Agriculture and the Social Cost of Carbon

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Putting a number on the economic damage from the emissions of greenhouse gases is a difficult undertaking. Recent advances in statistical methods, exponentially growing computing power, and the ever-increasing availability of detailed data on climate-sensitive sectors of the economy have led to significant new insights, which will affect regulation at the federal and global level.

A new major study on global climate damages shows significant impacts on the agricultural sector.

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This year produced much new evidence that the observed and anticipated impacts from human-caused climate change are bigger than previously thought. The release of a new report by the United Nations' Intergovernmental Panel on Climate Change made this point quite clearly by synthesizing tens of thousands of scientific papers. If you are still wondering whether it is indeed getting warmer, the answer is an unambiguous yes! Figure 1 displays the average measured daily temperature for the state of California, and the upward trend is clear.

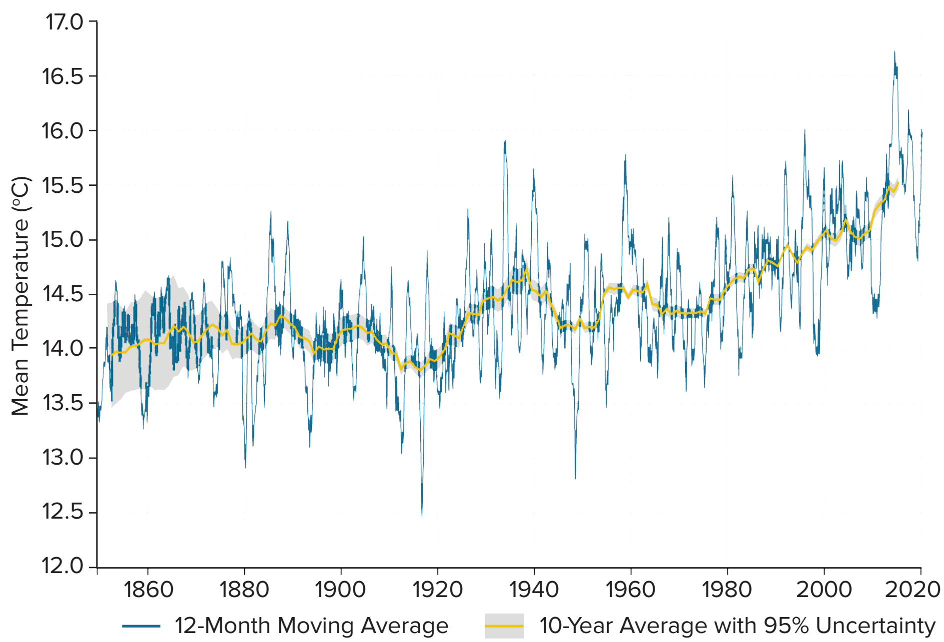
Economists have contributed significantly along multiple dimensions to our understanding of this shared future and the choices we face. On the one hand, many economists focus on designing more efficient and equitable policies to reduce emissions of global pollutants at the source of this problem. A lot of work has focused on how to design better carbon markets, taxes, and incentives for innovation. Another (much smaller) group of economists has focused on trying to quantify the anticipated impacts of climate change on climate-sensitive sectors.

How Does Climate Affect Agriculture?

Economists have tried to estimate the effect of a changing climate on the agricultural sector for many decades. Mendelsohn, Nordhaus, and Shaw, writing in the prestigious *American Economic Review* in 1994, used an early "big data" approach to develop a framework that exploits the fact that agricultural land across the United States varies greatly in terms of the climate it experiences.

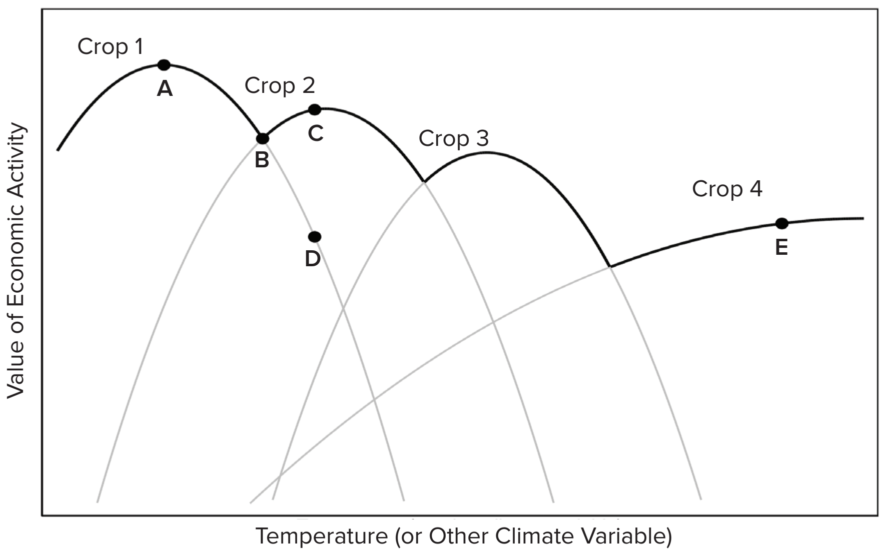
The intuition underlying this approach is that in a non-changing climate, farmers optimize their production technology and crop choice according to the environment they face. This includes soil quality, slope of the land, agroecological characteristics, and, of course, climate. The authors use standard statistical models to estimate a relationship between climate and the value or profitability of different agricultural lands over a long time period (e.g., 30 years). If land markets function perfectly, the land value should reflect the climate contribution to the value of a given piece of land.

Figure 1. Measured Daily Average Temperature for California Since the Industrial Revolution



Source: http://berkeleyearth.lbl.gov/regions/california#.

Figure 2. Crop Choice and Profits in the Long and Short Run



Source: Figure inspired by Mendelsohn, Nordhaus, and Shaw (1994).

Figure 2 helps cement the economic intuition behind this approach. Imagine a single farmer, who is currently growing crop 1 and earning profits of A. If faced with a significantly hotter climate, the farmer becomes indifferent between growing crop 1 and crop 2 at point B. If the climate warms further, the farmer is much better off switching to crop 2 at point C rather than continuing to grow crop 1 at point D.

Prior approaches often assumed that farmers would stick with a given crop and not switch, which is, of course, not what happens in the real world. In order to simulate what the agricultural sector looks like in a hotter world, you simply feed the model a hotter world and estimate what the crop distribution looks like across space. This work suggested that climate change could actually be beneficial for U.S. agriculture.

Examining this surprising result, Schlenker, Hanemann, and Fisher identified that an important factor driving agricultural land values—especially in the West—was omitted from the model. They pointed out that (as most Californians know) irrigation is an important driver of farm profits. When correcting for this, they showed that the estimated national-level agricultural impacts from climate change went from being slightly beneficial to robustly negative.

The subsequent literature has built upon these insights and tried to better model the fact that adapting to climate change is costly, especially in agriculture, where switching crops is expensive. A rich literature exploiting the exploding availability of high-resolution yield and weather data has emerged. A number of papers have used year-to-year variation in agricultural outcomes, temperature, and precipitation to estimate damage functions comparing outcomes of single areas in different weather years and have extracted a relationship between weather and yields or farm profits.

This approach, using statistical modeling, allows one to control for the issue of unobservable confounders—at a cost. The estimated response has often been characterized as a short-run response that does not capture long-run adaptation to a new climate. It is generally true that farmers have more adaptation choices in the long run than in the short run, and thus estimates which do not take this adaptation into account may overstate impacts.

For example, this may be true for some farmers in the northern hemisphere who can, in the long run, switch crops, change their cropping calender, or move their operations north. All of these options would moderate the estimated impacts of climate change. However, it is important to point out that there are also examples of adaptation options which are available in the short run and not in the long run (e.g., depletable groundwater resources).

One innovative approach to address the issue facing the literature discussed above is provided by a team of former Berkeley graduate students (Marshall Burke and Kyle Emerick), who use the fact that different areas experience different trends in climate. They exploit this approach statistically to control for confounding factors.

What the literature so far had left out, however, was the fact that many commodities are traded in global markets and that local climate impacts work their way through the global network of markets. Frances Moore of UC Davis, jointly with a number of coauthors, has thought carefully about this issue. She worked with a team that models trade in commodities (GTAP at Purdue University) to incorporate this type of response, while taking the most recent science on how crops respond to climate shocks seriously.

The Social Cost of Carbon

So why does all of this matter? On the one hand, if you are part of the agricultural sector you care about the impacts of climate change on agriculture. But more broadly, it turns out this work is crucial in helping the federal government calculate a very important number that most people have never heard of. The social cost of carbon (SCC) is the damage one ton of carbon dioxide does over its long lifetime across all sectors and the entire planet.

It turns out this is a difficult number to calculate for multiple reasons. First, most greenhouse gases are long-lived, with the most important one (carbon dioxide) surviving for thousands of years after it exits your car's tailpipe. Second, there are many sectors affected by hotter temperatures, changing rainfall patterns, rising sea levels, and more intense extreme events. Examples are not just agriculture, but energy, migration, health, infrastructure, labor productivity, conflict, water availability, fire, and species loss, to name but a few.

Further, how a hot day affects each of these sectors across the world may differ, depending on the capital you have available locally. For example, if you do not have air conditioning, you will be more vulnerable on a 100-degree day than if you do. Finally, as each ton of pollution emitted today has damages affecting humans and the environment for thousands of years, we need to calculate how, for example, temperatures affect these sectors in a future that is further removed from the present than the onset of the industrial revolution.

You might ask whether this has any practical implications. Turns out, it does! Cost-benefit analyses have been one of economics' biggest contributions to public policy. This type of analysis has been required for a significant share of federal regulations since the 1970s. If federal agencies want to impose a new regulation, often they have to show—as part of a regulatory impact analysis—that the benefits of the regulation (e.g., avoided pollution damages from lower energy consumption due to energy efficiency rules) are greater than the costs (e.g., higher cost of manufacturing said gadgets).

The Evolution of the Social Cost of Carbon

Since basically every human activity causes some greenhouse gas emissions, determining the amount of damage a ton of carbon dioxide does is key. There is a long history of ambiguity around the value of the social cost of carbon, going back to the George W. Bush presidency, when three different federal agencies applied three very different values for the same gas emitted.

During the Obama presidency, an interagency working group produced an official value of $42 per ton emitted in 2020, using a 3% discount rate. President Biden, in his first month in office, put in place a slightly updated social cost of carbon—which was $52 per ton—and ordered a significant update, which was supposed to take into account suggested improvements by the National Academies of Science and Engineering.

During the Trump presidency, which halted government work on the value of the social cost of carbon, UC Berkeley's David Anthoff and Resources for The Future's Kevin Rennert, along with a number of current-day and future all-star coauthors, began work that really pushed the envelope on how we calculate this number. They just published a new paper reporting the results in the journal *Nature*. The global press focused on the new central estimate of $185 per ton of carbon dioxide, which is more than thrice the current value of the social cost of carbon (at a 2% risk-free rate used to discount). While bigger numbers get a lot of attention, this paper presents a massive step forward in our modeling of this all-important number. Let me enumerate what I think is innovative here.

A Giant Step Forward

The new model lives in the light. One of the big advances in social sciences has been a push to publish your data and code so other teams can replicate your findings and possibly modify them to check for robustness. If you would like to run the model, you can! (The new model is openly available at: https://www.mimiframework.org).

One of the most important decisions modelers have to make is how much to discount the consumption of future generations. In order to do so, you must choose a number called the discount rate. The higher the rate, the lower the value we place on damages from climate change occurring further in the future.

Massive exercises in surveying experts in the field suggested that the government had been using a rate that was too high. The paper employs a 2% risk-free rate, which is lower than the lowest rate used before, and that is consistent with expert elicitation. The second update is that discounting now takes into account the rate of economic growth, which is key if you care about pricing risk correctly, which most economists do.

The thing we know best about the future is that it is highly uncertain. Social scientists have contributed frameworks that help us make optimal decisions depending on the degree and type of uncertainty we face. The approach adopted here is completely novel in fully characterizing uncertainty from beginning to end.

To recall, these models require many things. The first thing you need is future emissions based on income and population assumptions. In the old days we just put together a handful of scenarios that seemed reasonable and did not really attach probabilities to Earths with different levels of wealth and population. This paper went far beyond what one could hope for and combined cutting edge statistical approaches on really long-run forecasts with expert elicitation to characterize future states of the economy probabilistically! This sounds straightforward, but it's not, and this alone would have been a major step forward.

However, the authors do not stop there. They fully characterize the uncertainty in the socioeconomic, climate, damage, and discounting components of this novel model. Hence, this new model, called Greenhouse Gas Impact Value Estimator (GIVE), allows us to take into account the change in uncertainty and translates this into a distribution of the social cost of carbon. By taking these different sources of uncertainty into account, we can make better decisions.

One of the biggest criticisms of previous modeling approaches was the fact that the so-called damage functions (discussed earlier), which translate changes in temperature and sea level rise into economic damages, were severely outdated (in some cases based on 30-year-old science). One of the models used in the previous round of social cost of carbon calculations even suggested that higher global temperatures of up to 4 degrees Celsius were beneficial to global agriculture. The same model suggested that one-third of damages came from higher energy consumption. The paper by Rennert, Anthoff, and their team incorporates the work by Frances Moore and coauthors (referenced earlier) to reflect the impact of some agricultural and trade adaptations.

Does this simple switching out of a damage function make a difference? Yes, it does. The paper shows clearly that the agricultural sector across the globe will suffer from climate change. Damages to the sector make up almost a third of the social cost of carbon—which is significant.

Concluding Thoughts

This new paper in *Nature* made significant progress in reflecting the actual observed relationship between climate and crops when calculating one of the most important numbers in federal policymaking—the social cost of carbon. But it's not perfect.

First off, many sectors that are climate sensitive, like biodiversity, conflict, labor productivity, water availability, forestry, and fisheries, are not in the model. Further, the model does not claim to adequately deal with the notion that there are significant, low-probability events that may occur far into the future (e.g., ocean currents stopping, major ice sheets melting).

From a California perspective, many of the crops we grow here are specialty crops. Their climate sensitivity is not understood sufficiently to incorporate them into these models. I would welcome the opportunity to work with partners that have rich datasets on filling that gap.

Finally, anything that has four or more legs, or fins, is not in this model. It would be important to better understand the impact of a changing climate on the cattle, dairy, and aquaculture sectors. There is a lot of work to do. And we better do it fast.

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For additional information, the author recommends:

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