# Contents

# Introductory thoughts

- The impact of $CO_2$ on impacts has a much shorter half-life than of $CO_2$ in the atmosphere because of adaptation– but we know exactly how long that timescale is: a Bartlett kernel-weighted 30 years.
- The impact of a step change in temperature produces a short-term effect, in the immediate year, and a long-term effect, 30 years later.
- The damage function we estimate for IAMs should incorporate this transition, both in its estimation and in the information we provide to IAMs.

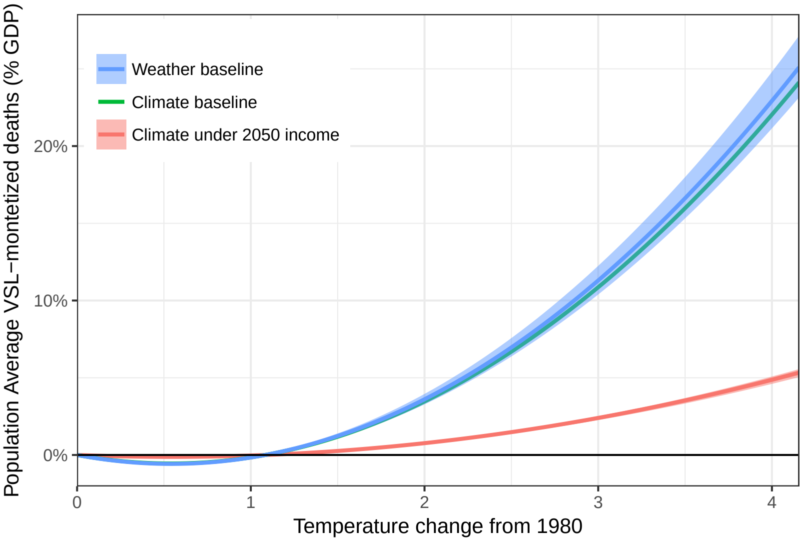
# A model of impacts

Changes in $CO_2$ leads to changes in temperature according to a scientifically assumed transfer function, $p_t = (1 - e^{-t/2.8})e^{-t/400}$: $T_t = C_t * p_t$. (Throughout, $*$ is the convolution operator.)
Assume that impacts are generated by

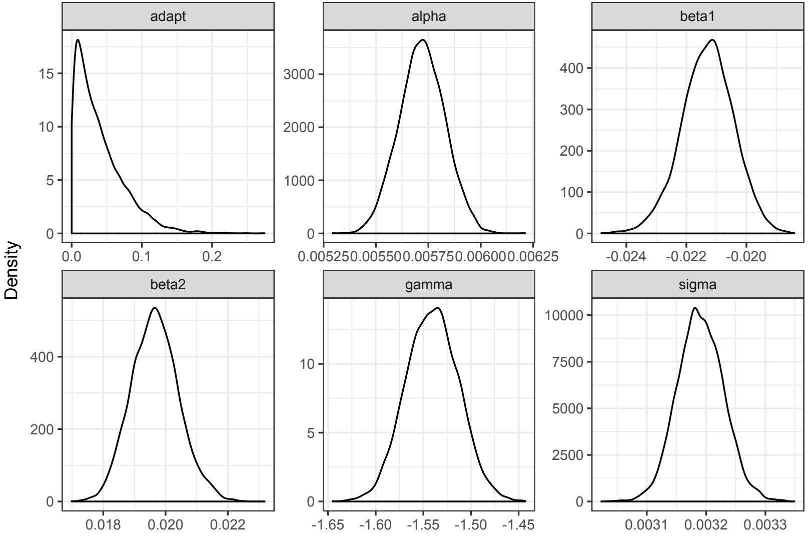
$$y = [f(T_t) - a(f(T_t) * b_t)]\,(\text{GDPpc})^{\gamma}$$

- $f(T_t)$ is an instantaneous damage function, generally of the form $\beta_1 T_t + \beta_2 T_t^2$.
- $b_t$ is the Bartlett kernel, and $a$ is the degree of temperature-driven adaptation.
- The last term provides a measure of elasticity of damages with income.

# Estimated damage function



# Bayesian fitted parameters

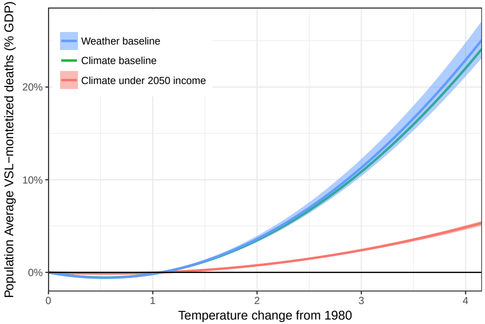


# Results

| RCP | SSP | Monetization | 0 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4.5 | SSP4 | VSL ag02 popavg | 49.765215 | 20.090173 | 11.188628 | 7.319126 | 5.2335889 | 3.9565314 | 3.1067942 | 2.5073709 |
| 4.5 | SSP4 | VSLY popavg | 27.076281 | 11.585834 | 6.923858 | 4.851441 | 3.7002694 | 2.9724734 | 2.4727046 | 2.1093082 |
| 4.5 | SSP4 | VSLY scaled | 4.846833 | 2.353378 | 1.527805 | 1.128928 | 0.8938308 | 0.7389402 | 0.6293463 | 0.5477955 |
| 4.5 | SSP4 | VSL ag02 scaled | 10.848195 | 5.175614 | 3.320996 | 2.429363 | 1.9066906 | 1.5647519 | 1.3247003 | 1.1474737 |
| 4.5 | SSP5 | VSL ag02 popavg | 22.639750 | 12.790459 | 9.110520 | 7.113661 | 5.8206464 | 4.9042500 | 4.2186996 | 3.6866908 |
| 4.5 | SSP5 | VSLY popavg | 11.801313 | 7.208263 | 5.423449 | 4.413440 | 3.7358821 | 3.2413275 | 2.8619107 | 2.5608733 |
| 4.5 | SSP5 | VSLY scaled | 3.848509 | 2.133306 | 1.521382 | 1.197915 | 0.9917263 | 0.8470242 | 0.7393777 | 0.6560325 |
| 4.5 | SSP5 | VSL ag02 scaled | 11.471691 | 5.608791 | 3.721099 | 2.799517 | 2.2450104 | 1.8726067 | 1.6050818 | 1.4037624 |
| 8.5 | SSP4 | VSL ag02 popavg | 112.962731 | 41.333858 | 21.802857 | 13.955777 | 9.9695436 | 7.6319429 | 6.1235417 | 5.0814877 |
| 8.5 | SSP4 | VSLY popavg | 54.144549 | 20.820391 | 11.622419 | 7.842783 | 5.8696309 | 4.6790999 | 3.8891723 | 3.3288767 |
| 8.5 | SSP4 | VSLY scaled | 10.365246 | 4.535453 | 2.715188 | 1.892462 | 1.4381250 | 1.1560006 | 0.9663930 | 0.8312908 |
| 8.5 | SSP4 | VSL ag02 scaled | 22.627928 | 10.012589 | 5.961467 | 4.101235 | 3.0711859 | 2.4350453 | 2.0115973 | 1.7132506 |
| 8.5 | SSP5 | VSL ag02 popavg | 43.699053 | 21.802650 | 14.734155 | 11.293759 | 9.2161600 | 7.8077671 | 6.7840025 | 6.0041636 |
| 8.5 | SSP5 | VSLY popavg | 20.489387 | 11.096381 | 7.938798 | 6.331466 | 5.3222833 | 4.6156765 | 4.0879440 | 3.6765711 |
| 8.5 | SSP5 | VSLY scaled | 6.789311 | 3.387298 | 2.244069 | 1.682805 | 1.3488154 | 1.1277918 | 0.9711668 | 0.8546137 |
| 8.5 | SSP5 | VSL ag02 scaled | 19.423931 | 8.974785 | 5.584819 | 3.984682 | 3.0697847 | 2.4871389 | 2.0886172 | 1.8013216 |

# Calculating an SCC (one slide for MG)

1. We estimate a global damage function: total monetized costs as they vary with temperature change from the baseline.




2. The damage function includes the effect of temperature adaptation (minor here) and income adaptation (huge).
3. We calculate ($A$) costs for each year according to an RCP scenario, and ($B$) costs for a 1 tonne boost in 2017 above that scenario.
4. The SCC is the present discounted value of $(B) - (A)$.

# Calculating an SCC

Let $x_t$ be a stream of $CO_2$ emissions and $y_t$ be the stream of impacts.
Let $f(t)$ be an impulse response function which describes how a single GT jump in $CO_2$ produces a stream of impacts. Then, $y_t = x_t * f(T)$, the result of a convolution.

1. We assume that each unit increase in CO2 has an impact that starts near 0, rises rapidly, and slowly decays. It also varies with average global temperature $T$.
2. The entire stream of impacts from CO2 is the just the sum of scaled and translated copies of this impulse response.
3. We calculate the coefficients that define that impulse response.
4. We calculate the NPV of the impulse response.

# A proposed structural form

Suppose that $f(T) = \sum_{k=0}^{K} (\beta_{k0} + \beta_{k1} T)\, t^k e^{-t/\tau}$, where $\tau$ is the residence time of $CO_2$ in the atmosphere, 400 yr under IPCC or 77 yr under DICE.
Then,

$$\begin{aligned} y_t &= \alpha + \sum_{s=0}^{\infty} x_{t-s} \sum_{k=0}^{K} (\beta_{k0} + \beta_{k1} T_{t-s})\, s^k e^{-s/\tau} + \epsilon_t \\ &= \alpha + \sum_{k=0}^{K} \beta_{k0} \sum_{s=0}^{\infty} x_{t-s} s^k e^{-s/\tau} + \sum_{k=0}^{K} \beta_{k1} \sum_{s=0}^{\infty} x_{t-s} T_{t-s} s^k e^{-s/\tau} + \epsilon_t \end{aligned}$$

This is just a weighted sum of recent $CO_2$ emissions as the predictors for a regression.

# Calculating an SCC

We are interested in the discounted sum of impacts. This can be calculated as,

$$
\begin{aligned}
SCC_t &= \sum_{u=0}^{\infty} e^{-\delta u} y_u(\delta_u) \\
&= \sum_{u=0}^{\infty} e^{-\delta u} \left[ \sum_{k=0}^{K} \beta_{k0} \sum_{s=0}^{\infty} \mathbf{1}\{u - s = 0\} s^k e^{-s/\tau} + \right. \\
&\qquad \left. \sum_{k=0}^{K} \beta_{k1} \sum_{s=0}^{\infty} \mathbf{1}\{u - s = 0\} T_{u-s} s^k e^{-s/\tau} \right] \\
&= \sum_{u=0}^{\infty} e^{-\delta u} \left[ \sum_{k=0}^{K} \beta_{k0} u^k e^{-u/\tau} + \sum_{k=0}^{K} \beta_{k1} T_t u^k e^{-u/\tau} \right]
\end{aligned}
$$