

## Podcast interview: Noah Diffenbaugh and Marshall Burke

**PNAS:** Welcome to Science Sessions. I'm Paul Gabrielsen. In a global economy, spanning a wide range of climate zones, a few extra degrees of warming can have opposite effects in different regions. In a recent PNAS paper, climate scientist Noah Diffenbaugh and economist Marshall Burke, both of Stanford University, report that climate change has impeded the narrowing of the global wealth gap. Wealthy countries improve productivity as they approach an optimal temperature, and countries already at an economic disadvantage, partly stemming from harsh climates, are pushed into increasingly challenging climate conditions.

Burke explains how the link between temperature and economy plays out across countries.

**Burke:** If it's really, really cold, crops can't grow, and if it warms up a little bit, your chance of having a productive agricultural season goes up. It turns out it's not just agriculture, it's also labor productivity. When temperatures are a little bit warmer, their economies are more productive. So, the opposite is going to be true in a hot country. So in a place like Norway, which is quite cool in our global sample, Norway does better when it warms up and a place like India, which is quite warm in our overall sample, does worse.

**PNAS:** Diffenbaugh and Burke sought to quantify the effect that climate change has had on inequality in today's economy. But conducting such an experiment is challenging. It lacks a control condition, or a world without warming – what scientists call a “counterfactual”. The solution, Diffenbaugh says, is to simulate that counterfactual.

**Diffenbaugh:** We have both the economic observations and the temperature observations that actually occurred over the last half century. So our counterfactuals are generated using global climate models to run the experiments that we'd like to run in the real world. And so we used those climate model experiments that have human emissions of greenhouse gases and aerosols, and then the same climate models run without those human contributions. Then we can compare the difference of those two, the temperature evolution in each country between those two climate model experiments, and that gives us the counterfactual temperature, the world that would have been without anthropogenic climate forcing.

**PNAS:** Diffenbaugh and Burke used the historical relationship between temperature fluctuations and economic output in a given year, which has a parabolic, or hill-shaped curve.

**Burke:** As the US warms, and warms into the future, we should see the US pushed off this optimum a little bit. As the US has warmed historically, maybe it's warmed a little bit towards this optimum. The effects are much smaller than in places that are further away from the optimum. So in Norway again you're going to see much larger positive effects and in India you're going to see much larger negative effects because they're

further from this optimum. To understand the impact of changes in temperature on economic output, you don't want to compare Norway and India. So instead what we do is compare Norway to itself over time. So imagine Norway exposed to a colder than average temperature as compared to a year when it's exposed to a hotter than average temperature. So then we can understand, for Norway, okay, as it warms or cools, how does the Norwegian economy perform? We can do the same thing for India.

**PNAS:** Diffenbaugh says that the effect of warming on economies has slowed progress toward reducing global inequality.

**Diffenbaugh:** Even though there have been substantial gains in improvements in closing the wealth gap between the richest countries and the poorest countries, global warming has been a drag on that, an anchor on that progress. And in our calculations, it's been about 25%. We're not arguing that global warming created inequality, we're not arguing that global warming reversed progress on inequality; what our results show is that inequality has declined globally, but that it would have declined faster without global warming. What is new in our study is the country-specific quantification of the impacts of historical global warming on per capita GDP on a country-by-country basis. And the impacts are substantial. They're more substantial than what many might have anticipated without doing the calculations.

**PNAS:** Burke says that another dimension to the problem of income equity is the inequality present within countries, and not only between them.

**Burke:** We're used to hearing a lot about inequality in the news, and everyone tends to think inequality has gone up. And that's very true if you look within certain countries, but it's absolutely not true if you look across countries as a whole. So, our results speak strongly to what climate change does to the between-country or cross-country distribution of income and the findings there are pretty stark in the sense that the countries that have not done much to contribute to the problem are the ones who are going to be harmed the most, and that has a clear equity dimension.

**PNAS:** Burke adds that climate is only one ingredient in the economic mix.

**Burke:** Climate is not the only story here. Between-country inequality has gone down a lot. What our paper says is that process would have happened even faster. So, climate change, warming has presented a serious headwind for a lot of these economies. They're still making progress, but now they're facing this headwind and that headwind is only going to get stronger as we move forward.

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