Agriculture and Forestry

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The share of employment in the agricultural sector has been continuously declining in the United States. In 1870, roughly 70-80 percent of the workforce was employed in agriculture. This share has dropped to 2-3 percent in today's economy. Employment in the agricultural sector decreased by 1.8% per year in the postwar period 1947-1985. At the same time agriculture exhibited one of the highest post-war productivity growth rate of 1.6% per year, only surpassed by communications (Jorgenson and Gollop, 1992). Many authors attribute this large increase in productivity to publicly funded research and development. In the second half of the 19th century, the Morrill Act and the Hatch Act created Land Grant universities with a mission to teach and study agriculture and created a cooperative extension service to interact with farmers.

The large growth in agricultural output is shown in Figure 1. The top row displays total production of corn, soybeans, and wheat for the years 1866-2009.[2] Each graph shows yearly outcomes as well as a trend line in grey.[3] With the exception of corn in the first half of the 20th century, production has continuously been drifting upward. The second row in Figure 1 examines more closely the source of this upward trend in production. Before World War II, yields have been rather stable over time and any increase in production was driven by an expansion of the growing area, especially in the Western United States. After World War II, growth switched from the extensive to the intensive margin: The growing area for both corn and wheat remained constant, while output per acre increased significantly due to new seed varieties and increased use of fertilizer. The exception is soybeans, a relatively new crop that is grown in rotation with corn, which showed area increase throughout the 20th century.

On a global scale, production also outpaced demand and commodity prices have been falling in real terms over the 20th century. As a result, agriculture's share of GDP is small as well: while estimates vary depending on how much of food processing and distribution is included in these calculations, the share is comparable to its employment share, i.e., 2-3 percent.

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[2] www.nass.usda.gov. The time series for soybeans does not start until 1924.

[3] The top two rows use a nonparametric smooth, while the bottom row uses a quadratic in time including confidence intervals..

Given the small share of GDP that is attributable to agriculture in the United States, some people have argued that climate change does not pose a significant threat. There are, however, three reasons why changing climate conditions might still be economically meaningful. First, while agriculture constitutes a small share of GDP, it is accountable for a sizable share of consumer surplus. Demand for agricultural goods is highly inelastic as discussed in Section 2.2 below. A shortage of food has the potential to drastically increase prices, as was evident in the fourfold price increase between 2005 and 2008. Second, agricultural production directly depends on weather fluctuations and is more susceptible to changing climatic conditions than other sectors of the economy. For example, most manufacturing today occurs within buildings, thereby insulating the process from weather fluctuations unless extreme events keep inputs or the workforce from reaching the plant. Third, agriculture in the *United States* is important as it constitutes a very large share of global production. Corn, rice, soybeans, and wheat comprise roughly 75 percent of the caloric consumption of humans (Cassman 1999). The United States share of the caloric production among these four commodities has been relatively constant around 23 percent for the last forty years. It is about twice as large as Saudi Arabia's share of world oil production (13 percent of world total, US Energy Information Administration).[4] Given its sheer size, any impact on US agricultural production can have large repercussion on world food markets. This will be topic of session 1 below.

While changing climatic conditions have the potential to impact agricultural output, the reverse is also true: agriculture and forestry have been mentioned as one of the cheapest mitigation measures to combat global warming that are immediately available. Forests store a large amount of carbon, and deforestation (mainly used to increase agricultural area) is responsible for 20 percent of annual carbon emissions (GTZ, 2007). The impact of various agricultural and forestry policies on climate change will be discussed in Section 2.

1. The Impact of a Changing Climate on Agricultural Output

Before we dive into how changing climate conditions impact agricultural output in the United States, a brief summary of predicted climate change scenarios might be in place.

[4] http://www.eia.doe.gov/emeu/cabs/Saudi_Arabia/Oil.html

1.1 Predicted Climate Change in the United States

There are roughly 20 modeling groups that utilize General Circulation Models (GCMs) to derive predicted climate change scenarios under various emission scenarios. While there are significant differences between models, some predictions are more contentious than others. Most models agree that temperatures will rise by the end of the century and that higher latitudes see large increases than the equatorial zone. The non-uniform warming scenario implies that the United States is predicted to experience much larger temperature increase than the global average. At the same time, historic variation has also been higher at northern hemisphere. Battisti and Naylor (2009) observe that equatorial regions have a higher likelihood of experiencing temperatures that are outside the historic range even though predicted temperature increases are lower. Statistically, this makes identification in the Northern Hemisphere more reasonable as larger historic variation can be used to establish a model, yet predicted climate change impacts do not require out-of-sample interpolations.

On the other hand, precipitation changes vary much more between models (and in some regions of the world models disagree whether precipitation will increase or decrease). Since predicted climate change impacts are a function of (i) the uncertainty of the climate forecast and (ii) the model uncertainty linking various weather measures to agricultural output, there is less confidence on the impact of changing precipitation than for temperature even if the model parameters are estimated with comparable precision. Similarly, changes in variability are much less well understood.

1.2 Changing Weather Conditions and Yields

Economic studies have used cross-sectional variation (Mendelsohn et al. 1994) and panel data (Deschenes and Greenstone, 2007) to link agricultural output to year-to-year weather fluctuations or weather averages. For the case of corn and soybeans, similar relationships between yields and temperatures were found using a 56-year panel of yields, a cross-section linking average yields to average weather outcomes, and a time series linking annual yields to annual weather outcomes (Schlenker and Roberts, 2009). Temperature effects were modeled using a flexible functional form: yields are increasing in temperature up until 29C (84F) for corn and 30C (86F) for soybeans, but further temperature increases are harmful to yields. The ideal growing condition would be a constant temperature of 84F for corn and 86F for soybeans. Deviations from this optimal temperature result in approximately linear yield reductions: being 4 degrees above (below) the optimal temperature is twice as bad as being 2 degrees above (below). However, the slopes of these linear declines are vastly different: Exceeding the optimal growing temperature is significantly more harmful than falling below it by the same amount. The single best predictor of year-to-year yield variability is extreme heat as measured by degree days, which is the number of degrees above a baseline, summed over all days for the growing season. For example, a temperature of 34C with a baseline of 30C would result in 4 degree days, while all temperatures below 30C would results in zero degree days. The optimal bounds are 29C for corn and 30C for soybeans.

Table 1 displays results of a time series regression linking yield shocks to weather variables of Schlenker and Roberts (2009). The weather variables were constructed for the years 1950-2005, and the analysis is hence limited to those 56 years. A weather variable is the area-weighted average of all counties. In other words, the amount of extreme heat is measured for each of the roughly 3000 counties in the United States, and the annual outcome is the average of all the county measures weighted by the harvested cropland area of the crop in question.

Columns (1) and (3) regress yield shocks on the crop-specific measure of extreme heat. The variable is highly significant and explains roughly one third of the year-to-year variation in yields. The magnitude is large: each degree above 29C (84F) for each day of the growing season reduces corn yields by 0.34 percent. Columns (2) and (4) add other control variables: a measure for the beneficial effects of moderate heat as well as a quadratic in precipitation. The R-square improves only moderately even though the number of explanatory variables increases fourfold. The precipitation variables are significant in the corn regression, but not the soybeans regression. Given the quadratic functional form, the optimal precipitation levels can be easily calculated as 18 inches for corn and 19 inches for soybeans, which are close to published estimates from the agronomic literature.

All coefficients have the expected sign: Deviations from optimal precipitation levels (both too little and too much are harmful). An increase in moderate heat (shifting from cold temperatures to moderate temperatures) is beneficial while an increase in extreme heat is detrimental. Shifting the lower (colder) part of temperature distribution towards the optimum temperature of 29C or 30C is beneficial, but the effects are dwarfed by the damaging effects of more frequent hot temperatures. The dominating factor that drives predicted yield impacts is the measure of extreme heat as (i) the magnitude of the coefficient is large, and (ii) the measure of extreme heat is predicted to increase significantly in higher latitudes as described in the previous section.

1.3 Policy Issues

The large increase in yields following World War II (green revolution) has widely been attributed to publicly funded research and development. The Consultative Group on International Agricultural Research (CGIAR) has several research centers around the world designed to improve yields of plants that are native to a region. Norman Borlaug, a previous director at CGIAR's International Maize and Wheat Improvement Center in Mexico received the Nobel Peace Prize for his work in improving yields and avoiding starvation.

While breeding new crop varieties is a long-term process, recent articles have highlighted that the budget for various CGIAR centers, e.g., the International Rice Research Institute, have been cut significantly as world production outpaced demand and lead to a downward drift in prices until 2005.[5] Climate change has the potential to severely impact yields through the higher frequency of extreme heat. One potential hedging strategy would be breeding for heat tolerance. The private sector currently focuses primarily on drought resistance. Some biotechnology companies have reported success in developing new strains with increased drought tolerance, yet critics have argued that such success has been reported before but did not materialize in the field.[6] There are very few reports on increased heat tolerance.

Heat tolerance and drought tolerance are inherently intermingled: a plant has a water requirement that increases in temperature. Seeing a wilted plant implies that it did not receive enough water, which could be caused by lower than normal precipitation or by higher than normal temperatures. While plants require more water when temperatures go up, historic weather data in the United States has shown the opposite association: there is a negative correlation between extreme heat and precipitation in the 56-year time series for corn in Table 1 as evaporation following rainfall results in cooling. This explains the highly damaging effect of extreme heat in the historic time series: water requirements increase with extreme heat, yet water availability decrease.

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[5] "World's Poor Pay Price as Crop Research Is Cut," New York Times, May 18, 2008.

[6] "Drought Resistance Is the Goal, but Methods Differ." New York Times, October 22, 2008.

A 100-year time series of corn yields in Indiana has shown that the detrimental effect of too much or too little precipitation has decreased over time (Roberts and Schlenker 2009). On the other hand, the harmful effect of extreme heat started to decrease with the introduction of double-crossed hybrid corn in the 1940s, was lowest in the late 1960s when farmers switched to single-crossed hybrids and has been increasing again since. The marginal effect of extreme heat was most damaging at the end of the sample period in 2005. This is in line with the third row of Figure 1, which shows absolute yield shocks over time: While average yields have been increasing steadily, the relative variance has remained steady over time: It is not true that plants are less sensitive to fluctuations in extreme heat now compared to 50 years ago.

2. The Impact of Agricultural Practices on Climate Change

The previous section has highlighted the effect of changing climatic conditions on agricultural yields. The reverse link has received considerable attention as well: how does agriculture, and more specifically agricultural policies, impact climate change. Forests store a large amount of carbon. Most deforestation transforms forests into agricultural land, which can lead to sizable carbon emissions, while reforestation can sequester emitted carbon. 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, biofuels have received a lot of attention as a tool to reduce CO_2 emissions.

2.1 The US Ethanol Mandate

The United States have passed an ethanol mandate, which requires refineries to blend gasoline with biofuels, primarily derived from corn-based ethanol. Burning fuels that have been grown on agricultural land is supposed to release carbon that was previously sequestered. Two issues remain: agricultural production is highly energy intensive and a sizable amount of fossil fuels is required to grow these crops. While inputs like fossil fuel and fertilizer reduce the net efficiency of biofuels, most authors argue that biofuels still result in a net decrease in emissions. The second, more controversial, issue relates to indirect land use change. If agricultural policies raise commodity prices, farmers all over the world will be induced to increase the growing area. This area expansion is likely to come from deforestation, which would result in significant CO_2 emissions (Searchinger et al. 2008).

2.2 Implications of the US Ethanol Mandate on World Food Prices

Indirect land use change directly depends on the predicted increase in commodity prices. The US ethanol mandate has the potential to significantly impact world food prices as the United States is accountable for such a large share of world agricultural production. As mentioned in the introduction, it comprises 23 percent of global caloric production in the four basic commodities corn, rice, soybeans, and wheat. The ethanol mandate shifts one third of US corn production into ethanol production, which is approximately 5 percent of world caloric production of these four staple crops.

Recent research has used exogenous yield shocks to estimate demand and supply elasticities for world agricultural commodities (Roberts and Schlenker 2010). Both are highly statistically significant. The demand elasticity is -0.055 while the supply elasticity is 0.13. The ethanol mandate is predicted to increase commodity prices by roughly 30 percent if none of the corn used in ethanol generation is recycled as feed stock. In case one third of the corn is can be recycled as distiller's grain, the price increase would scale back accordingly to 20 percent. A 30 percent price increase is equivalent to an annual 155 billion dollar loss of global consumer surplus from food consumption. While much of this loss is offset by an increase in producer surplus, it is a huge transfer from consumers to agricultural producers, especially farmers in the United States.

2.3 Policy Issues

The commodity price increase has not only distributional implications, but also impacts the efficiency to reduce CO_2 emissions. Two large agricultural exporters, the United States and Brazil, have area elasticities of 0.32 and 0.38, respectively. This expansion will likely come from deforestation, with the potential to wipe out any positive CO_2 effects of biofuels. even if the deforested area is eventually used to grow biofuels, forests would have captured a much larger amount of carbon (Searchinger et al. 2009).

3 Conclusions

This paper addresses the interplay between changing climate conditions and agricultural output. On the one hand, changing climate conditions, specifically the increased frequency of extreme heat, have the potential to significantly decrease yields of staple crops that form the basis of our caloric consumption. The big question is whether advances in biotechnology will increase heat tolerance enough to make crops more resistant to extreme heat. The recent trend, however, has been towards varieties with higher average yields that are *more* sensitive to extreme. On the other hand, policies that mandate the use of biofuels have been designed to reduce carbon emissions. The current corn-based biofuel mandate is predicted to significantly increase world commodity prices, which will induce farmers to increase the growing area. If the additional carbon emissions from this indirect land use change are included in the lifecycle analysis of biofuels, the net effect of biofuels is likely an increase in CO_2 emissions.

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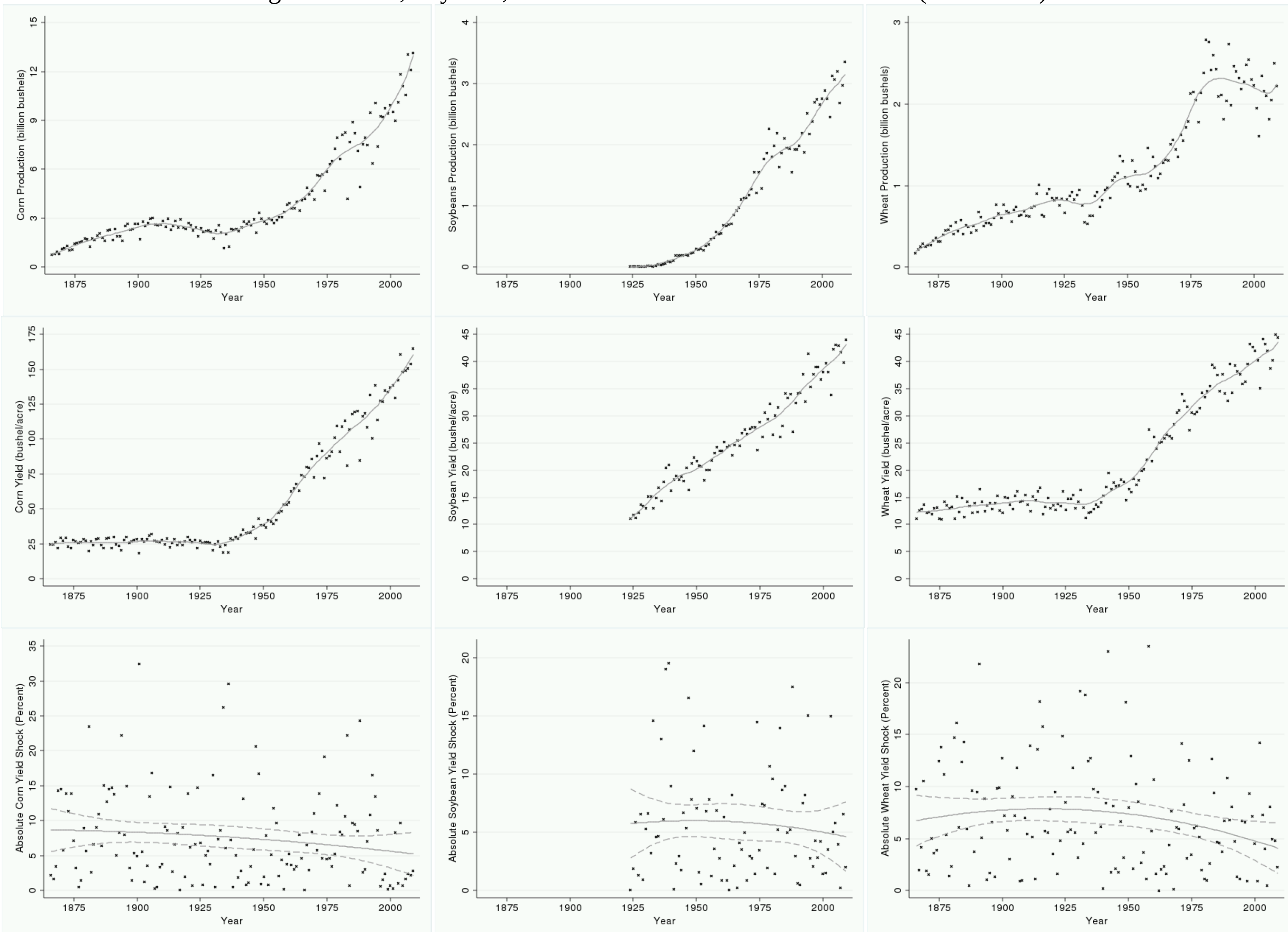
Figure 1: Corn, Soybean, and Wheat Yields in the United States (1866-2009)



Notes: Columns depict results for corn, soybeans, and wheat, respectively. The top row shows total production over time (1866-2009 for corn and wheat and 1924-2009 for soybeans). The middle row displays yields for the same time period, while the bottom row displays the absolute value of the deviation from the yield trend in percent. Yearly observations are shown as crosses. The first two rows include nonparametric trend lines in grey (Epanechnikov kernel with a bandwidth of 10 years), while the third row estimates a quadratic time tend including confidence intervals.

Table 1: The Influence of Weather on Yields

	Corn	Corn	Soybeans	Soybeans
Extreme Heat	-0.342***	-0.414***	-0.340***	-0.358***
	(0.065)	(0.075)	(0.065)	(0.082)
Moderate Heat		0.0214*		0.0101
		(0.0110)		(0.0095)
Precipitation		5.70***		3.07
		(2.11)		(1.86)
Precipitation Squared		-0.0613***		-0.0315
		(0.0214)		(0.0188)
R-square	0.3382	0.4885	0.3332	0.3825
Observations	56	56	56	56

Notes: Table regresses yield shocks (percent deviations from trend) of aggregate US yields on weather variables, which are area-weighted averages all counties for the months March-August of a given year. Extreme heat is measured by degree days above 29C for corn and degree days above 30C for soybeans. Moderate heat is measured by degree days between 0C and 29C for corn, and 0-30C for soybeans. Precipitation is measured in cm.