COMMENTARY

Reduced emissions through climate damage to the economy

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Today, most global economic production depends on energy produced from burning fossil fuels, which emit carbon dioxide as a byproduct. Although the costs of carbon-free energy such as wind and solar have come down dramatically over recent decades, there are substantial challenges to completely decarbonizing our electricity system, and even greater challenges to completely decarbonizing the transportation and industrial sectors (1). Thus, economic activity is projected to produce greenhouse gas emissions throughout this century. These emissions of greenhouse gases are causing Earth to warm, and, in aggregate, the effects of global warming are expected to be deleterious. These deleterious effects are expected to harm global welfare and diminish economic productivity. This diminution of production, other things being equal, would lead to a reduction in greenhouse gas emissions and, thus, would lessen the anticipated warming. In PNAS, Woodard et al. (2) find that the reduction in emissions through damage to economic activity is roughly the same magnitude as, but opposite in sign to, natural carbon cycle feedbacks that are projected to increase carbon dioxide levels relative to a world without carbon–climate feedbacks. The net effect of the socioeconomic carbon–climate feedbacks is estimated to be about the same magnitude as, but opposite in sign to, natural biogeophysical carbon–climate feedbacks. As a result, the level of greenhouse gases in the atmosphere in 2100 is projected to be about the same as if neither feedback (socioeconomic or natural biogeophysical) were active.

Woodard et al. (2) analyze various influences on carbon dioxide emissions using the Kaya identity, which represents these emissions as the product of population, per-capita productivity, energy used per unit of production [energy intensity of gross domestic production (GDP)], and carbon emitted per unit of energy used (carbon intensity of energy). Reduced per-capita economic productivity due to climate change is projected to be the most important negative socioeconomic climate–carbon feedback (Fig. 1).

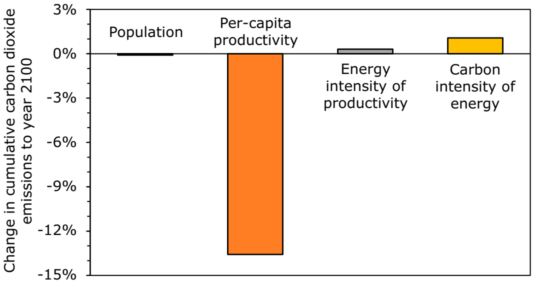

Fig. 1. Influence of climate change on cumulative carbon dioxide emissions to the year 2100 via pathways of population, per-capita productivity, energy intensity of productivity, and carbon intensity of energy, reported relative to a base-case projection that considers only purely biogeophysical carbon–climate feedbacks. Data from ref. 2.

Population

Woodard et al. (2) consider how climate change might affect population through its impact on mortality. The factors considered are heat exposure, disease, extreme weather, and food and water scarcity. While climate change's impact on mortality is no doubt of great concern to the people affected (and those who care about them), from the perspective of greenhouse gas emissions, these mortality effects have the smallest contribution of the four terms considered (Fig. 1).

Whereas Woodard et al. (2) consider one possible economic pathway by which climate change could affect population growth, other pathways exist that could potentially prove important. For example, a strong empirical relationship between extreme poverty and high population growth rates has been observed. If climate change were to exacerbate poverty, this could result in higher population and overall increased emissions. So, climate change might slow population growth through effects that increase mortality or it could accelerate population growth through effects on fertility rates.

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Per-Capita Productivity

Woodard et al. (2) also consider how climate change might affect per-capita productivity (or per-capita global GDP). Per-capita productivity is expected to be affected by climate change due to decreases in labor productivity under high-temperature conditions (3, 4); due to loss of infrastructure associated with both mean changes [e.g., sea-level rise (5)] and extreme events (e.g., floods); due to decreases in agricultural yields (6, 7); and because resources are diverted into adaptation efforts and into producing more expensive carbon-free energy technologies.

This is the factor most strongly influencing the results of Woodard et al. (2) (Fig. 1) and is also one of the more difficult-to-predict quantities. In their central case, decreased productivity associated with temperature changes reduces cumulative carbon dioxide emissions to the year 2100 by almost 14% [304 Pg of carbon (PgC) out of 2,238 PgC]. Reductions in GDP due to climate change were estimated using the results of Burke et al. (8), which projected more than a 20% reduction in per-capita GDP by the year 2100 relative to a no-climate-change scenario (in which productivity increases many times over). These estimates are quite uncertain and have been challenged by other authors (9, 10), but even Burke et al. (8) left open a roughly 30% chance that climate change will cause gains in per-capita GDP by 2100 (because much of the world population is currently on the cold side of their inferred optimum temperature for economic growth). The relevance for Woodard et al. (2) is that a climate-change-produced gain in per-capita GDP would reverse the sign of their central result, causing the socioeconomic carbon cycle feedback to be positive.

Energy Intensity of GDP

The third term that Woodard et al. (2) consider is the impact of climate change on the energy intensity of economic productivity (GDP) through warming's impact on heating and cooling demand (Fig. 1). Generally, it is thought that warmer global temperatures will cause energy demand to decrease in the high latitudes, primarily through reduction in heating demand, and increase in the low latitudes, primarily through increases in cooling demand. In the central case considered by Woodard et al. (2), they project increases in cooling demand to dominate over decreased heating demand, resulting in an increase in carbon dioxide emissions. However, at the scale of the global economy, these effects are projected to be small, resulting in a 0.3% increase in cumulative carbon dioxide emissions to the year 2100 (7 PgC out of 2,238 PgC).

Carbon Intensity of Energy

The final term considered by Woodard et al. (2) is the carbon intensity of energy. They conjecture that climate change will cause the amount of carbon dioxide emitted per unit of energy used to increase by ~1% by 2100 (Fig. 1). For example, it has been projected that hydroelectricity production could be negatively impacted by climate change (11). Further, different types of solar photovoltaic cells decrease their output by about 0.2 to 0.5% with the considered levels of increasing temperature (12). Effects of climate change on wind energy are likely to vary with both region and season (13). Basic theory suggests that decreased equator-to-pole temperature differences should decrease wind speeds overall. Indeed, one idealized study (14) concluded that the generation and dissipation of atmospheric kinetic energy would decrease by ~10% in a world with quadrupled atmospheric carbon dioxide. However, how this plays out in the utility of wind power production is yet to be determined.

If hydropower, solar power, and possibly wind power could be negatively impacted by climate change, the effect on carbon intensity of energy depends on the assumption of what technologies would be available to supplant these decreases in energy generation. If the response is simply to build more hydropower, solar power, and/or wind power, this would show up as an increase in the cost of energy production, which would affect per-capita economic productivity. If the response were to build, for example, more nuclear power, then there would be little influence on carbon intensity of energy supply. However, if the response were to build additional fossil fuel plants, then carbon intensity of energy production would increase. Thus, the consequences of climate change on the carbon intensity of energy depend not only on the uncertain responses of future energy technologies to environmental change but also on the technoeconomic assumptions regarding which technologies would make up for lost power.

In PNAS, Woodard et al. find that the reduction in emissions through damage to economic activity is roughly the same magnitude as, but opposite in sign to, natural carbon cycle feedbacks that are projected to increase carbon dioxide levels relative to a world without carbon–climate feedbacks.

Discussion

In climate science, human-caused greenhouse gas emissions are usually treated as being exogenous to the system under consideration. If we want to calculate, say, how much it will warm by 2100, it would be conventional to first define an amount of cumulative human greenhouse gas emissions by 2100 and then to consider how this amount of emissions will stimulate other changes in the climate system. The initial perturbation and these other changes, like those associated with natural carbon cycle feedbacks, would then be considered together in the calculation of the ultimate level of warming. Part of Woodard et al.'s approach (2) brings society into the fold as part of the dynamic system being analyzed. These authors conceptualize a 21st century in which human emissions of greenhouse gases rise continuously, but the impacts of climate change are allowed to feed back and reduce the level of greenhouse gas emissions.

Considering society to be part of the dynamic system undergoing analysis is intriguing, but are damages to the economy the most plausible pathway in which climate change will feed back on human greenhouse gas emissions? Climate change's impact on human perception of current and future risk will continue to motivate individuals and governments to reduce emissions. This type of feedback that involves human awareness of the situation and foresight has already led some to believe that the high-end business-as-usual scenario used by Woodard et al. (2) is much less realistic than it was when first proposed (15).

Experience with storms, droughts, and other extreme events that can be attributed to climate change could cause a shift in public opinion that would motivate politicians to enact policies to reduce greenhouse gas emissions. Convincingly incorporating this form of socioeconomic climate–carbon feedback in a mathematical model would be a formidable undertaking. However, one might hope that this socioeconomic feedback operates more effectively than the feedbacks identified by Woodard et al. (2). Reducing emissions through policy (e.g., a carbon tax) is much less costly than reducing emissions through climate damage to the economy. Central estimates suggest that stabilizing carbon dioxide at 450 ppm (roughly 400 ppm less than what might occur under a business-as-usual situation) would shave roughly 5% off of global production by 2100 (16), while Woodard et al. (2) show that a 100-ppm reduction in carbon dioxide results from a 20% reduction in productivity caused by climate change. Thus, depending on climate–economic feedbacks to reduce emissions is likely to be more than an order of magnitude more costly than relying on improvements in energy systems and land-use practices to reduce emissions.

As a global community, we can decide what policies we would like to implement to influence population growth; we can invest more in capital infrastructure to increase economic productivity; we can engage in efforts to improve the efficiency of energy use; and we can research, develop, and deploy technologies that can provide useful energy without carbon dioxide emissions. The feedback framework treats these decisions as largely deterministic and predictable. Perhaps the results of Woodard et al. (2) are a wake-up call, indicating what our world could be like if we act as *Homo economicus* in accordance with past patterns of behavior. Perhaps the key message is that we should not allow ourselves to become reactive components in feedback loops, but that we need to exercise our agency to produce the kind of future we really want.

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