Research on Climate Change Impacts and Associated Economic Damages

Wolfram Schlenker
Columbia University and NBER

For most of human history, agriculture accounted for the dominant share of GDP and employed most labor. Johnson (1997) estimates that in 1800 about 75-80% of the labor force in developed nations was engaged in farming. Before 1930, production increases were mainly driven by an expansion of the farming area while yields (output per area) remained flat. The picture flipped around 1930, when production increases switched from the extensive to the intensive margin: increases in output mainly came from increases in yields, while the total farming area remained rather constant. Yields of most commodities increased roughly threefold in the second half of the 19th century in the United States as well as other developed countries. The large increase in yields has lead to a general downward trend in agricultural prices over the 19^{th} century. As a result, agriculture now constitutes a small share of GDP in developed countries (2-3% in the United States).

1) Why impacts on US agriculture might be economically meaningful

While agriculture is a small share of GDP, it is arguably responsible for a large amount of consumer surplus. GDP is simply the value of all produced goods and services in a country. As far back as Adam Smith, researchers have examined the paradox of "value" and asked why an essential good (water or food) can have a much lower value or price than a nonessential good (diamonds). The reason is that the price of a product is determined by its scarcity: food is currently abundant and therefore the price is low in real terms. This, however, does not mean that changes in food production have small impacts on welfare.

Demand for basic food is highly inelastic. The four basic commodities - corn, soybeans, rice, and wheat - account for roughly 75% of the calories humans consume. A demand elasticity of 0.05 for calories from these commodities implies that a 1% shortfall in production increase prices by 20%. The recent tripling of commodity prices for the basic four commodities has hardly impacted the amount of food consumed in developed countries, yet reduced global consumer surplus by roughly 1.25 trillion dollars annually (Roberts and Schlenker, 2010). Any shortfall in the production of basic food commodities has the potential for large changes in welfare.

The U.S. is by far the largest producer of basic food calories and responsible for 23% of world caloric production of the four basic commodities. Its share of basic caloric production is roughly three times as large as Saudi Arabia's share in oil production. Any impact in the United States would have repercussions on world food markets simply due to the dominating share of US production.

2) Potential climate change impacts on US agriculture

Schlenker and Roberts (2009) use a new fine-scale weather dataset that incorporates the whole distribution of temperatures within each day and across all days in the growing season to estimate the influence of various temperatures on crop growth in a county-level panel analysis in the United States. Yields increase with temperature up to 29°C (84°F) for corn and 30°C (86°F) for soybeans. If farmers could freely choose their growing conditions, a temperature of, respectively, 84°F or 86°F every day all year long would be ideal. Both lower and higher temperatures result in suboptimal yield growth. The troublesome fact though is that the slope of the decline above the optimum is about ten times steeper than the incline below it. In other words, being 1°F above the optimum reduces yields ten times as much as being 1°F below it, or, equivalently, being 1°F above the optimum reduces yields as much as being 10°F below it. The strong relationship between temperatures above the optimum and yields implies that roughly half of the year-to-year variation in crop yields can be explained by one single measure: how often and by how much temperatures exceed the crop-specific optimum. The concept of degree days simply adds all temperatures above the optimum for each day. One day that is 10 degrees above the optimum is as harmful as 10 days that are 1 degree above the optimum. Corn futures markets confirm this highly significant relationship: futures prices for deliveries at the end of the growing season are highly sensitive to extreme heat events during the growing season, but not average temperature.

Climate change is predicted to increase the daily minimum and maximum temperatures. During the summer months, the minimum is usually below 84°F in the Midwest, the major agricultural growing area in the United States. At the same time, there are many days when the maximum temperature is above 86°F. Warming therefore has countervailing effects: shifting minimum temperatures upward closer towards the optimal growing temperature is beneficial for yields, however, shifting maximum temperatures that already exceed the optimal levels further upward decreases yields. Since the slope of the decline above the optimum is much steeper than the incline below it, the latter effect dominates, resulting in sharp net yield losses for most climate scenarios. Holding current growing regions fixed, area-weighted average yields are predicted to decrease by ~40% before the end of the century under the slowest (B1) warming scenario and decrease by ~75% under the most rapid warming scenario (A1FI) under the Hadley III model. Predicted temperature changes have larger effects that predicted precipitation changes.

Year-to-year weather fluctuations are arguably different from permanent shifts in climate. While the former are unknown at the time of planting, farmers can adapt to the latter. To examine how farmers respond to changes in average condition, one can also link *average* yields to *average* temperatures. A priori, one would have expected that areas in the Southern United States that experience temperatures above 84-86°F more frequently had an incentive to adapt to these temperatures and are hence less sensitive to extreme heat. However, the same nonlinear and asymmetric relationship is found in the time-series and cross-section. This suggests limited historical adaptation of seed varieties or management practices to warmer temperatures because the cross-section includes farmers' adaptations to warmer climates and the time-series does not. A model using farmland values instead of crop yields finds similar predicted declines if one controls for the damaging effects of extreme heat (Schlenker, Hanemann, and Fisher, 2006). Moreover, the negative coefficient on extreme heat is highly robust to various specification changes.

Similar relative sensitivities are found using a panel of yields in Africa (Schlenker and Lobell, 2010). While countries in Africa are already hotter and hence more susceptible to further temperature increases, predicted temperature increases are lower than in higher latitudes. Confidence bands on estimated yield-weather relationships are larger in Africa where both yield and weather data are measured with less precision.

3) Adaptation to climate change: evolution of heat tolerance

Given the large damaging effect of extreme heat on yields for at least two basic food commodities (corn and soybeans), the big question becomes whether technological innovation can reduce the sensitivity to these extreme temperatures. If changes in climatic conditions reduce yields, prices would rise, giving seed companies a strong incentive to innovate and make seeds more heat resistant. On the other hand, one might wonder how difficult it is from a breeding standpoint to reduce heat tolerance.

The recent past might give us some guidance: while average corn yields increased continuously in the second half of the 19^{th} century by a total factor of three, the evolution of heat sensitivity is highly nonlinear, growing with the adoption of double-cross hybrid corn in the 1940's, peaking around 1960, and then declining sharply as single-cross hybrids come online. Corn in Indiana, the state with the longest detailed daily weather record, is most sensitive to extreme temperatures at the end of the sample. Since climate change models predict an increase in extreme temperatures, the big question is whether the next breeding cycles can increase both average yields and heat tolerance simultaneously as in the period 1940-1960, or whether continued increases in average yields can only be achieved at the expense of heat tolerance as in the period from 1960 onwards. Important areas for future research are to better understand how such innovations could happen.

Genetically modified crops are the biggest hope to usher in a new era of innovation that limits a plant's sensitivity to extreme heat. To date most commercially successful genetically modified crops resist pests or herbicides. But more ambitious efforts exist to develop plants that manufacture their own nitrogen fertilizer and possess more nutrients. While public funding of basic research has diminished, private donations from charities like the Gates Foundation or by profit-driven companies like Monsanto might replace these funds. However, given public good attributes of research, there remain important questions about the extent to which private incentives to fund basic research align with potential social welfare.

4) Biofuels as mitigation option: the US ethanol mandate and food prices

Previous sections highlighted the effect of changing climatic conditions on agricultural yields. The reverse link has also received considerable attention: how does agriculture, and more specifically agricultural policies, impact climate change? Forests store a large amount of carbon, and most deforestation is done to convert forests to agricultural land. Houghton et al. (1999) estimate that 10-30 percent of fossil fuel emissions in the United States were offset by land use changes that lead to reforestation in the 1980s. By the same token, biofuel policies, especially the US ethanol mandate, have received a lot of attention as a tool to reduce CO_2 emissions and limit climate change.

Roberts and Schlenker (2010) develop a new methodology to estimate both demand and supply elasticities of agricultural commodities (maize, rice, soybeans, and wheat). While *current* weather shocks have been used to estimate demand elasticities ever since P.J. Wright introduced the concept of instrumental variables, *past* weather shocks can be used to estimate supply elasticities.

Since the estimated supply elasticity is roughly twice as large as the demand elasticity, one third of the caloric input used in biofuel production comes from reduction in food consumption while two thirds come from increases in food production. The US ethanol mandate is predicted to decrease food consumption by 1% and increase commodity prices by 20% assuming that one third of the calories used in ethanol production are recycled as feedstock for animals. Future research should examine how changes in the variance and correlation of weather shocks will impact food price spikes.

Lastly, the predicted increase in food prices due to biofuel mandates might lead to expansion of agricultural areas, which, dependent on where they occur, might result in significant increases in CO_2 emissions (Searchinger et al., 2008). This is an ongoing research area to correctly assess the effect of various mandates, e.g., the low carbon fuel standard in California.

5) References

Houghton, R. A., J. L. Hackler, and K. T. Lawrence. 1999. "The U.S. Carbon Budget: Contributions from Land-Use Change." *Science*, 285(5427):574-578.

Johnson, D. Gale, “Agriculture and the Wealth of Nations,” *American Economic Review*, May 1997, *87* (2), 1–12.

Roberts, M. J. and W. Schlenker, “Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate” *NBER Working Paper 15921*, 2010.

Roberts, M. J. and W. Schlenker, “The Evolution of Heat Tolerance of Corn: Implications for Climate Change,” *NBER Conference Volume: The Economics of Climate Change – Adaptations Past and Present*, 2011.

Searchinger, Timothy, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change.” *Science*, 319(5867): 1238-1240.

Schlenker, W., W. M. Hanemann, and A. C. Fisher, “The Impact of Global Warming on U.S. Agriculture: An Econometric Analysis of Optimal Growing Conditions,” *Review of Economics and Statistics*, 2006, 88(1), p. 113-125.

Schlenker, W. and M. J. Roberts, “Non-linear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change,” *Proceedings of the National Academy of Sciences*, 2009, 106(37), p. 15594-15598.

Schlenker, W. and D. B. Lobell, “Robust Negative Impacts of Climate Change on African Agriculture,” *Environmental Research Letters*, 2010, 5(1), p. 1-8.