Extending the SSP scenarios beyond 2100

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August 20, 2021

The following text is modified from the supplemental information descriptions in Dietz et al. [2021] and Kikstra et al. [in press].

To estimate population and income levels past 2100 along the SSP scenarios, we fit a model to the available pre-2100 SSP scenario data and use the fitted model to extrapolate. The same model is applied to both income and population and is defined in terms of growth rates. The model postulates that changes in pre-2100 income and population growth rates are explained by a rate of convergence and a rate of decay.

The model is as follows:

$$\text{Growth}_{it} = (1 - \beta - \delta)\text{Growth}_{i,t-1} + \delta\text{MeanGrowth}_{t-1}, \tag{1}$$

where i indexes the region, t indexes years, δ is the rate of convergence, β is the decay rate and

$$\text{MeanGrowth}_{t-1} = \sum_i \frac{\text{Population}_{i,2015}}{\sum_j \text{Population}_{j,2015}} \text{Growth}_{i,t-1}. \tag{2}$$

Below, we write this as $\text{Growth}_{\cdot,t-1} \cdot w$, where w is the vector of global population shares for each country.

SSP data are not available in every year, so fitting Eq. (1) requires a model with dynamics. We use a two-step approach, fitting the model using Stan, a computational Bayes system. The first step uses the available data directly, fitting

$$\text{Growth}_{is} \sim \mathcal{N}\left([1 - \Delta t(\beta + \delta)]\text{Growth}_{i,s-1} + \Delta t \delta \text{MeanGrowth}_{s-1}, \sigma_i\right), \tag{3}$$

where s is a time step, Δt is the number of years between time steps, and country i has uncertainty σ_i. We apply a prior that both β and δ are between 0 and 0.5.

Next, we fit the full model, using the results of the simplified model to improve the Bayesian model convergence. In this case, for a given Markov chain Monte Carlo draw of β and δ, we calculate the entire time series:

$$\widehat{\text{Growth}}_{it} \sim \mathcal{N}\left((1-\beta-\delta)\widehat{\text{Growth}}_{i,t-1} + \delta\left[\widehat{\text{Growth}}_{\cdot,t-1} \cdot w_{\cdot}\right], \sigma_i\right) \tag{4}$$

starting with $\widehat{\text{Growth}}_{i,2015}$ as reported in the SSP dataset.

The probability evaluation is over both the performance of the fit and the priors:

$$\begin{aligned}
\text{Growth}_{is} &\sim \mathcal{N}\left(\widehat{\text{Growth}}_{i,t(s)}, \sigma_i\right) \\
\beta &\sim \mathcal{N}\left(\mu_\beta, \sigma_\beta\right) \\
\delta &\sim \mathcal{N}\left(\mu_\delta, \sigma_\delta\right) \\
\log \sigma_i &\sim \mathcal{N}\left(\mu_{\sigma,i}, \sigma_{\sigma,i}\right)
\end{aligned}$$

where $\mu_{\cdot}$ is the mean estimate for the corresponding parameter, and $\sigma_{\cdot}$ is the standard deviation across its uncertainty. The prior for σ_i is defined as a log-normal, centered on the mean of the estimates of $\log \sigma_i$.

The estimates for each SSP are shown in Table 1, with visualizations of timeseries data for SSP2 and SSP5 in Figure 1.

References

Simon Dietz, James Rising, Thomas Stoerk, and Gernot Wagner. Economic impacts of tipping points in the climate system. *PNAS*, 2021.

Jarmo S. Kikstra, Paul Waidelich, James Rising, Dmitry Yumashev, Chris Hope, and Chris M. Brierley. The social cost of carbon dioxide under climate-economy feedbacks and temperature variability. *ERL*, in press.

Table 1: Estimated convergence and decay rates for extrapolation of growth of GDP per capita and population in the SSP socio-economic scenarios beyond 2100

SSP	Variable	δ	β
1	GDP per capita	0.006205028	0.005930520
1	Population	0.008967453	0.005215835
2	GDP per capita	0.004190444	0.007228942
2	Population	0.001276993	0.011064426
3	GDP per capita	0.006273030	0.009597363
3	Population	0.001064697	0.007688331
4	GDP per capita	0.006895296	0.009651277
4	Population	0.001867587	0.003461600
5	GDP per capita	0.007766807	0.003843256
5	Population	0.003470952	0.004305310

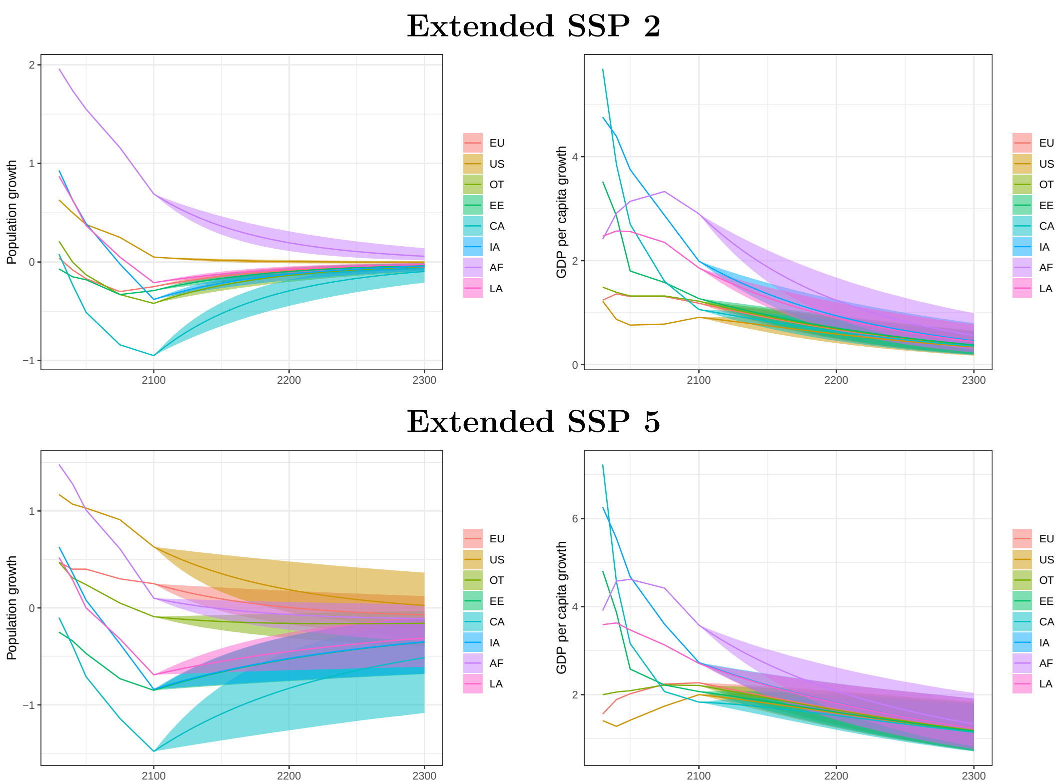

Figure 1: Extended SSP population and per capita GDP for SSP 2 and SSP 5. Shaded areas show 95% credible intervals.