# Estimating Impacts of Climate Change on California's Most Important Crops

***Maximilian Auffhammer***

Understanding the historical and future impacts of climate change on California's specialty crops should be a research priority for the state.

California produces almost 50% of U.S.-grown fruits, nuts, and vegetables. Consumers across the United States regularly purchase crops produced solely in California. After milk, grapes and almonds have become the state's top-two valued commodities accounting for 4.5 and 4.3 billion dollars of output, respectively. Strawberries lettuce, walnuts, and tomatoes also make the top ten, jointly accounting for another 5.9 billion dollars of output.

California's 80,500 farms sold their output for $42.6 billion, which comes out to about 2% of gross state product. Exports accounted for 43% of that output. A look at the historical statistics on yields for a sample of important California agricultural products shows an incredible record of yield growth over the past 70 years.

As shown in Figure 1, strawberry yields today are ten times higher than they were in 1940. Almond yields are 8.5 times higher, and tomatoes are 7.3 times higher. Not all crops have experienced similarly steady and rapid yield growth, but even broccoli and lettuce experienced a three-fold increase in yields over this period.

Agronomists and agricultural economists have empirically documented factors, which can explain this growth in yields: irrigation, fertilizers, pesticides, high-yielding varieties and better farming practices, to name but a few. Further, California's farmers have pushed the frontier in terms of technological innovation for decades and in turn helped increase incomes of rural communities throughout the state.

The agricultural sector in California faces a number of old and some new challenges. There is increasing competition from abroad for a number of California's key crops, irrigation water is scarce due the ongoing drought and state legislation, input prices (e.g., labor, fuel, fertilizers, and pesticides) are on the rise, and there is the permanent threat of pest damage. The most recent addition to this list of threats to California's agricultural sector is climate change.

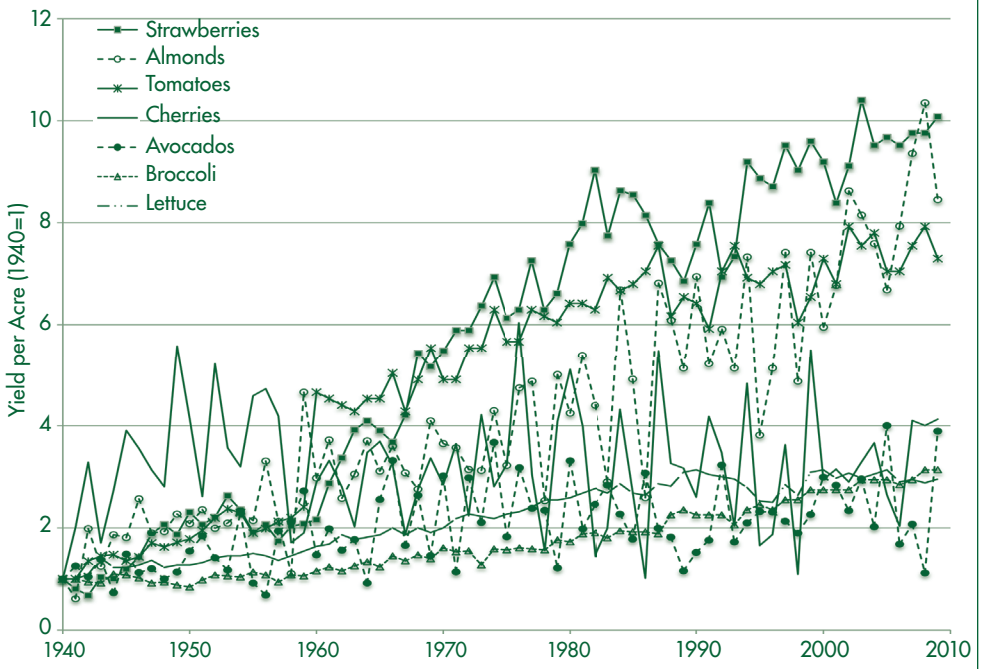
California's relatively mild climate is partially responsible for the high quality and quantity of output of the major crops grown here. Further, there are many microclimates, such as the Napa Valley, which have enabled the birth and continued success of California's agricultural commodities and differentiated products on the world market.

## Challenges in Estimating Impacts of Climate Change on Crops

The major concern arising from anticipated climate change is that the "new" climate will negatively affect the quality and overall output of these important commodities. There are a number of ways in which a change in climate regime might affect the sector. Warming will lead to an upwards shift of the distribution of temperatures experienced on the ground. This shift will lead to fewer cold days and more extreme heat days. A warmer climate will also negatively affect our ability to store irrigation water naturally in the snowpack.

Shifting fog patterns might affect the suitability of certain areas for growing crops, which rely on this fog and affect the quality of the product. Changing precipitation might affect water availability for irrigation. All

Figure 1. Yields per Acre for Seven Commodities




*Source: United States Department of Agriculture, National Agricultural Statistics Service*

of these statements are conjecture, which need to be backed up by careful analysis. The so-called "perfect experiment" to study these impacts would be to randomize different concentrations of greenhouse gases across a few hundred otherwise identical planets and observe what happens to crop yields on planets with higher concentrations. This is clearly not an experiment that can be run. So how does one estimate impacts in practice?

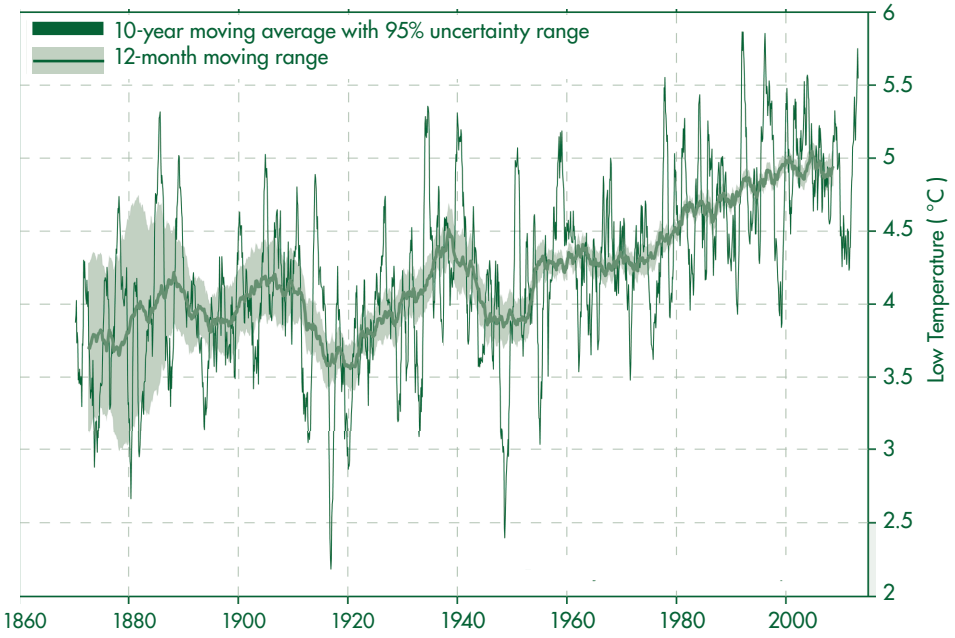
In order to estimate impacts of climate change on agriculture, a researcher needs to understand two factors. The first ingredient is a "counterfactual" climate under past or future climate change. If one looks into the past, one could look for trends in measured climate that are consistent with climate change.

A truly "nonpartisan" dataset of observed temperatures was assembled by formerly confessed climate skeptic Professor Richard Muller at UC Berkeley. The Berkeley Earth Project assembled maybe the most extensive public database of global weather data records and analyzed them using a transparent and consistent set of rules. The data show an undisputable trend in global surface temperatures, which cannot be explained by any other factor than anthropogenic emissions of greenhouse gases. Figure 2 above shows the recorded minimum temperatures for Modesto from this dataset.

This figure displays a clear trend, which accelerates in the early 1960s. The calculated change in *average* temperatures for this location is roughly 1.6 degrees Fahrenheit since 1960, which is significant. It is important to note that there is and always will be significant year-to-year variability in weather. However, there is a clear detectable trend in temperatures, which is more pronounced in nighttime temperatures than in daily maximum temperatures.

The warming trend in Modesto is slightly slower than the global average

Figure 2. Minimum Temperatures for Modesto, California




*Reference Location: 37.78N, 120.00W; Nearby Cities: Modesto, Merced, Turlock*
*Source: Berkeley Earth Project*

trend or the trend for North America. Further, it is important to note that the observed trends in temperature cannot account for which part is from anthropogenic emissions of greenhouse gases versus which part might be due to changes in land use patterns. So the record shows that there has been warming, which is consistent with what we would expect from climate change.

If we are interested in projections of future climate, Ben Santer's piece in this issue discusses how global climate models can be used to project future climate with and without human-caused climate change. These models can be used to construct a counterfactual future climate with and without anthropogenic emissions of greenhouse gases.

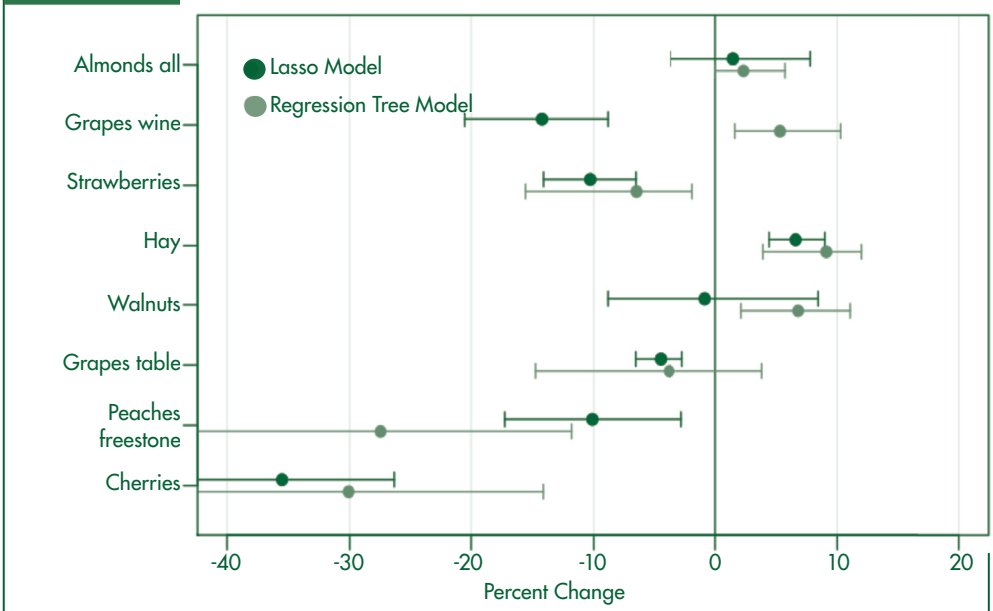
## Climate Sensitivity of Crops

The second ingredient required for an impact study is a reliable estimate of how individual crop yields respond to variation in weather or climate. We call this a *climate sensitivity*. This is not an easy challenge. As discussed above, the researcher needs to statistically separate the contribution of climate/weather to yields from that of irrigation water, fertilizer, pesticides, labor, prices and soil quality, to name but a few. In order to conduct such an exercise, the optimal data one would want will cover a large spatial area, preferably at the field level, over many growing seasons. This can easily be done for corn, soy, cotton and wheat, as there hundreds of counties growing these commodities. The data for specialty crops are more limited.

Due to the data availability, the literature has focused largely on the climate sensitivity of cotton, soy, wheat and corn. There is strong evidence showing that these field crops suffer very badly from just a few days above 30 degrees Celsius, so-called extreme heat days. While we do grow some of these row crops in California, these are by no means the economically most important crops in the state. Grapes, almonds, strawberries, lettuce, walnuts, and tomatoes are economically much more significant here.

In order to arrive at estimates of impacts of climate change on the crops of economic significance to California, you combine the climate sensitivity of a crop with observed or

Figure 3. Estimated Impact of 2°C Warming on Crop Yields




*Source: California Perennial Crops in a Changing Climate, Lobell and Field, PIER Program, 2009*

projected changes in climate. This is where the trouble begins. There are very few studies that have looked at the climate sensitivity of the economically significant crops in California.

One of the first studies was conducted for the California Public Interest Energy Research (PIER) program by David Lobell and Chris Field. They use data for the crops of interest, estimate climate sensitivities, and project impacts for a two-degree warming scenario. Figure 3 shows the estimates of the impact of two degrees of warming on yields for the crops analyzed. The model predicts large negative impacts on cherries; negative, but uncertain, impacts on peaches; and a slight negative yield impact for berries.

If we take a step back and assess whether we have the necessary information to plan for the decades of warming ahead, I would argue that we are ill-prepared. We simply do not have a good understanding of the climate/temperature sensitivities of California's most important crops. While there are lots of aggregate studies that look at the sensitivity of the total value of crops—or the area planted—to temperature and rainfall, these are only of limited use. We need to understand how individual crops (e.g., avocados, tomatoes, almonds, walnuts, etc.) respond to changes in the aspects of climate important to their yields.

While we have access to county-level crop reports, there is a need for academics with extensive statistical toolkits to collaborate with the agricultural organizations of the state in order to once again push the frontier of what is known. What we lack are good sources of data for the crops that are the backbone of California's agricultural sector and that are not being researched by national agricultural services due to their mostly local importance.

Further, the yield studies cited above do not do a satisfactory job at incorporating the potential for adaptation. If summers are hotter, one might shift the planting calendar forward. If climate zones shift northward, so might some agricultural production. Further, if farmers have a good understanding of the changes they will be facing in this new world, they will likely do what they have always done—innovate and meet the climate challenge head-on.

The California Department of Food and Agriculture recently convened a Climate Change Consortium for Specialty Crops, whose report outlines both impacts and strategies for resilience. This forum brought together academics, representatives from the agricultural sector, and policy makers to chart a path forward in our understanding of the challenges ahead.

While climate change is by no means the only risk California's agricultural sector faces, it is a slow-moving process, which we can anticipate to a certain degree and jointly develop adaptation strategies.

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*Maximilian Auffhammer is the George Pardee Jr. Professor of Sustainable Development in the Department of Agricultural and Resource Economics at UC Berkeley and a lead author of the recent IPCC 5th assessment report. He can be reached by email at auffhammer@berkeley.edu.*

## For additional information, the author recommends:

California Department of Food and Agriculture, 2013. "Climate Change Consortium for Specialty Crops: Impacts and Strategies for Resilience." www.cdfa.ca.gov/environmentalstewardship/pdfs/ccc-report.pdf.

Lobell, D.B., and C. Field, 2009. "California Perennial Crops in a Changing Climate." *CEC PIER Program Report*. www.energy.ca.gov/2009publications/CEC-500-2009-039/CEC-500-2009-039-F.PDF.

Lobell, C.B. Field, K.N. Cahill, C. Bonfils, 2006. "Impacts of Future Climate Change on California Perennial Crop Yields: Model Projections with Climate and Crop Uncertainties," *Agricultural and Forest Meteorology* 141(2–4): 208-218. ISSN 0168-1923, http://dx.doi.org/10.1016/j.agrformet.2006.10.006.

Berkeley Earth Project. http://berkeleyearth.org/