Understanding Productivity Growth in Agriculture: Introduction

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Abstract

Agricultural yields, i.e., production per unit area, have been increasing at a steady pace since the green revolution started in the middle of the 20th century. At the same time, inflation-adjusted agricultural commodity prices have been trending downward as increases in supply outpaced increases in demand. Recent bad weather events, biofuel mandates, and a switch to a meat-heavy diet in emerging economies that requires more calories in its production has increased commodity prices, at least temporarily. Food is an essential good, and while its price is currently low due to its abundance, it is responsible for a large consumer surplus given the highly inelastic demand. This book contains eight chapters that were presented at a NBER conference in May 2017. They examine in further detail what contributes to the remarkably steady increase in yields, i.e., how the adoption of genetically engineered crops, pest control, the diversity of the crop mix, adoption of irrigation, and climate influences productivity. Other chapters examine how government polices did help - or hinder - productivity growth, specifically through the lens of trade reform and crop insurance. The final chapter examines whether consumers are willing to pay a premium to reduce the environmental cost of agricultural intensification through water saving technologies.

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Agriculture historically employed a large share of the overall population. For example, even in 1800, more than half the population in most European countries were working in agriculture (Allen 2000). With the start of the industrial revolution and the accompanying mechanization, labor shifted out of agriculture. Still, throughout the 19th century and the beginning of the 20th century, increases in agricultural production were mainly driven by an increase in the growing area, whereas yields (output per area) were rather constant. Figure 1 displays corn yields for Iowa from 1866-2016, the longest time span for which they are available from the National Agricultural Statistics Service.[1] Yields were flat until roughly 1950, when the green revolution lead to a robust and persistent positive trend in average yields through 2016. A restricted cubic spline with 5 knots is added as a dashed line to showcase the rather smooth constant upward trend since 1950. Restricted cubic splines are local third-order polynomials between the knots, i.e., they flexibly allow for nonlinearities, yet, the trend appears linear. A similar trend break from flat average yields to monotonically increasing average yields holds for other crops and other countries, although the point at which the break occurs might diver.

The steady growth in productivity is remarkable: US agriculture exhibited one of the highest post-war productivity growth rates of 1.6% per year, only surpassed by communications (Jorgenson & Gollop 1992). This volume examines various aspects of the productivity growth in agricultural, highlighting how modern breeding methods, pest control, irrigation, or biodiversity influence productivity, and how climate change might hinder such productivity growth. Government policies, trade reform and crop insurance, are shown to have an effect on farm productivity. This productivity growth has important implication for food prices and food security across the globe.

More recent data on agricultural production is available for the entire globe: Figure 2 shows total global production of the four basic staple commodities following Roberts & Schlenker (2013). Both the Food and Agricultural Organization (FAO) as well as the Foreign Agricultural Service (FAS) of the United States Department of Agriculture (USDA) give estimates of the total amount of production for various crops from 1960 onwards. The graph shows global production quantities for the four basic staple commodities: maize (corn), wheat, rice, and soybeans that account for 75% of the calories that humans consume, either directly, or indirectly when they are used as feedstock for animals. Individual production quantities are multiplied by the amount of calories that each metric ton of a particular crop generates. Table 1 gives the caloric conversion factors for each crop. The calorie per pound numbers are taken from Williamson & Williamson (1942) and converted into how many people could be fed by one metric ton on a 2000 calorie per day diet for 365 days. These resulting unit, number of people fed for a year, are easier to interpret than trillions of calories, although a 2000 calorie per day diet that is solely based on eating corn and nothing else would obviously not be healthy or nutritiously balanced. The graph shows the numbers from the Foreign Agricultural Service through 2016. The global total is slightly higher in the FAO data, which covers

[1] https://quickstats.nass.usda.gov/

more countries that the FAS data.

Global production for soybeans is extremely smooth as idiosyncratic production shocks average out. The lines for wheat and rice have a bit more year-to-year variability around the trend, but most of the year-to-year variability is for corn. More than 40% of global corn production is located in the United States, predominantly the Corn Belt, which is susceptible to common weather shocks. The importance of trade in smoothing out production shocks is further demonstrated in Figure 3 that plots yield shocks, i.e., deviations in log yields (production per unit area) from a quadratic time trend on various geographic scales. Stafford County, Virginia is the county with the smallest growing area that continuously reports corn yields from 1960-2016. The growing area averaged 1686 acres in those 51 years, which is almost exactly twice the area of Central Park in New York City. Annual yield shocks are shown in light blue and exceed -0.6 (a decline of more than 60 log points). The largest decline during the time period is -0.69. When corn yields are averaged for the state of Virginia in the dark blue line, the variability starts to decline but is still significant as farms in Virginia face correlated weather shocks. The red line uses corn yields for the entire United States. While there are years with significant yield declines, most notably 1988 and 2012, log yield deviations never exceed -0.3. Finally, the black line shows global yield for the three largest staple commodities (corn, wheat and soybeans) by dividing the aggregate caloric production quantity from Figure 2 by the combined growing area. Soybeans were excluded as the growing area was not reported in the FAS data. The variability of aggregate global caloric yield shock is much lower than for small areas. The largest negative shock was -0.069, i.e., one tenth of that for Stafford County, Virginia.

While aggregate production variability of the four staple commodities is limited, prices can vary substantially. Figure 4 shows commodity prices in real terms from 1866-2016 as reported by the National Agricultural Statistics Service (NASS) by the United States Department of Agriculture (USDA) for the years they were available. Nominal prices were deflated to transfer them into real prices. The figure shows log prices to show relative deviations. It normalizes log prices by subtracting the mean for 1960-2016, the same time period for which global production data is available in previous figures. The first noteworthy fact is that limited aggregate global production shocks imply much larger swings in prices, suggesting that demand is highly inelastic. Second, prices have generally followed a downward trend since the middle of the 20th century, when the green revolution led to a sustained increase in agricultural output. This trend seems to stop with the onset of the 21st century, although it is too early to tell from the graph whether recent price drops will revert to the previous downward trend or whether factors (climate change, emerging countries that switch to a more meat heavy diet that requires more calories, and biofuel mandates) have led to a breakpoint where demand increases start to outpace supply increases. When prices tripled in the early 2000s, they were still low in real terms by historic standards.

One of the “fathers” of the Green Revolution, Norman Borlaug, was awarded the 1970 Nobel

Peace Price for his contribution to ending world hunger by boosting agricultural productivity around the globe and making basic calories cheaper. Will productivity continue to increase through the adoption of new technologies or cropping practices? Will it be limited through climate change or policies that encourage maladaptation? The remaining chapters examine various aspects.

Lusk, Tack & Hendricks (2018) examine the role of genetically engineered (GE) corn on yields using a panel of county-level corn yields in the United States from 1980-2015 that is matched with adaptation rates of GE corn. They authors find that the adoption of genetically engineered corn has increased average yields by 17% if the adoption rate goes from zero to 100 percent. At the same time, it did not increase the resilience to heat or water stress. The gains in average yields are spatially heterogeneous and are correlated with soli quality suggesting that productivity enhancements are not uniform. Since the adoption rate has trended upwards over time, the authors emphasize the importance of controlling for time trends as well as weather, which trended over this time period.

The chapter by Huang & Moore (2018) looks at farmer responses to the US federal crop insurance program, specifically whether pre-planting precipitation, which influences soil moisture and possible planting dates, influences the insurance coverage a farmer chooses. The US crop insurance program is subsidized, as farmer premiums are not sufficient to cover average payouts. The authors utilize that in 2008, i.e., halfway through their sample period, the US farm bill temporarily introduced the Supplemental Revenue Assistance Program, which lowered farmer deductible and switched from insuring individual crops to a combined insurance for all crops grown on a farm. This gave farmers an incentive to change their crop mix as well as the insurance coverage they choose. The paper demonstrates this by compiling detailed data for each 1x1 mile section in four states: Illinois, Iowa, Nebraska and North Dakota from 2001-2014. The observed behavioral response is more pronounced in the drier states of Nebraska and North Dakota, where soil moisture at planting is crucial. The federal crop insurance program can lead to moral hazard and impair farmers' optimal responses.

Bellora et al. (2018) use a micro-level data set to examine whether crop diversity has an effect on agricultural productivity. Ecologist have long emphasized that fields that grow a set of crops will produce higher biomass than monocultures, which has been confirmed in field experiments of grasslands. The authors obtain a field-level data set for South Africa that is merged with satellite data on the Normalized Difference Vegetation Index (NDVI). Most research to date focused on developing countries, so it is informative to see whether similar results hold in emerging economies. The benefits of crop diversity might be different, e.g., because the beneficial effect of diversity on pest suppression is different in places that use different amount of pesticides. The authors have only one observation per field, and therefore have to control for various other controls. They include farm fixed effects to compare fields of different diversity within farms and find that more diverse fields are more productive.

The chapter by Carroll et al. (2018) examines the benefits of pest control on agricultural productivity in a dynamic model, highlighting that contamination not only impacts the current crop but has implication for future plantings as the pest stays in the soil. A dynamic model that incorporates these linkages gives different results than a standard static model. There is an intertemporal externality as contamination in the current period impacts pest outcomes and profits in future periods as well as supply chain externality as seed companies might deliver seeds that are contaminated and testing for the pest is costly. Specifically, the authors examine the case of *Verticillium dahliae*, a fungus that gets spread through spinach seeds and impacts lettuce crops that are grown year round in Monterrey County, California. The county grows a significant share of US lettuce. Data on pesticides use (to fumigate fields) as well as cropping choices are merged and aggregated to the monthly level. The structural model reveals that growing spinach is less desirable than what can be explained by its price for the current period - a consequence of the negative effects of possibly contaminated seeds on future productivity.

Wang et al. (2018) model the effect of climate change on US agricultural productivity using a stochastic frontier approach for the last half century (1960-2010). "Bad" weather as modeled by the temperature humidity index (heat waves) and the Oury index (droughts) is pushing yields inside the possibility frontier. The authors do not model individual crops, but state-level aggregate output and how individual variables (e.g., heat wave and droughts) push observed output inside the frontier. The effect of medium-term climate change on the production efficiency under climate change is simulated, which is generally negative, but spatially heterogeneous with the largest decrease in efficiency in the Delta Region.

The chapter by Brown, Ferguson & Viju (2018) examines the role of trade on farmer decisions. The authors study the removal of a freight subsidy in Canada that totaled 700million a year in 1995. Farmers further from a ports, who face longer transportation routes, saw a bigger wedge between the world price that is paid at the port and the realized price at the farm gate (net of transportation cost). The authors were able to utilize a micro-level Census data set on farm outcomes to study the issue of trade access and transportation cost. They find that in the short-term the shift from low-valued to high-valued crops as well as adoption of new seed varieties is driven by changes in existing farms and not by acreage changes between farms. In the long term, the opposite is true: most of the observed changes in technology can be explained by shifts in acreages to farms that utilize these technologies more.

The last two chapters examine the negative environmental externality from overusing irrigation and the willingness to pay of consumers for low-water crops. Badiani & Jessoe (2018) study groundwater use of Indian districts over time as state-level electricity subsidies change, controlling for district and year fixed effects (and controlling for weather and state elections in another specification). They authors find that changes in electricity subsidies impact aggregate water use, which in turn impacts agricultural output. While irrigation water use increases agricultural productivity, it depletes aquifers for the future. This problem is amplified when electricity prices are kept artificially low through subsidies.

Finally, Krovetz, Taylor & Villas-Boas (2018) conduct an online experiment to elicit the willingness to pay for water-saving technologies for four water-intensive crops: avocados, almonds, lettuce and tomatoes. For example, the average water use for almonds is approximately one gallon for each almond. The authors find an implicit willingness to pay of about 12 cents per gallon of water saved. Informing consumers about the drought conditions in California did not statistically significantly increase the willingness to pay. Consumers would respond to a label about the water technology used, similar to USDA organic.

Together, these chapters demonstrated that there are both technological as well as policy choices that impact agricultural productivity, and that consumers have preferences over the technology that is used to grow a crop.

Finally, each paper in this book that was presented at the NBER conference in May 2017 had a discussant, and I wanted to thank the discussants for the time they took to prepare their comments. These comments were essential in revising the presented papers before they became book chapters. The discussants of each chapter were, respectively, Michael J. Roberts (University of Hawaii at Manoa), Joshua Woodard (Cornell University), Eyal Frank (University of Chicago), Paul T. Scott (New York University), Ximing Wu (Texas A&M University), Paul Rhode (University of Michigan and NBER), Nicholas Ryan (Yale University and NBER), Dmitry Taubinsky (University of California, Berkeley and NBER). Kelsey Jack (Tufts University and NBER) and Thibault Fally (University of California, Berkeley and NBER) also discussed papers, but these papers are not included in the final volume.

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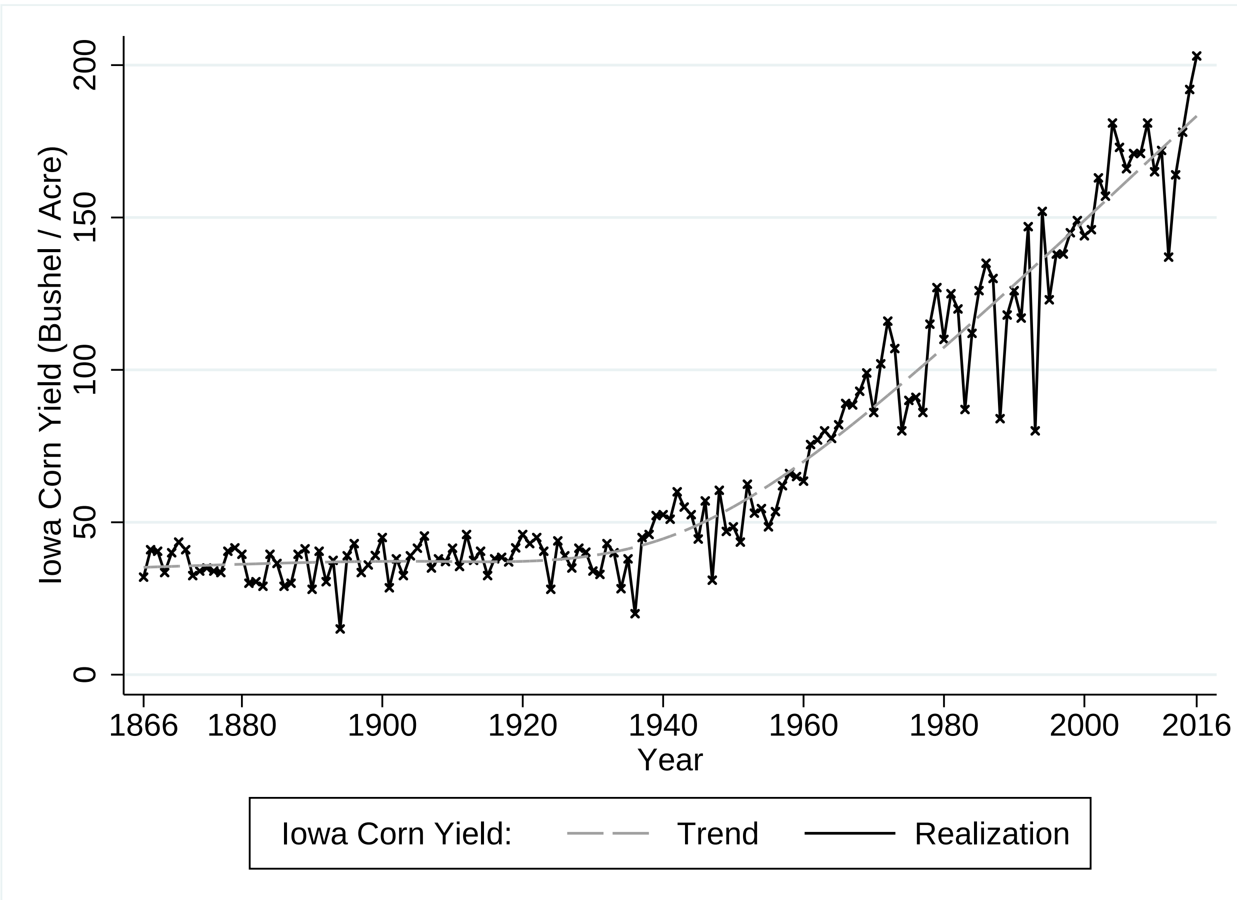
Table 1: Caloric Conversion Factors

Crop	**People Fed**
Maize / Corn	3.34
Wheat	2.99
Rice	2.84
Soybeans	4.51

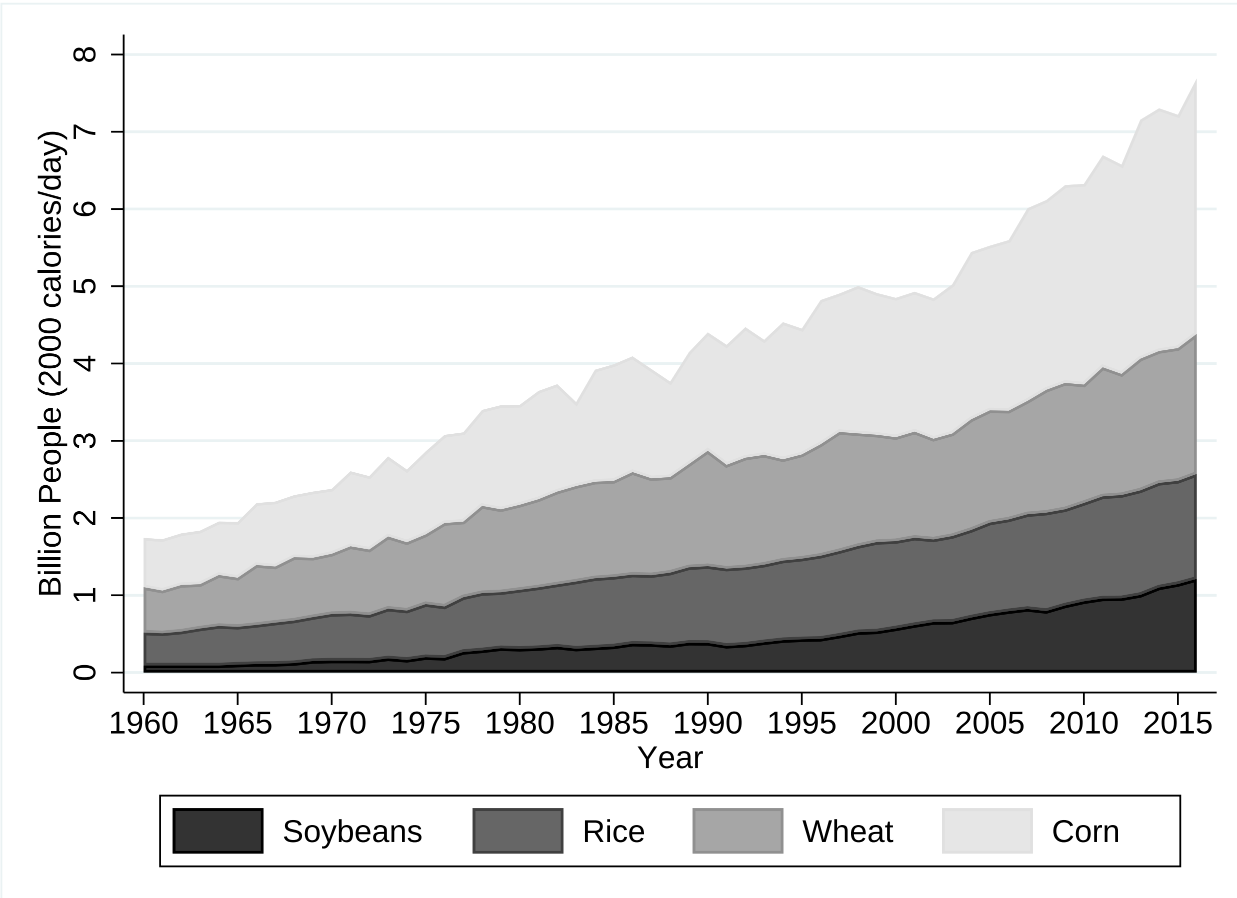
Notes: Table lists caloric conversion factors for various crops. The numbers are taken from (Williamson & Williamson 1942) and converted so the right column gives the caloric equivalent for a metric ton of a crop, i.e., how many people could be fed 2000 calories per day for a year, or 0.73 million calories.

Figure 1: Iowa Corn Yields (1866-2016)



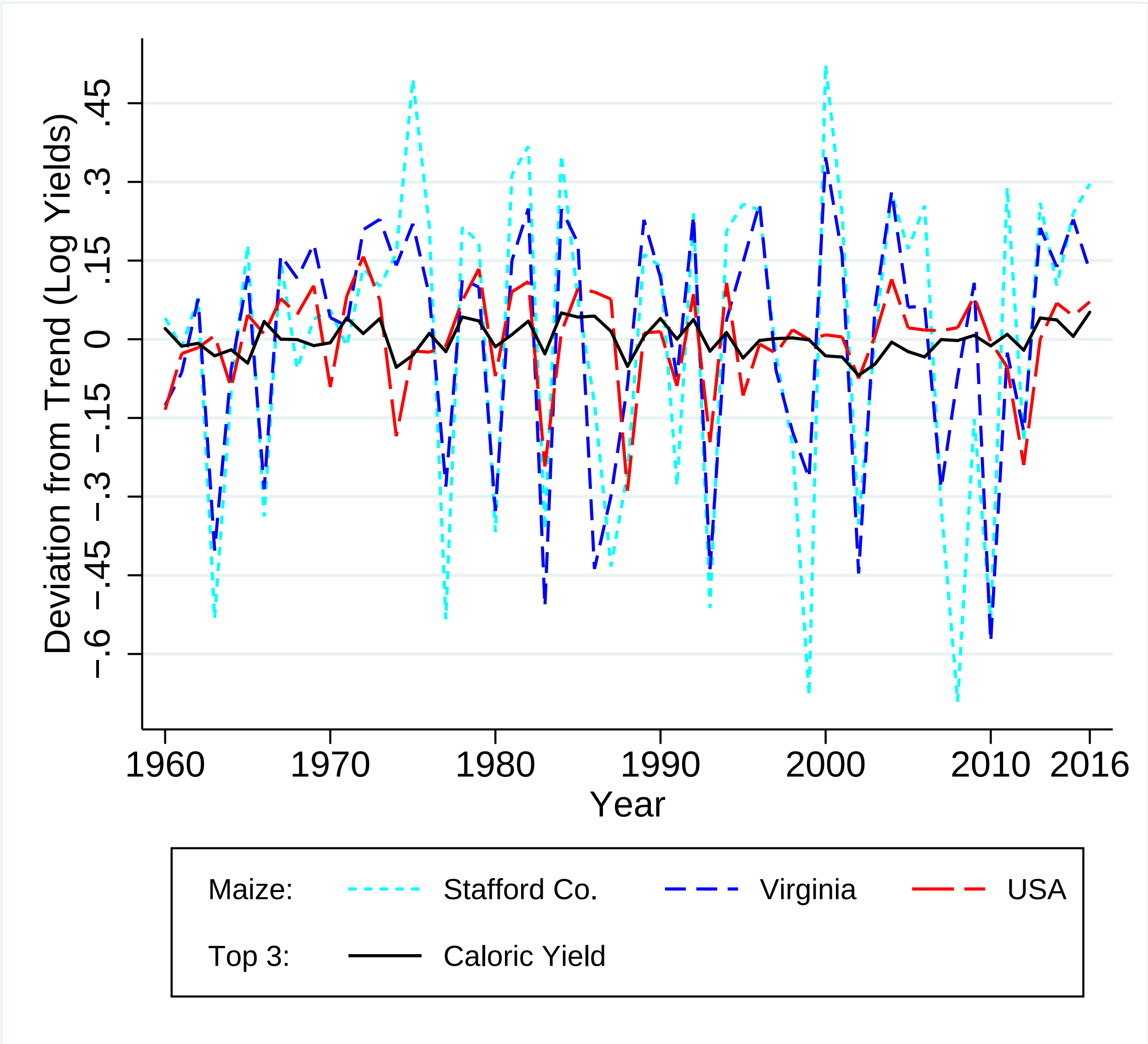
Notes: Figure displays corn yields (bushel / acre) in Iowa for the years 1866-2016 from the National Agricultural Statistics Service (NASS). The grey line shows the trend following a restricted cubic spline with 5 knots. The black line and x show realized yields in each year.

Figure 2: Global Caloric Production of Basic Staple Commodities



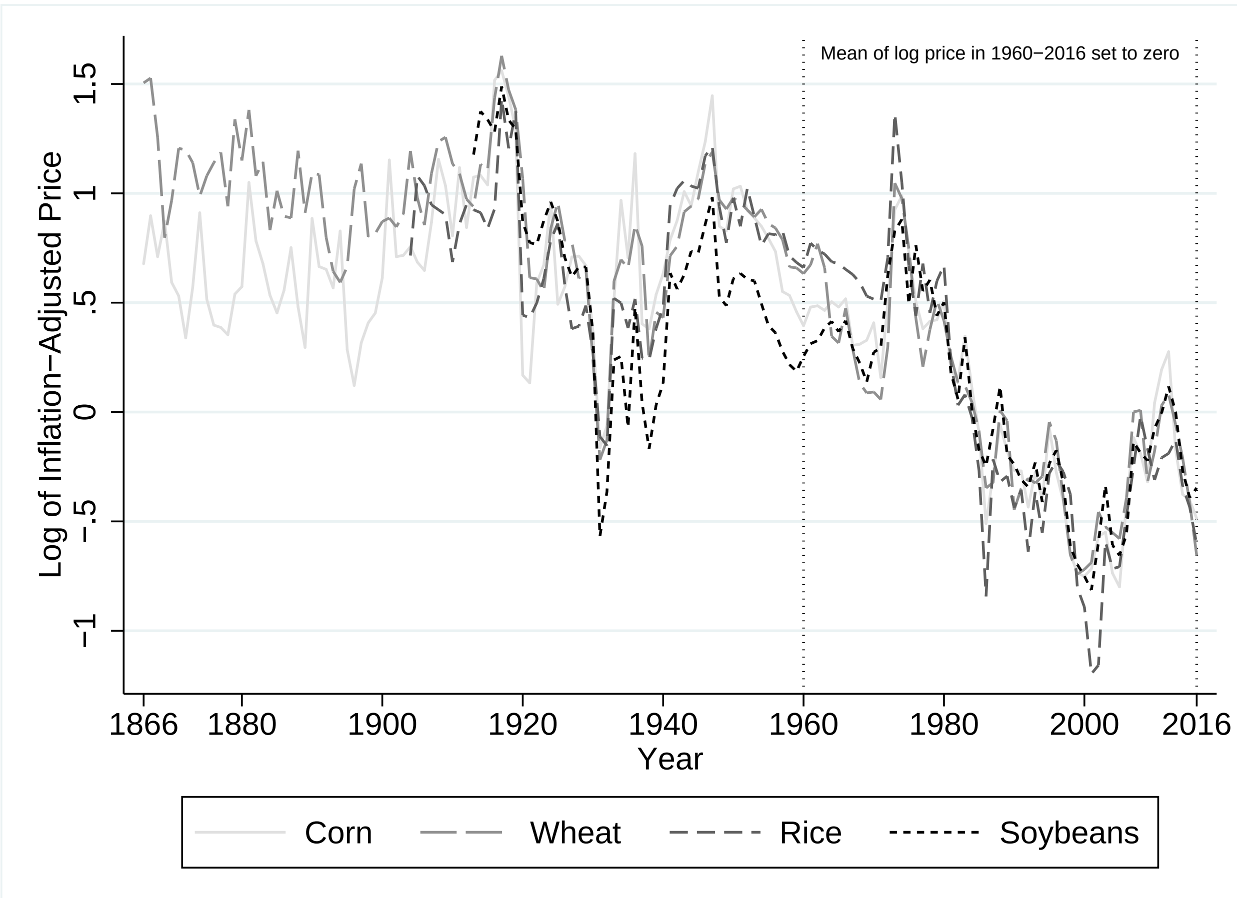
Notes: Figure displays global production of the four staple commodities (corn, wheat, rice, and soybeans) that are responsible for 75% of the calories humans consume. Total production quantities are taken from the Foreign Agricultural Statistics Service of USDA and converted into the number of people that could be fed 2000 calories per day (see Table 1).

Figure 3: Smoothing of Idiosyncratic Production Shocks Across Globe



Notes: Figure displays yield shocks (log deviations from a quadratic trend) at various geographic scales for 1960-2016. Idiosyncratic shocks average out for larger geographic scales. Yield shocks for Stafford County, Virginia are shown in light blue. It is the county with the smallest corn growing area (1686 acres on average) that reports yields every year from 1960-2016. Yield shocks for Virginia are shown as blue line, while the red line shows shocks for US corn yields. Finally, the black line shows deviations when aggregating global caloric production from corn, wheat and rice (see Figure 2) and dividing it by the combined growing area.

Figure 4: Log Crop Prices



Notes: Figure displays the log of inflation-adjusted prices for 1866-2016 using the Minneapolis Federal Reserve's long-term CPI. Price series were normalized by subtracting the mean for 1960-2016.