Investigating the effects of direct productivity damages in MPC-DICE (2969 words)

In this essay I question MPC-DICE's assumption of sustained economic growth by looking at how higher temperatures might affect labour productivity. As DICE has been used to estimate the social cost of carbon (SCC) - "the economic cost caused by an additional ton of carbon dioxide emissions or its equivalent" (Nordhaus, 2014) - the accuracy of its estimates are important for social welfare. I show that even small damages to growth increase the SCC substantially, particularly in early periods.

I will start by outlining the place of growth in MPC-DICE. The model contains two variables for economic output. Gross output is that which would be available if there were no climate change related costs *in that period*, and increases primarily according to an exogenously defined growth path. Net output is the usable portion of gross output remaining after damages and emission abatement costs are accounted for. Since environmental damages only affect output, the losses are static, and have almost no effect on the economic growth rate. This is deliberate, with Nordhaus (2014) stating his assumption of "continued rapid total factor productivity growth over the next century, particularly for developing countries". Total factor productivity (TFP) represents the portion of economic output unexplained by the level of factor inputs. TFP growth occurs due to technological development, institutions, and human capital investment, amongst other things. In MPC-DICE it includes labour productivity, since the model's labour input is global population, which does not vary with worker productivity. It grows according to the following equation:

$$(1) \qquad A(i{+}1) = \frac{A(i)}{1 - g_A \exp(-\delta_A \Delta(i-1))}$$

where $A(i)$ is TFP, g_A the base TFP growth rate, and δ_A the rate at which that growth rate decreases. In the model this translates to an 8.2% increase in TFP during the first five years, with that percentage discounted by approximately 2.6% in each future five year period. As Dietz and Stern (2015) show, growth dominates the effects of the model, making most environmental harms trivial because future generations are assumed to be far wealthier. The problem is corroborated by the assumption that environmental damages are perfectly substitutable with consumption, so that future generations' increased wealth more than compensates for damage caused by extreme rises in temperature.

However, there are reasons to think that economic growth might be affected by climate change. One way is if higher temperatures reduce labour productivity. Two arguments explain how this could occur. Firstly, empirical evidence suggests a direct effect. The International Labour Organisation's 2019 report on the impact of heat stress on labour productivity shows that by 2030, 2.2% of global working hours will be lost to heat stress. Associated losses are projected to reach $2.4 trillion, almost 9x higher than in 1995. These estimates are based on a global temperature rise of 1.5ºC by 2100 - for comparison, MPC-DICE's standard optimisation leads to 1.5ºC being reached in 2035, and a 3.5ºC rise by 2100. Somanathan et al. (2021) suggest an even greater effect. Using micro-data from almost 70,000 Indian manufacturing firms, they find that output value declined by approximately 3% for every degree that temperature rose above average, with worker heat stress explaining this reduction. Furthermore, the estimated effect of heat stress is large enough to account for the entire reduction in manufacturing output during India's hotter years. If temperatures are permanently higher, this implies a lower growth rate. Their results also suggest that the effect on productivity is non-linear and adaptation has been largely non-existent. This agrees with the findings of Burke et al. (2015), who demonstrate that macroeconomic productivity declines strongly at high temperatures, and find "no evidence that experience with high temperatures or technological advances since 1960 have altered the global response".

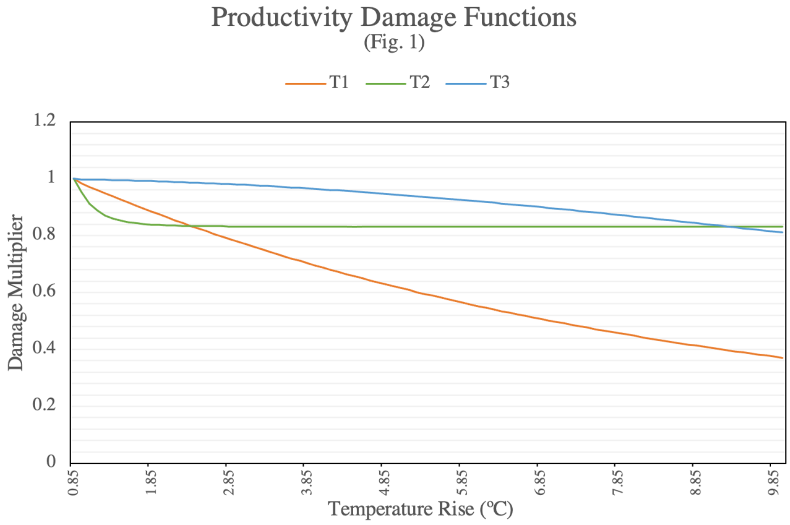
There is also an indirect effect through reduced crop yields. Schlenker and Roberts (2009) find that U.S. crop yields for corn and soybeans, two of the four largest global calorie sources, decline sharply upon reaching the critical threshold temperatures of 29ºC and 30ºC, respectively. They predict a 30-46% decrease in yields under the IPCC fourth assessment report's slowest warming scenario (1.8ºC by 2100), and a 63-82% decrease in yields for the fastest warming scenario (4ºC by 2100). Lobell et al. (2011) look more broadly and observe that a 1°C temperature rise “tends to lower [crop] yields by up to 10% except in high-latitude countries”. Furthermore, these studies do not consider the increased probability of extreme weather events such as floods and droughts, which could further damage crops.

The indirect effect on productivity arises when reduced crop yields lead to undernutrition. The IPCC’s fifth assessment report (2015) cites undernutrition as the biggest health threat associated with climate change. Undernutrition is linked to growth through its effects on the labour force: it reduces energy levels, increases disease, and impairs childhood development. Arcand (2001) estimates that eliminating undernourishment in Sub-Saharan Africa could increase economic growth by 4.63 percentage points. This is an extreme upper bound, but supports the argument that global warming could significantly impact growth. Moreover, even Arcand’s lower estimate of 0.34 percentage points would lead to substantial differences in long term wealth projections. Cole and Neumayer (2006) also find productivity relates to undernutrition, with a 1% increase in undernourishment reducing TFP by approximately 0.2%. If undernourishment increases with temperature, TFP growth could be continuously reduced. The effect is likely to be largest in the developing countries which drive Nordhaus’s assumption of rapid productivity growth, since their climates tend to be hotter and nutritional requirements are met less securely.

Technological developments and adaption may prevent these outcomes from occurring; increasing costs may even drive such innovation. But there are also reasons to think growth will be damaged, and MPC-DICE neglects such considerations.

I therefore alter the TFP equation in order to incorporate temperature related damages to the total factor productivity growth rate, MPC-DICE’s only source of long-term economic growth. I consider three different productivity damage functions $\boldsymbol{\Omega_P(i)}$, shown in Figure 1, which act as multipliers on the TFP growth rate g_A. “$T_{AT}(i)$” refers to atmospheric temperature above the 1900 baseline, and starts at 0.85ºC.

$$(2) \qquad A(i{+}1) = \frac{A(i)}{1 - \boldsymbol{\Omega_P(i)} g_A \exp(-\delta_A \Delta(i-1))}$$



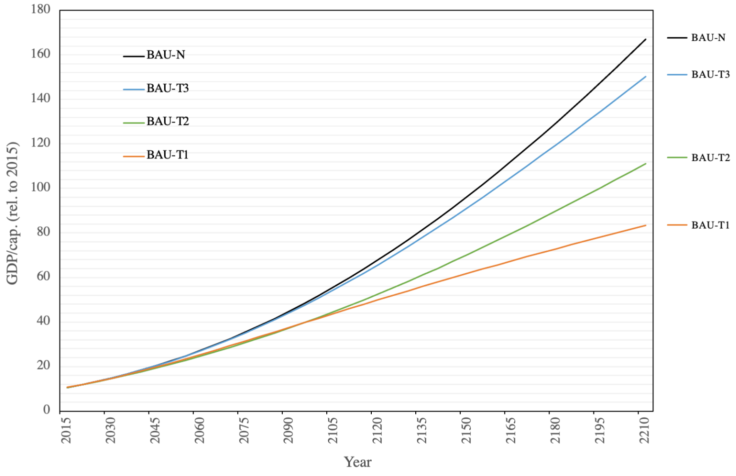
$$T1 : \Omega_P(i) = 1.3^{-\frac{T_{AT}(i)}{2}} + 0.1$$

$$T2 : \Omega_P(i) = \frac{0.1}{T_{AT}(i)^4} + T_{AT}(i)^{0.001} - 0.17$$

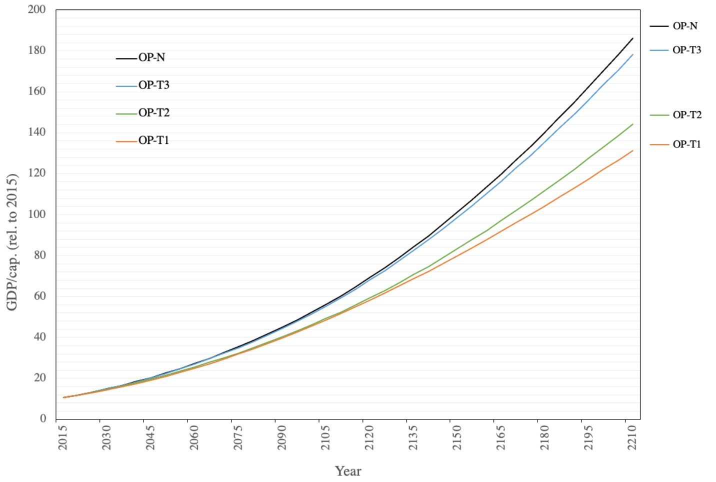
$$T3 : \Omega_P(i) = \frac{1}{1 + 0.00236 T_{AT}(i)^2}$$

Adding the productivity damage functions makes TFP’s growth path depend on atmospheric temperature. As temperature rises, TFP grows less quickly than it otherwise would. T1 represents the possibility that damages to growth will be continuous and considerable, based on the argument that large declines in agricultural productivity lead to increasing food shortages which have compounding effects on all aspects of TFP. In T2, growth is significantly lower than expected in the initial period of warming due to lagged adaptation, but eventually adaptation occurs and damages stop increasing. The dependence on temperature is an imperfect approximation in T2, since adaptation will depend on both the absolute temperature rise *and* how quickly

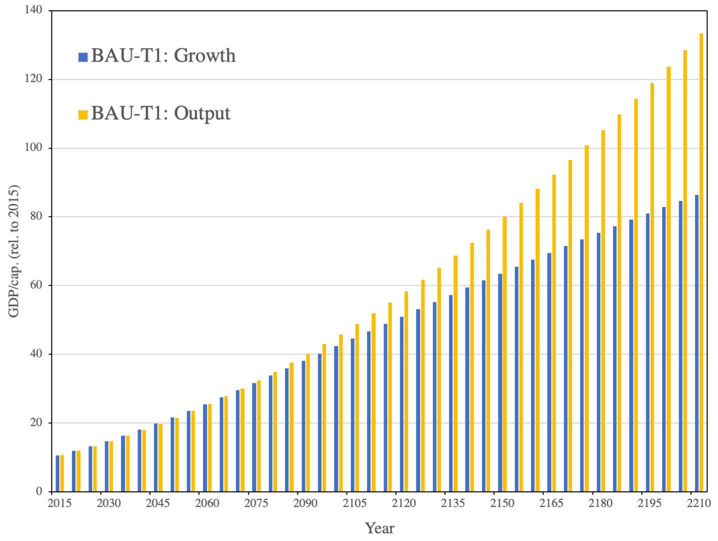
Per capita consumption as a multiple of per capita consumption in 2015, "Business as usual" (Fig. 2)



Per capita consumption as a multiple of per capita consumption in 2015, "Optimal Policy" (Fig. 3)



Per capita consumption when damages are targeted at output versus growth in MPC-DICE (Fig. 4)



that rise occurs, but the effects are very similar because the first 1.5ºC temperature rise in MPC-DICE tends to follow the same time schedule. Finally, T3 is a duplicate of Nordhaus's damage function, used for comparisons with the standard model.

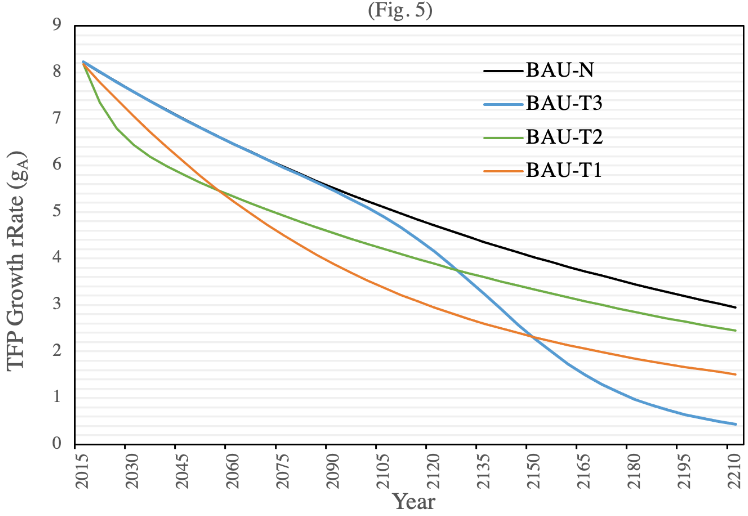
Figure 2 shows how these damages affect per capita consumption under the "business as usual" scenario, where emissions mitigation rate μ is zero (implying no climate policy), and Figure 3 shows the same thing when μ is optimised. "BAU" stands for "business as usual" and "OP" for "optimal policy". T1, T2, and T3 delineate the productivity damage function used, and "N" (Nordhaus) is the standard case without damages to productivity.

Notably, all damages to productivity have a substantial effect on per capita consumption without optimal policy (BAU). The starkest reduction in consumption is unsurprisingly with T1, where damages to growth are the most severe. Two features are of particular importance.

The first is the magnitude of the damages caused by T1. For comparison, Figure 4 shows BAU consumption over time when T1 only damages net output, versus only damaging growth. Consumption per capita is thirteen times higher in 2210 than 2015 when output is damaged compared with eight times higher when only growth is damaged. This is a sizeable difference considering the temperature rise in both scenarios is ≈7ºC, which translates to half of output being lost. Such damages would intuitively be disastrous, yet the effect on welfare is significantly less than when TFP growth is reduced from an average of 1% a year to 0.75% a year - less than the minimum effect of undernourishment estimated by Arcand (2001). The effect of growth is so much larger because damages are permanent and compound over time, whereas damages to output are theoretically reversible with future growth. The problem here is that even extreme environmental damages are overcome by growth in the long run, making MPC-DICE's standard consumption output insensitive to temperature increases.

The second noteworthy feature is that optimal policy has a relatively small effect on T2, where growth suffers mostly in the early periods. This is partly by design - the functional form of T2 ensures there will *not*

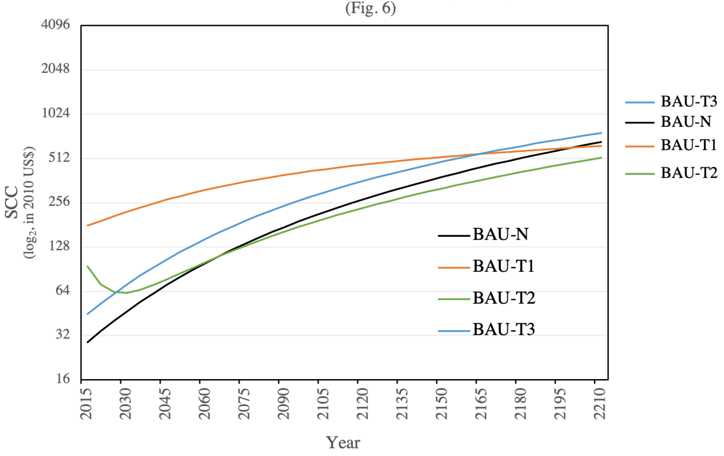
A Comparison of TFP Growth Rates (g_A), "Business as usual" (Fig. 5)



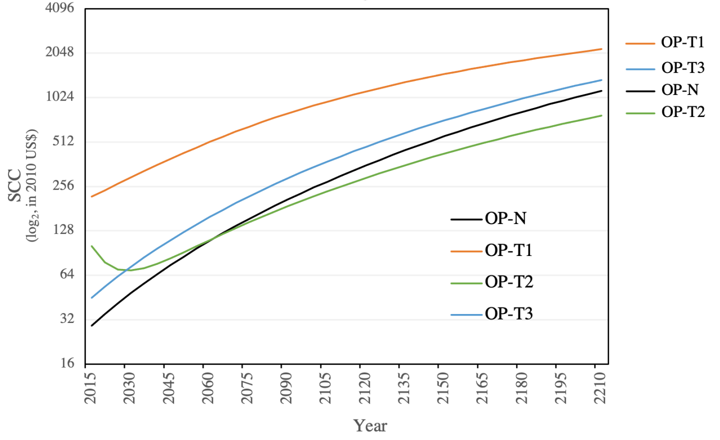
be real-world optimal policy in the initial stage of global warming due to lagged adaptation. However, it also illustrates the cumulative effect of early growth damages on long term wealth. Only after 2110 does BAU-T2 per capita consumption rise above BUA-T1, which has a far more aggressive productivity damage function for all temperatures above ≈1.85ºC. A comparison of "business as usual" TFP growth rates (g_A) is given in Figure 5, showing that BAU-T2 has higher TFP growth than BAU-T1 for all years after 2050. It therefore takes 60 years of high "late" growth to make up for 35 years of low "early" growth of the same magnitude. Consequently, if productivity damages occur primarily in the coming decades when growth is expected to be highest, the effect will be seriously prolonged. Figure 5 also shows why the effects are relatively small for T3: T3's concave shape (Figure 1) means it takes until 2090 for the growth rate to be negatively affected, by which point TFP has already tripled, and lower future growth can build upon this higher base. Thus, T3's effect is comparatively small for the same reason that T2's effect is comparatively large - growth builds over time. This also applies to the optimal policy cases, since higher mitigation can stop late but not early growth damages, explaining why OP-T2 remains far lower than OP-T3.

To show how these changes might affect environmental policy, Figure 6 displays SCC over time under "business as usual" and Figure 7 shows it with optimal policy. A logarithmic scale is chosen to show the relative size of differences over time, and some key results are in Table 1 on the following page.

SCC (in 2010 US$) with different levels of productivity damage, "Business as usual" (Fig. 6)



SCC (in 2010 US$) with different levels of productivity damage, "Optimal Policy" (Fig. 7)



The first thing which stands out is that with T2, SCC is convex rather than concave for the first twenty years. For each of these periods, the most severe damage to growth (the highest δ_A) occurs in the present. If we recall that the SCC represents the present value of all future carbon costs, the decreasing SCC means that the present value of future costs is less than the costs in the current period, so that once the current period passes, the SCC is lower. Once future costs exceed those in the current period, the SCC begins to increase again.

However, the most important observation is that the factor increase in the SCC from 2015 to 2210 is lower whenever growth is damaged, and that the greater the damages to growth, the higher is the present SCC relative to future SCC. The reason for this is Ramsey's discount rule, $r = \rho + \eta g$, where r is the social discount rate, ρ is the

Table 1 SCC with productivity damages

	SCC in 2015 (2010 US$)		*SCC in 2110 (2010 US$)*		*Factor Increase*	
Productivity Damage	*BAU*	*OP*	*BAU*	*OP*	*BAU*	*OP*
None (N)	28.8	29.3	663.2	1140.1	23.0	38.9
T1	179.7	218.9	623.2	2177.5	3.5	9.9
T2	94.6	100.9	518.4	774.2	5.5	7.7
T3	44.9	45.2	761.9	1349.5	17.0	29.9

pure rate of time preference, η is the elasticity of marginal utility of consumption, and g is the economic growth rate. Accordingly, a lower growth rate leads to future costs being discounted less, which explains why damages to growth have a stronger effect on the SCC early on compared with output damages, which tend to increase the SCC by a similar amount in all periods. Therefore, although the SCC is always highest in OP-T1 (compared with the other optimal policy cases), it is *relatively* higher in 2015 versus 2210, and in BAU-T1 the growth rate is so low that by 2210 SCC is actually beneath that of BAU-T3 and BAU-TN, despite emissions continuing to be more damaging.

The main implication of this investigation is that if global warming affects growth, climate policy should be far more stringent in the present day so that growth is preserved for as long as possible. The SCC under optimal policy is higher in the present period for all cases: 1.5x with minimal effects to growth (T3), 3.4x with early damages (T2), and 7.6x with increasing damages (T1). Furthermore, mitigation rates are always higher, leading to lower rises in temperature. If the SCC is equal to the optimal carbon tax, these levels would imply a sharp reevaluation of our approach to climate policy. However, it may be difficult to enforce such rates in practice, particularly when the largest emitters are not likely to be the countries whose growth will be most harmed by rising temperatures. While looking at labour productivity, I argued that the countries whose growth is most at risk are the developing countries which drive Nordhaus's modelling of TFP. Higher average temperatures, larger agricultural sectors, and less nutritional security mean that heat stress and damaged crop yields could have a severe effect on developing countries growth rates. In the worst case scenario there could be a persistent poverty trap like that seen in the world's poorest countries today, where basic needs are so narrowly met that people do not have the means to develop technologies or institutions which could lead to sustained growth. Hence, considerations of productivity add yet another distributive concern regarding the damages caused by climate change. With this in mind, it may be that wealthier nations have a responsibility to take even more action than my estimates for the SCC suggest. My analysis showed that early growth is particularly crucial in the long term. If developing countries have the potential to grow more quickly, and both global warming and a prohibitively high carbon price will limit that growth, then social welfare may be maximised by richer countries reducing their emissions even further to compensate. At any rate, incorporating productivity damages into MPC-DICE suggests the need for a determined global response.

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