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Introduction

Wolfram Schlenker

Agriculture historically employed a large share of the overall population. For example, as recently as 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 I.1 displays US corn yields from 1866 to 2016. Yields were flat until roughly 1950, when the Green Revolution led to a robust and persistent positive trend in average yields through 2016. The yield trend is added as a dashed black line showcasing the switch from constant average yields prior to 1950 toward a rather smooth constant upward trend following 1950. The steady growth in productivity is remarkable: US agriculture exhibited one of the highest postwar productivity growth rates of 1.6 percent per year, only surpassed by communications (Jorgenson and Gollop 1992).

On the other hand, the thick dashed line in figure I.1 displays the trend in the variability of yields around the trend—specifically, the trend in absolute yield deviations from the yield trend. When average yields started to increase, so did yield shocks (deviation from the average). The United States had tremendous technological progress in average yields, which increased by a factor of six between 1950 and 2016. At the same time, there was no prog-

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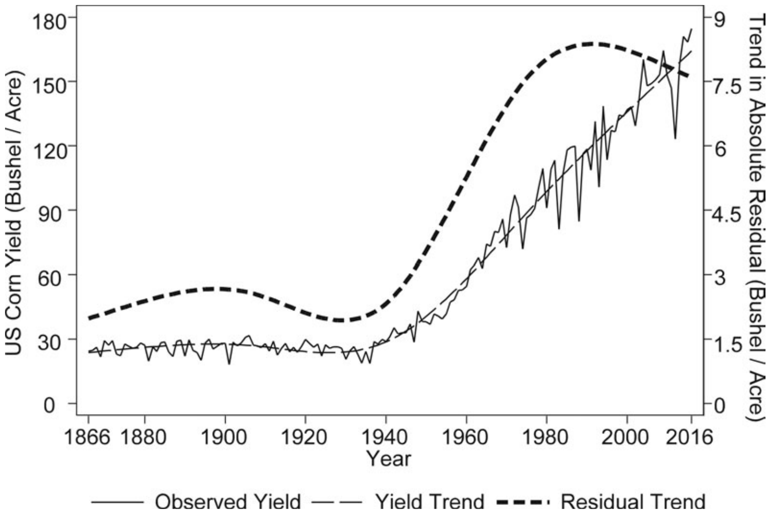

Fig. I.1 US corn yields (1866 to 2016)

Notes: This figure displays US corn yields (bushel/acre) for the years 1866 to 2016 from the National Agricultural Statistics Service (NASS). The solid line shows realized yields in each year. The dashed line shows the trend in yields. The thick dashed line shows the trend in the absolute residual, where the scale is given on the right vertical axis. All trends are estimated using restricted cubic splines with five knots, which are local third-order approximations.

ress in determining how well plants can withstand year-to-year shocks. The coefficient of variation—that is, the standard deviation of the fluctuation around the mean divided by the mean—remained rather constant. Empirical studies therefore often focus on relative yield deviations in a log model, as yield deviations are constant in relative terms.

A similar trend break from flat average yields to monotonically increasing average yields and an accompanying increase in yield variability hold for other crops and other countries, although the point at which the break occurs might differ, as might the slope.

Studying growth in agricultural productivity is still crucial, as it has important implications for food prices and food security across the globe. This book examines specific aspects of the observed productivity growth in agriculture, highlighting how modern breeding methods, pest control, irrigation, or biodiversity influence productivity and how climate change might hinder such productivity growth. Government policies in the form of trade policy and crop insurance are shown to have an effect on farm productivity.

Recent data on agricultural production is available for the entire globe: figure I.2 shows total global production of the four basic staple commodities following Roberts and Schlenker (2013). The graph shows global production quantities for the four basic staple commodities—maize (corn), wheat, rice, and soybeans—that account for 75 percent of the calories that humans

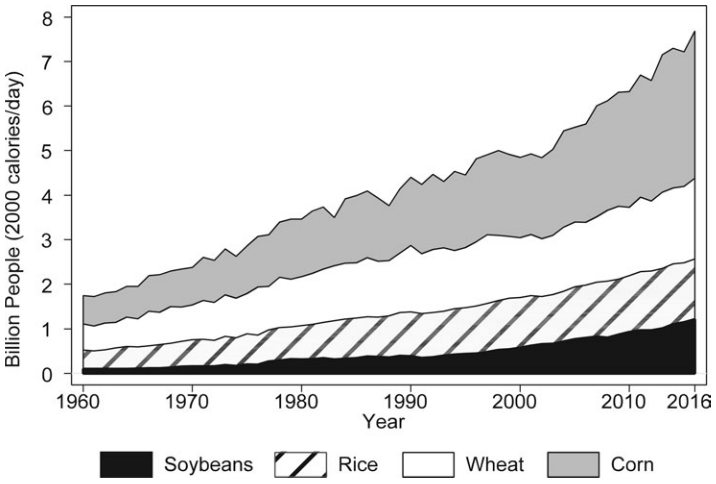

Fig. I.2 Global caloric production of basic staple commodities

Notes: This figure displays global production of the four staple commodities (corn, wheat, rice, and soybeans) that are responsible for 75 percent of the calories humans consume. Both the FAO as well as the FAS of the United States Department of Agriculture (USDA) give estimates of the total amount of production for various crops from 1960 onward. The graph uses data from the USDA Foreign Agricultural Statistics Service and converts them into the number of people who could be fed 2,000 calories per day (see table I.1).

Table I.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 and Williamson (1942) and converted so the right column gives the caloric equivalent for a metric ton of a crop—that is, how many people could be fed 2,000 calories per day for a year, or 0.73 million calories.

consume, either directly or indirectly when they are used as feedstock for animals. Individual production quantities are multiplied by the number of calories that each metric ton of a particular crop generates. Table I.1 lists the caloric conversion factors for each crop, which are taken from Williamson and Williamson (1942) and converted into how many people could be fed by one metric ton on a 2,000-calorie-per-day diet for 365 days. The resulting unit, number of people fed for a year, is easier to interpret than trillions of calories. Obviously, a 2,000-calorie-per-day diet that is solely based on eating corn and nothing else would not be healthy or nutritiously balanced. The graph relies on data from the Foreign Agricultural Service (FAS) through

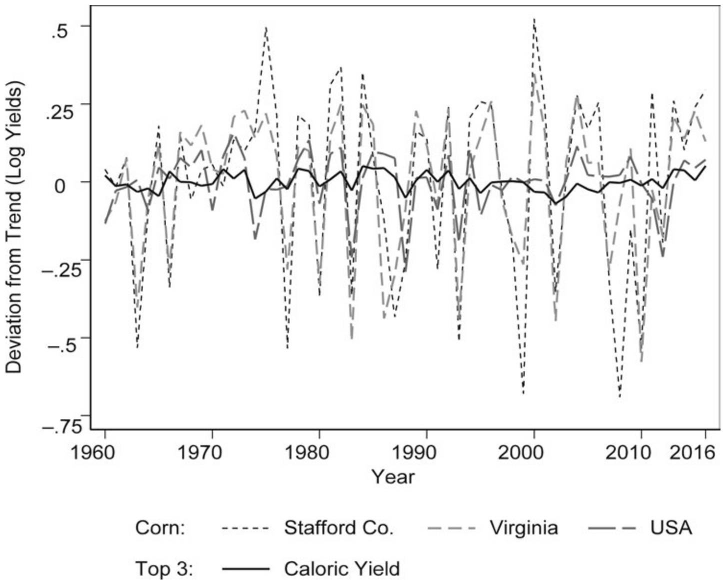

Fig. I.3 Smoothing of idiosyncratic production shocks across globe

Notes: This figure displays yield shocks (log deviations from a quadratic trend) at various geographic scales from 1960 to 2016. Idiosyncratic shocks average out for larger geographic scales. Yield shocks for Stafford County, Virginia, are shown in gray. It is the US county with the smallest corn-growing area (1,686 acres on average) that reports yields every year from 1960 to 2016. Yield shocks for Virginia are shown as a gray dashed line, while the long-dashed line shows shocks for aggregate US corn yields. Finally, the solid line shows yield shocks by aggregating global caloric production from corn, wheat, and rice (see figure I.2) and dividing it by the combined growing area.

2016. The global total is slightly higher in the Food and Agricultural Organization (FAO) data, which covers more countries than the FAS data.

Global production for soybeans is extremely smooth, as idiosyncratic production shocks average out. The lines for wheat and rice have slightly more year-to-year variability around the trend, but most of the year-to-year variability is observed for corn. The reason is that more than 40 percent of global corn production is located in the United States—predominantly in the Corn Belt, which is susceptible to common weather shocks.

The importance of trade in smoothing out production shocks is further demonstrated in figure I.3, which plots yield shocks—that is, 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 to 2016. The growing area averaged 1,686 acres in those 51 years, which is almost exactly twice the area of Central Park in New York City. Annual yield shocks are shown with a small dotted line and exceed −0.6 (a decline of more than

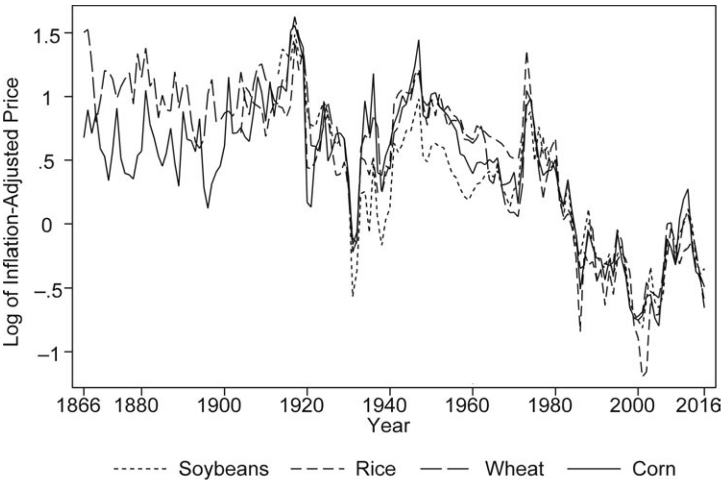

Fig. I.4 Log crop prices

Notes: This figure displays the log of inflation-adjusted prices from 1866 to 2016. The mean of log prices from 1960 to 2016 is set to zero. Nominal prices were downloaded from the NASS and adjusted to real dollars using the Minneapolis Federal Reserve's long-term consumer price index. Price series were normalized by subtracting the mean from 1960 to 2016.

60 log points). The largest decline during the time period is −0.69. When corn yields are averaged over the state of Virginia, the variability starts to decline but is still significant, as farms in Virginia face correlated weather shocks. The long-dashed line in figure I.3 displays aggregate 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 solid line shows global caloric yields for the three largest staple commodities (corn, wheat, and soybeans) by dividing the aggregate caloric production quantity from figure I.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. The largest negative shock was −0.069—that is, one-tenth the size of the maximum shock for Stafford County, Virginia.

While aggregate production variability of the four staple commodities is limited, prices can vary substantially. Figure I.4 shows commodity prices in real terms. The figure shows log prices to show relative deviations. It normalizes log prices by subtracting the mean from 1960 to 2016, the same time period for which global production data are 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 are highly correlated, as they are substitutes on the margin. Third, 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 productivity. 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 Prize 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. The first two chapters examine long-term drivers of agricultural productivity growth—specifically, the adoption of hybrid corn and changes in climatic factors.

Lusk, Tack, and Hendricks (2018) examine in chapter 1 the effect of genetically engineered (GE) corn on yields using a panel of county-level corn yields in the United States from 1980 to 2015 that is matched with adaptation rates of GE corn. The authors find that the adoption of GE corn has increased average yields by 17 percent 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 soil quality, suggesting that productivity enhancements are not uniform. Since the adoption rate has trended upward over time, the authors emphasize the importance of controlling for time trends as well as weather, which trended over the same time period.

Wang et al. (2018) model in chapter 2 the effect of climate change on US agricultural productivity using a stochastic frontier approach for the last half century (1960 to 2010). Similar to the previous chapter, the authors document spatially heterogeneous trends in weather. "Bad" weather, as measured by the temperature humidity index (heat waves) or the Oury drought index, is pushing yields inside the production possibility frontier. The authors do not model individual crops but rather 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 next three chapters examine how farmers adjust production practices to changing governmental regulations—specifically, crop insurance (chapter 3), transport subsidies (chapter 4), and electricity subsidies (chapter 5).

Chapter 3 by Huang and Moore (2018) looks at farmer responses to the US federal crop insurance program—specifically, whether preplanting precipitation, which influences soil moisture and possible planting dates, influences the insurance coverage. The US crop insurance program is highly subsidized, as premiums are not sufficient to cover average payouts. The authors address the US Farm Bill's temporary introduction of the Supplemental Revenue Assistance Program in 2008—that is, halfway through their sample period. This policy lowered farmer deductibles and moved from insurance of individual crops to a combined insurance for all crops grown on a farm. The policy change gave farmers an incentive to change their crop mix as well as their insurance coverage. The chapter utilizes detailed data for each 1 × 1 mile section in four states—Illinois, Iowa, Nebraska, and North Dakota—from 2001 to 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 is found to lead to moral hazard and impair farmers' optimal responses.

Brown, Ferguson, and Viju-Miljusevic (2018) examine in chapter 4 the role of trade subsidies on productivity measures. The authors were able to gain access to microlevel census data on farm outcomes to study the issue of trade access and transportation cost. They examine the removal of a 700-million-a-year freight subsidy in Canada and find that farmers further from a port, 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). In the short term, the shift from low-value to high-value 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.

Badiani-Magnusson and Jessoe (2018) study groundwater usage in Indian districts in chapter 5, utilizing changes in state-level electricity subsidies. The chapter uses a panel setting to control for district and year fixed effects (and controlling for weather and state elections in another specification). The 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.

The final three chapters of the book study the effects of specific farm practices on agricultural productivity and consumer demand. These include crop diversification (chapter 6), disease management (chapter 7), and water-saving methods (chapter 8).

Bellora et al. (2018) use an innovative microlevel data set to examine whether crop diversity has an effect on agricultural productivity. Ecologists have long emphasized that fields that grow a diverse set of crops will produce higher biomass than monocultures. This finding has been confirmed in field experiments of grasslands. The authors obtain field-level data 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, for example, because the beneficial effect of diversity on pest suppression is different in places that use a 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.

Chapter 7 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 also has implications for future plantings, as the pest stays in the soil. 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. A dynamic model that incorporates these linkages is developed. The authors apply their model to the case of *Verticillium dahliae*, a fungus that gets spread through spinach seeds and impacts lettuce, which is grown year-round in Monterey County, California. The county accounts for a significant share of total US lettuce production. Data on pesticides used to fumigate fields as well as cropping choices are merged. 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.

Finally, in chapter 8, Krovetz, Taylor, and 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. The average water use for almonds is approximately one gallon for each almond. The authors find an implicit willingness to pay about 12 cents per gallon of water saved. On the other hand, informing consumers about the drought conditions in California did not statistically significantly increase the willingness to pay, possibly because they were already aware of it. The study finds that consumers would respond to a label about the water technology used, similar to the USDA organic seal.

Together, the following eight chapters demonstrate 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.

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