforestation, DEF_t .

$$E_t = EIND_t + DEF_t \quad (P_t^E) \quad (13)$$

⁷ Measured as the total increase in the average atmospheric temperature since 1900 (deg. C)

$$EIND_t = \sigma_t Q_t (1 - MIU_t) \quad (14)$$

where σ_t is a declining value that represents exogenous improvements in energy efficiency.

The representative agent's preferences are defined by a constant elasticity of substitution (CES) function where utility is derived from per capita consumption:

$$U(C_t/L_t) = (C_t/L_t)^{1-\varepsilon} / 1 - \varepsilon \quad (15)$$

Period utility is aggregated across time to form a social welfare function:

$$W = \sum_{t=1}^T \frac{L_t U(C_t/L_t)}{(1+\rho)^{\Delta(t-1)}} \quad (16)$$

3.2 First Order Conditions (Behavioural Equations)

In order to properly model the BAU and climate denial scenarios, the first order condition method, as laid out by Shiell and Lyssenko (2014) and Gerlagh (2008), is implemented. First, the structural equations from the social planner's problem are used in the construction of a typical Lagrange constrained optimization problem. Then the first order conditions (FOC's), also called behavioural equations, are obtained, and are as follows;

$$P_t^K = P_t^Y \quad \forall t \leq T - 1 \quad ^8 \quad (17)$$

$$P_t^K \leq P_t^Y \quad \forall t = T \quad (18)$$

$$P_t^C = P_t^Y \quad (19)$$

⁸ T is the terminal period.

$$P_t^{DAM} = P_t^Y Q_t (1 - MIU_t) \quad (20)$$

$$P_{t+1}^{FORC} = C_1 P_t^{TAT} \quad (21)$$

$$P_t^E = C_2 P_t^{MAT} \quad (22)$$

$$P_t^Y = \left(\frac{1000C_t}{L_t}\right)^{-\alpha} / (1 + \rho)^{\Delta(t-1)} \quad (23)$$

$$P_{t+1}^{MAT} \theta_{11} = P_t^{MAT} - P_{t+1}^{MU} \theta_{12} - P_t^{TATM} C_1 \left[\left(\frac{\eta}{\log(2)}\right) / MAT_t \right] \quad (24)$$

$$P_{t+1}^{ML} \theta_{33} = P_t^{ML} - P_{t+1}^{MU} \theta_{32} \quad (25)$$

$$P_{t+1}^{MU} \theta_{22} = P_t^{MU} - P_{t+1}^{MAT} \theta_{21} - P_{t+1}^{ML} \theta_{23} \quad (26)$$

$$P_{t+1}^K (1 - \delta) = P_t^K - P_t^Y \alpha A_t (K_t^{\alpha-1} L_t^{1-\alpha}) DAM_t \\ - P_t^{MAT} C_2 \sigma_t (\alpha A_t (K_t^{\alpha-1} L_t^{1-\alpha}) (1 - MIU_t)) \quad (27)$$

$$P_{t+1}^{TAT} \left(1 - \frac{C_1 \eta}{\gamma} - C_1 C_3 \right) = P_t^{TATM} - P_{t+1}^{TLO} C_4 \\ - P_t^Y Q_t \left[1 - \beta_1 MIU_t^{\beta_2} \right] \left[\left(\frac{\beta_3}{4.5}\right) TAT_t \right] / [1 + (\beta_3/9)(TAT_t^2)] \quad (28)$$

$$P_{t+1}^{TLO} (1 - C_4) = P_t^{TLO} - P_{t+1}^{TAT} C_1 C_3 \quad (29)$$

$$P_t^{DAM} \beta_1 \beta_2 MIU_t^{\beta_2-1} = P_t^E \sigma_t A_t (K_t^\alpha L_t^{1-\alpha}) \quad (30)$$

$$P_T^K K_T = P_T^{MAT} MAT_T = P_T^{MU} MU_T = P_T^{ML} ML_T = P_T^{TAT} TAT_T = P_T^{TLO} TLO_T = 0 \quad (31)$$

3.3 Model Scenarios and the FOC's

In the optimal and constrained optimal scenarios, all of the FOC's are included in the optimization. The social planner has all the necessary information to choose the best combination of emissions reductions and investment in order to maximize consumption and minimize climate related damages. I make no distinction as to how the social planner receives the true price of emissions. It could be a carbon tax or quantitative limit as in Weitzman (1974), or a cap and trade system as in Stavins (2008).

The model structure for COPT is identical to OPT, but the agent faces the exogenous constraint that MIU_t is equal to zero in all periods. The agent would choose positive levels of mitigation, he has all the information the planner in OPT does, but he is bound by the zero emissions reductions constraint. This scenario is not realistic but is included as a reference point for comparison with other studies.

Consistent with the current state of affairs, BAU agents incorrectly perceive the price of emissions to be zero. In this model, because the agent believes there is no cost to emit, the shadow values for climate variables are zero. This results in the agent facing all the structural equations (1)-(16), but only equations (17)-(19), (23), and (27) from the first order conditions. In fact, equation (27) is modified from OPT to reflect the zero shadow value for MAT_t .

It is now;

$$P_{t+1}^K(1 - \delta) = P_t^K - P_t^Y \alpha A_t (K_t^{\alpha-1} L_t^{1-\alpha}) DAM_t \quad (32)$$

Due to the fact that agents feel their emissions have no impact on the outcome of climate change, their optimal choice of mitigation is zero in every period. Output is damaged only by the increase in atmospheric temperature; damages related to mitigation costs are zero. The new damage function in the FOC's for BAU is;

$$DAM_t = [1]/[1 + (\beta_3/9)(TAT_t^2)] \quad (33)$$

Agents who are in climate denial face the same set of constraints from BAU, with one additional wrinkle. In both BAU and CD the damaging effects from increases in TAT_t are incorporated into the shadow value for capital. In BAU, TAT_t moves freely and the value from an additional unit of capital reflects the change in TAT_t .

However, when an agent is in climate denial, he assumes there will be no change in atmospheric temperature, it is assumed to be the same for all periods going forward. TAT_t is exogenously constrained to be equal to its initial value for all periods. Not only does the agent deny any contribution to climate change, he denies its existence entirely. Thus, the agent misjudges the value of capital and in the long run over accumulates capital relative to BAU. The damage function in the FOC's and the structural equations for CD is;

$$DAM_t = [1]/[1 + (\beta_3/9)(TAT_1^2)] \quad (34)$$

3.4 Parameters and Initial Values

All parameters and initial values were taken from Nordhaus's DICE Model. The climate parameters came from the 2013 version, while the damage functions and associated parameters are from the 1994 version. A list of important parameters can be seen in Table 1.

4. Results

Following Shiell and Lyssenko (2014), the equations listed above are solved for a finite time horizon using the optimization software GAMS.⁹ The number of five-year periods is 60, for a total horizon length of 300 years. Time paths of important

⁹ CONOPT 3 is the solution algorithm used here.

economic and climate variables are presented now, with further examination of the solution in specific time periods to follow.

The time path of per capita consumption and net output under the four scenarios can be seen in Figure 1 and Figure 2, respectively. The time paths of consumption in the COPT and OPT paths are similar up until 2060, at which point the lack of mitigation in COPT reduces the amount of output available, and consumption suffers for the rest of the horizon. Output in CD is much higher than in BAU for all periods but the first. Consumption in CD is also higher, except for the first two periods.¹⁰ This can be explained by Figure 3, which plots the path of the capital stock in the four scenarios. The capital stock is larger in all periods in CD, and this translates into higher output and consumption in the long run. The average change in atmospheric temperature can be seen in Figure 4. CD is omitted from this chart because agents believe there is no climate change, and so they act as if TAT_t is fixed. TAT_t can be tracked in the background, but it is clear that the CD path results in a higher change in temperature than any other scenario, due to the larger capital stock. Interestingly, the average atmospheric temperature change is higher in COPT than BAU.

The focus of this paper is on the intergenerational effects of implementing optimal climate policy. Figure 5 plots consumption in COPT, BAU, and CD relative to the OPT path for the first 150 years.

According to Rezai (2011), the main problem with previous modelling efforts is the use of an inconsistent baseline-COPT. Use of the COPT scenario as a baseline to judge the costs of optimal policy shows a significant climate sacrifice in early periods that in fact may be negligible or non-existent. From Figure 5, it is easy to see that those results are confirmed in this model. Consumption in COPT is slightly above OPT levels for the first 50 years, at which point the smaller stock of capital in COPT reduces output and consumption relative to OPT. In the initial periods of the model, COPT agents are underinvesting in capital relative to OPT. This is because the only course of action to avert the eventual damage from accumulation of GHG's

¹⁰ This is due to the capital stock being run down as discussed in Section 5.

is to choose a lower level of capital. The externality is internalized, but mitigation is constrained to zero. With the resulting lack of investment, more output is available for consumption, which is seen in Figure 5. Consistent with Rezai (2011), the climate sacrifice applies. Moving to the OPT path would involve a reduction in consumption of 1.8% in the first period, which falls to 0.01% in period 2050. This result is the main argument of climate policy naysayers; i.e. present generations should not have to sacrifice well-being in order to bequeath benefits to future generations.

The results from Rezai (2011) are ground breaking, in that: the argument of a climate sacrifice no longer applies. When the true baseline, BAU, is compared to the optimal path the sacrifice disappears. There are no costs to optimal policy, all generations can benefit from internalization of the externality.

However, when looking at the BAU paths in Figures 1 and 5, it is evident the results obtained here do not coincide with those of Rezai (2011). Period 1 consumption in BAU is 31.7% higher than in the OPT-the sacrifice applies and is considerably larger than in COPT. By the third period, the sacrifice is no longer present, being on the OPT path is much more rewarding. The choice of investment seems to be the reason for increased consumption in the first period of BAU. BAU agents in this model, contrary to theoretical expectations, underinvest in capital relative to OPT, and so the capital stock in the second period falls.

This unexpected result can be explained by the model specifications. Due to the fact that agents in BAU view the problem of climate change as one they have no impact on, they incorrectly assume the shadow values of climate variables to be equal to zero. This has large effects on equation (27), which defines the motion of the shadow value of capital. In BAU, the shadow value of capital is initially low, relative to the other scenarios, due to the fact that climate shadow values are zero.¹¹ This results in higher consumption and lower investment in the first period of the model. Consumption is relatively high because, from equations (17), (19), and (23), it is clear the marginal utility of consumption is equal to P_t^K . Thus, when P_t^K is low,

¹¹ See equation (23). A high C_t translates into a low P_t^Y , which is equal to P_t^K .

consumption must be higher because the marginal utility is low (diminishing marginal utility of consumption).¹²

Due to the lack of investment in period one, the capital stock falls in period two, and consumption suffers because of it. The agent's assessment of the shadow value of capital in the first period causes a re-valuation in the second period, with a higher P_t^K . The combination of lower period two output and a higher P_t^K results in lower consumption and increased investment. However, investment is still very low, because gross output has decreased following the fall in capital after period one. Almost all net output in period two goes to consumption, because of the tendency to smooth consumption. A plot of gross investment can be seen in Figure 6, and net investment can be seen in Figure 7.

It is apparent from these results that the BAU agent perceives a dynamic inefficiency, where the capital stock is initially too large. The solution is to run down the capital stock as seen in the first few periods. Once the capital stock has been adjusted, the agent begins to accumulate capital but at much lower rate than seen in the other scenarios. This adjustment procedure takes some time, due to the agents' consumption smoothing preferences. If it were possible, the BAU agent would immediately reduce the capital stock to the "correct" level, but this would involve a huge drop in period-two consumption not allowed by smoothing preferences.

The shadow value of capital equation will govern the optimal choice of consumption and investment, and since it is incorrect, these choices will not be optimal. The decline in the capital stock during the initial adjustment periods is due to a perceived dynamic inefficiency. By the time the agent eliminates the inefficiency, the capital stock is too low to ever reach levels where output is similar to OPT. Heavily investing in capital at this point is not an option, due to damages from the increase in atmospheric temperature, and consumption smoothing preferences. Instead, the capital stock grows steadily but at a much lower rate than in OPT for the rest of the horizon.

¹² Recall $P_t^K = P_t^Y = \text{Marginal Utility of Consumption}$.

The results from the climate denial simulation are much different than those seen in BAU. The fact that agents choose zero mitigation, and make investment decisions based on constant damage function (34), results in a widely different outcome.

Due to the fact the agent assumes constant damage, the optimal choice of investment is higher than OPT in every period. CD agents fail to account for the damaging effects of a higher capital stock on net output, and so they over accumulate capital. First period investment is higher in CD than in OPT, and so consumption in CD is marginally lower (0.2%). This interesting results means that there are no costs to optimal policy in the first period, when moving from the CD baseline to the OPT scenario. In every subsequent period, consumption is higher in CD due to the larger capital stock. However, it is not appropriate to look past the second period results from CD, as from that point on, the agent is using the wrong damage function. This scenario should only be used as a baseline to compare the initial periods of the model: the open loop solution is not accurate for the entire horizon. In order to assess the results from this scenario in the distant future, a closed-loop solution would have to be employed.¹³

5. Reflections on Rezai

Rezai (2011) used a Ramsey growth model along with the climate sector of DICE 2008 when analyzing the opportunity cost of climate policy. This is a similar approach to the one taken in this paper. As such, I expected the results to be similar, but that is not the case. There are significant costs to climate policy in early periods, according to the results presented above, which are not found by Rezai (2011). The solution method in Rezai (2011) is different than the one used here, but that should not have such significant effects on the overall conclusion. Rezai employs the N-agent approach as developed by Shiell and Lyssenko (2008), while I use the FOC condition approach as in Rezai et al. (2012) and Shiell and Lyssenko (2014).

¹³ This method is discussed in the Section 7.

It is most likely that differences in the solutions are a result of the choice of parameters in DICE 2008. Close inspection of the parameters reveals large changes in the DICE model from 2008-2013, especially in the climate sector. In addition, equation (10) is much different than the forcing equation in Rezai (2011). While the overall model structure is very similar, it is likely these changes to the environmental variables that result in such different solutions.

These are not the only discrepancies I found based on model specification. In Rezai et al. (2012), the first order condition method was applied to a Ramsey growth problem with a simplified climate sector. Comparing these results to those obtained in Rezai (2011), it is clear that the choice of model can have large impacts in the outcome of a simulation. The results from the NA approach used in Rezai (2011) and the FOC approach as in Rezai et al. (2012), are consistent in their evaluations of the BAU and OPT scenarios. The sacrifice no longer applies using the correctly specified BAU. However, the results from the COPT scenario in Rezai et al. (2012) are different than those found using the N-Agent approach. The optimal choice of capital in period two COPT from Rezai et al. (2012), is lower than the initial value of capital stock. Thus, agents immediately reduce the capital stock, as that is their only option to avert climate disaster. This is not consistent with the results from this paper, or the results from Rezai (2011). I found that in COPT, the capital stock continues to grow, but at a lower rate than in OPT.

Clearly, the choice of model and parameters can have large impacts on the outcome of the simulation. Despite using a very similar model, or the same solution method, the BAU results found here do not coincide with Rezai (2011) or Rezai et al. (2011).

6. Modelling Alternatives: The Case of Climate Denial

In this paper, climate denial has been modelled as an open loop simulation in which the agent makes consumption and investment decisions for the entire horizon in the first period. While it is interesting to note the outcome of a model where the agent

solves for all periods with the wrong information, it is not very realistic. In the long run, it would not be rational to use the same damage function over and over again. It would be advantageous for the agent to re-optimize given new information.

Modelling this scenario could be possible using a closed-loop solution, where, when the agent moves forward one period, he realizes he was wrong about the climate outcome. He then uses the new temperature information incorporated into the damage function (34), to re-optimize as if it were period one again. However, he makes the same mistake of assuming the temperature will not change from its new level, and so he misallocates resources again. This process would continue for every period, and, as Yang (2003) demonstrated, would generate the closed loop solution for climate denial.

Although the long-run results would be more relevant using this approach, it is still unrealistic in that, eventually, the agent would certainly realize climate change is occurring. At this point the model structure would change and the economy would be in one of the other scenarios, depending on the assumptions you make about the agents new view of climate change.¹⁴

7. Conclusion

The reality of climate change is one decision makers across the globe are slowly coming to accept. Correcting the externality associated with the emissions needs to be a top priority, or else we will face disastrous consequences in the future. Exactly how to correct the externality has been under debate, but could be through taxation, quantitative limits, a cap and trade system, or a combination of the above options. Regardless of the method, the objective is for agents to internalize the price of emissions, and in turn, allocate resources efficiently. Instead of accumulating capital, agents will invest in mitigation to avert some of the effects of climate change. This

¹⁴ Perhaps they are in OPT with the mitigation instrument available, or COPT without it. They could even be in BAU, as they could perceive a zero price of emissions while acknowledging climate changes existence.

will leave a much better mix of conventional and climate capital for future generations.

While it is desirable to bequeath a moderate climate to future generations, the extent to which current generations should sacrifice consumption to do so is under intense scrutiny. Prior to Rezai (2011), most IAM's showed an intergenerational sacrifice must be made in order to implement efficient climate policy. However, Rezai (2011) showed that when the BAU baseline is properly estimated and used as a consistent reference point, there are no costs to climate policy.

The exact nature of Rezai's BAU leaves something to be desired, as agents are seemingly "too smart". To account for this, I propose a new baseline, climate denial. CD attempts to capture the reality that agents are acting as if climate change is not occurring when making investment decisions. The results from my version of CD are consistent with BAU as in Rezai (2011): there are no costs to optimal policy in the first period, it is, actually a benefit. However, the benefit is extremely small, only 0.2%, and benefits disappear after the first period because investment is higher in CD than OPT. Therefore, agents under the illusion of CD perceive a significant long-run cost to optimal climate policy.

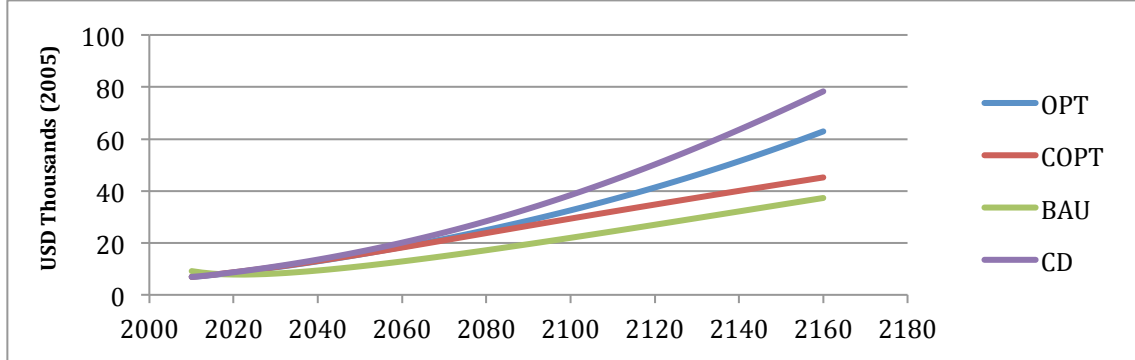
The open-loop version of CD is not relevant past the second period, which is a weakness that could be addressed. Using the closed-loop approach as in Yang (2003) could yield a solution that is more applicable, especially when analyzing long run results. If more time were available, that would be the approach I would use to produce more robust results.

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Table 1: Initial Values and Parameters

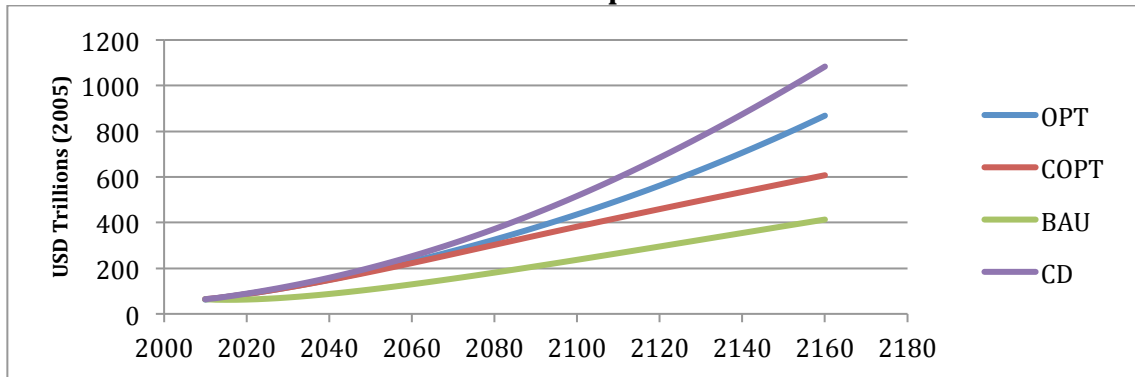
Y_1	63.69 Trillion (2005 USD)	θ_{21}	0.3833
K_1	135 Trillion (2005 USD)	θ_{22}	0.6142
L_1	6838 Million	θ_{23}	0.0025
MAT_1	830.4 GtC	θ_{32}	0.0003375
MU_1	1527 GtC	θ_{33}	0.9996625
ML_1	10010 GtC	η	3.8
TAT_1	0.800 Deg. Celsius	ρ	0.015
$TOCEAN_1$	0.0068 Deg. Celsius	γ	2.9
A_1	3.80	C_1	0.098
α	0.300	C_3	0.088
Δ	5 (Years per period)	C_4	0.025
δ	0.100	β_1	0.0686
θ_{11}	0.9120	β_2	2.887
θ_{12}	0.088	β_3	0.133

Consumption Per Capita

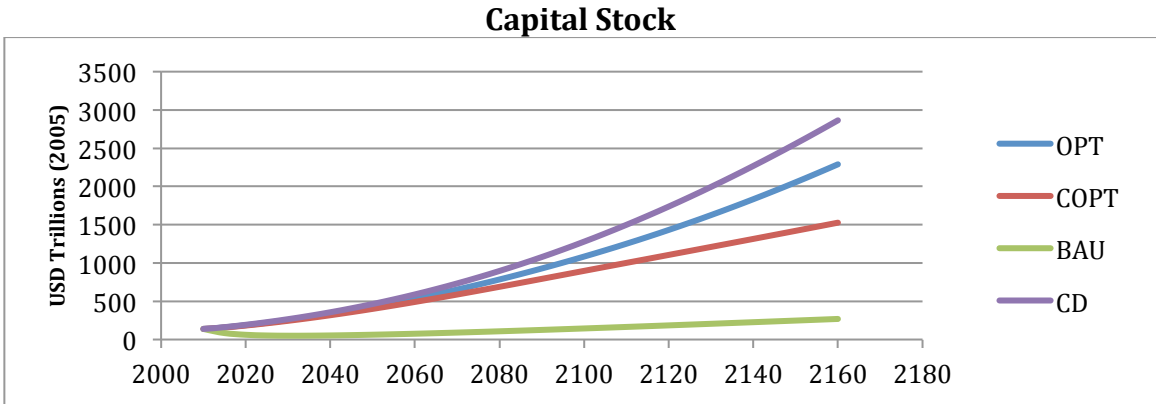


*Figure 1

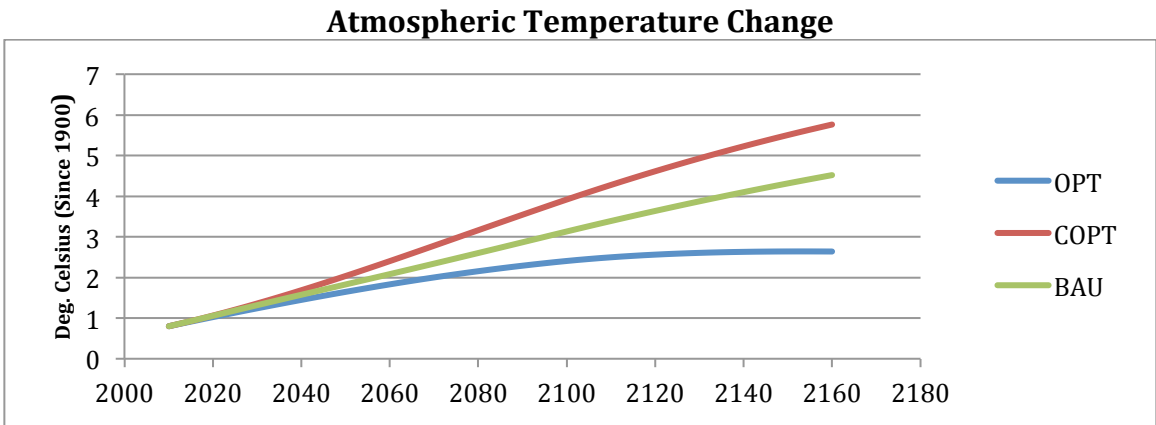
Net Output



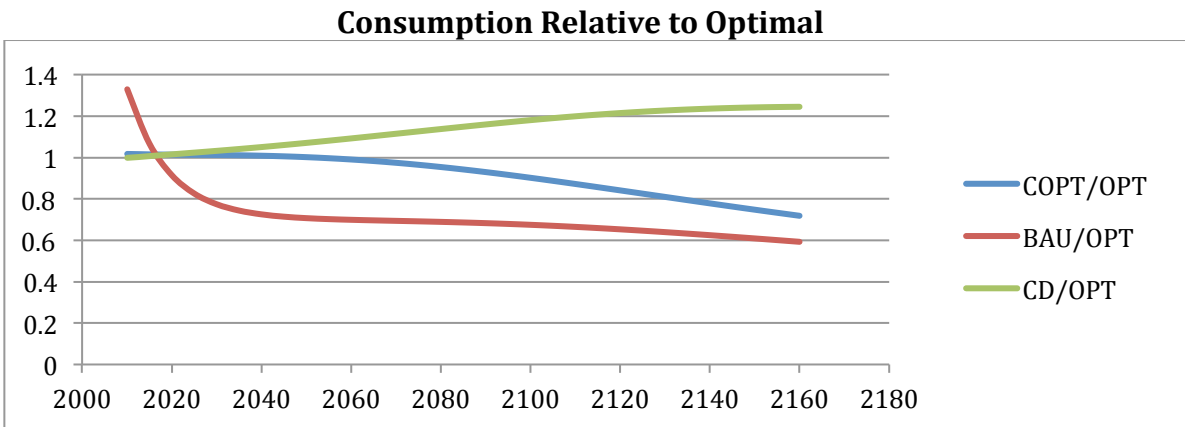
*Figure 2



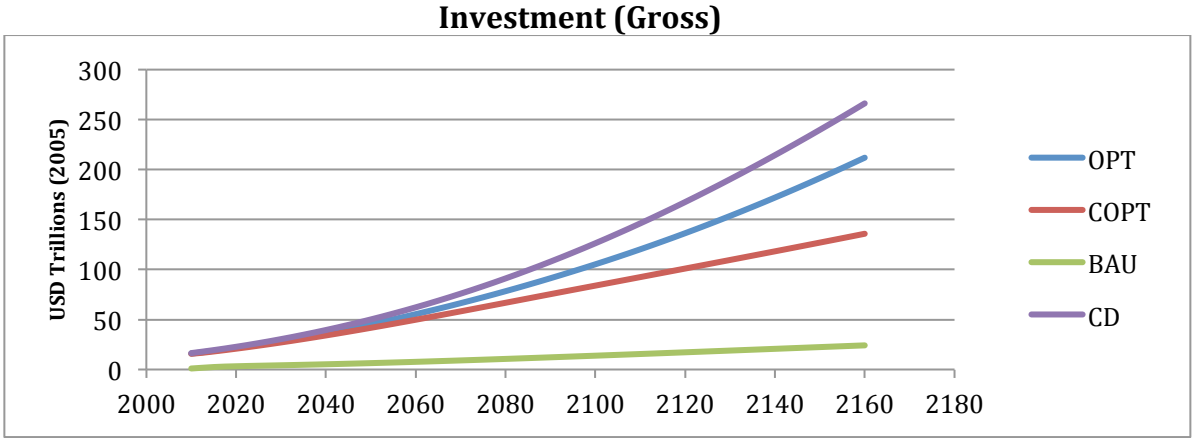
*Figure 3



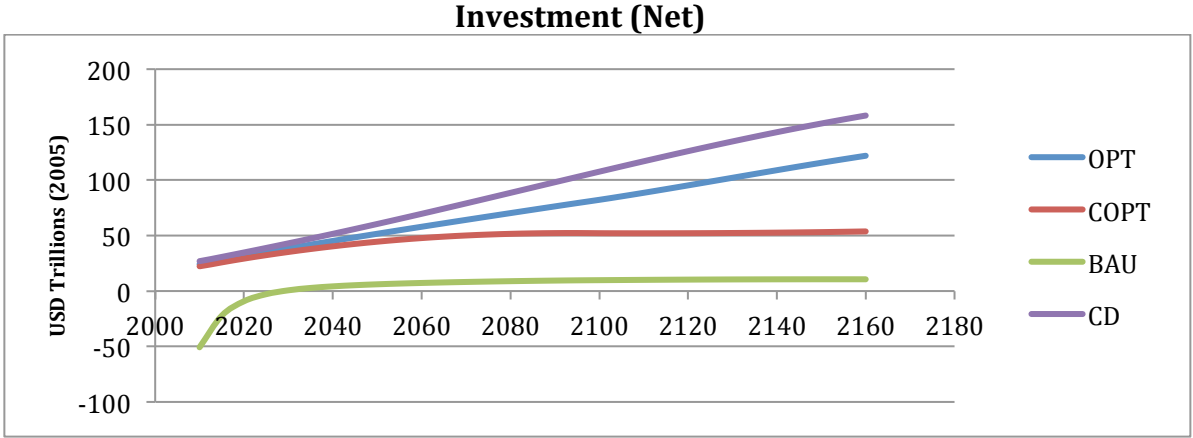
*Figure 4



*Figure 5



*Figure 6



*Figure 7