GENERAL DISCUSSION Michael Kiley offered a comment on emerging literature in the monetary policy space and highlighted the implications of the developing consensus for the paper. Kiley began by noting that while the authors make some efforts to respond to recent data suggesting lower long-run real interest rates, they may have still underreacted to the plausibility of baseline real interest rates below or even well below 2 percent. He argued that estimates of the social cost of carbon (SCC) will be highly sensitive to the prevailing real interest rate, particularly as that rate approaches zero. Given the focus of the paper on the various sources of uncertainty in estimates of the SCC, he suggested that this is yet another source of uncertainty with the possibility of substantially increasing the SCC.

Kiley continued, remarking that the climate beta value is often positive, reflecting assumptions about the damage function and GDP projection. He added that those GDP projection pathways generally reflect fairly stable economic growth over the long run, albeit with considerable uncertainty. Kiley contended that bad climate scenarios are potentially ones in which the macroeconomy is riskier, implying a negative climate beta and a possibly higher SCC. He noted that this is intuitive at the microeconomic level, with increased probability of localized climate disasters resulting in poor economic outcomes, but argued there are possibilities for macroeconomic growth disasters due to warming that increase the welfare impacts of mitigation efforts. Kiley concluded by acknowledging that this would be a new area, but one that is potentially valuable for future iterations of the SCC literature.

David Popp referenced discussant Mar Reguant's concluding point, which identified a feedback loop wherein climate policy itself is an additional source of uncertainty and is impacted directly by calculations of the SCC. Popp wondered whether it was possible for the model to include a projection of the emissions pathway if climate policies followed the proposed SCC and thus could limit the calculation to internally consistent estimates for the SCC (e.g., the SCC is estimated at $56 conditional on some emissions pathway, but that emissions pathway is not itself possible under a $56 cost of carbon). Popp questioned whether there might be some way to link those elements of the calculation to come up with an internally consistent estimate.

Wendy Edelberg pointed out that, due to the wide bands of uncertainty in the paper's SCC estimates, the distributions sometimes suggest a negative value for the SCC. She wondered if that was a natural consequence of simulations that are not bounded at zero or whether that is a legitimate possibility. Edelberg also asked how adaptation plays into the model.

While acknowledging that projecting adaptation into the future is a difficult task, she wondered if that was factored in and whether that may be a contributing factor to the distributions including negative values for the SCC estimates.

Glenn Rudebusch pointed out that there are also cases where the SCC can become infinite, particularly when the real interest rate will be negative for a long time. He noted that this phenomenon has already been evident recently in the data, so this was an additional factor the discounting module would have to grapple with. In particular, Rudebusch questioned how long negative real interest rates could persist, and in turn how far r^* could fall. He referenced his paper with Michael Bauer that attempted to answer a similar question.[1]

Adrian Raftery responded to the questions posed by discussant Reguant and followed up by Popp regarding climate feedback loops within the model. Raftery specified that for the population model, climate feedbacks weren't explicitly included but were implicitly included. He pointed out that it would be difficult to identify exactly what those feedbacks would be, and thus the population model is a statistical model with some adjustments based on expert elicitation. He clarified that the biggest driver of future population is fertility, and there is no evidence to date that climate has a direct impact on fertility (though there is evidence for the inverse). Raftery then mentioned that there are big climate impacts on mortality, but while they result in large damages overall, they are only maybe one-third of 1 percent of total deaths.[2] He argued that small changes in public health would likely have larger overall mortality impacts than the climate. He continued with the point that migration has very little effect on world population overall. One exception is international migration with people from poorer countries moving to relatively richer countries. Raftery posited that climate disasters tend to lead to more internal migration than external migration, with exceptions being small island nations and Bangladesh, meaning that the ultimate effects are hard to nail down.[3] He concluded by arguing that the authors have implicitly included the climate feedbacks

1. Michael D. Bauer and Glenn D. Rudebusch, "The Rising Cost of Climate Change: Evidence from the Bond Market," *Review of Economics and Statistics* (forthcoming), https://doi.org/10.1162/rest_a_01109.

2. World Health Organization, "Climate Change and Health," October 30, 2021, https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health.

3. Shuaizhang Feng, Michael Oppenheimer, and Wolfram Schlenker. 2012. "Climate Change, Crop Yields, and Internal Migration in the United States," working paper 17734 (Cambridge, Mass.: National Bureau of Economic Research, 2012), https://www.nber.org/papers/w17734.

toward population because the model is estimated based on seventy years of data from 1950 to 2020, which is a period during which there has been 1 degree Celsius of warming.[4] As such, the model is estimated based on data from a period during which there has been substantial warming and anticipates similar warming rates, meaning the model is implicitly incorporating elements of climate feedbacks.

Kevin Rennert followed, clarifying that the paper does not directly incorporate feedbacks—for example, from climate damages onto economic growth—by design because the intention is for the integrated assessment model to itself calculate the damages and then feed that back onto the pathway for economic growth. This is preferred to experts or the underlying statistical model calculating damages and adding them on top because that would lead to double counting.

Richard Newell spoke to the distinction between the marginal benefits of taking action and the marginal cost of taking action, and the degree to which they should be matched or equated within the model. Newell specified that while integrated assessment models are sometimes used to determine an optimal carbon tax (set at a level in which the emissions level is consistent with marginal damages), the authors intentionally do not do that in this paper. Rather than trying to inform a decision about the global optimal level of emissions, Newell pointed out that their paper intends to aid in the cost-benefit analysis and regulatory analysis for individual regulations or smaller actions in the scheme of global climate action. He contended that it is appropriate to separate and not directly couple emissions within the model to marginal damage estimates.

4. NASA, "World of Change: Global Temperatures," https://earthobservatory.nasa.gov/world-of-change/global-temperatures.