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Climate Change and Aflatoxin in Corn

Jina Yu, David Hennessy, Jesse Tack, and Felicia Wu
jinayu@uic.edu.cn; hennessy@iastate.edu; jtack@ksu.edu; fwu@msu.edu

THE POSSIBLE impacts of climate change on field crop production are many; however, most attention to date has been paid to projecting locational effects on yield and commercial viability (e.g., Zhao et al. 2017). But an altered climate will also have more nuanced effects through impacts on grain composition, safety, and quality. Our interest here is in how changing summertime weather patterns in the US central Corn Belt can provide an opening for increased aflatoxin damage in corn.

When conditions are warm and dry in mid-summer and the crop is stressed, the fungus *Aspergillus flavus* (*A. flavus*) can colonize the corn ear, feeding on kernels and producing aflatoxins. The fungus must breach the plant's defense mechanisms to colonize, which it typically does through the silks or through insect-damaged kernels. *A. flavus* can also colonize grain stored in humid conditions.

The resulting grain is not just waste—the toxins will cause morbidity and even mortality at high doses when fed to almost any species. Hence, the US Food and Drug Administration (FDA) regulates "total aflatoxins" in human food, pet food, and livestock and poultry feed through action levels. These toxicity routes are subject to the strictest FDA aflatoxin action level: 20 parts per billion (ppb). No more than 300 ppb may be included in feed for beef cattle, 200 ppb in feed for finishing hogs, 100 ppb for poultry, and less than one ppb for milk. Consequently, affected grains are discounted at point of sale and, if contamination is severe, may have no market.

The market for biofuels is also compromised because the toxins persist after distillation and are found in concentrated amounts in the dried distillers grains co-product that is marketed as animal feed (Wu and Munkvold 2008). Because aflatoxin is a more common problem for corn produced in interior eastern Texas, Oklahoma, Kansas, and the Mississippi Alluvial Plain, the problem constrains corn production in these areas. As some of the corn produced in this region is unavailable for feed in Southern Plains cattle feedlots and southern broiler poultry farms, feed needs are met through additional shipments from the Midwest.

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Others, such as Battilani et al. (2016), note that aflatoxin-caused damage to the European corn crop will likely increase as a warming climate generates conditions favorable to the fungus *A. flavus* in more northerly parts of the continent. In what follows, we review and discuss recent findings by Yu et al. (2022) on how changing weather patterns may induce a similar northerly migration of occurrence here in the United States.

Historical patterns in insurance claims

As far as we know, in no grain-growing region of the world do grain intake facilities report aflatoxin test results to entities that make summary data available. Thus, evidence on the regional and temporal extent of aflatoxin incidence in commercial markets is indirect. In the United States, data are available from insurance claims made to the USDA Risk Management Agency for quality loss due to mycotoxins, where aflatoxin is the primary mycotoxin afflicting corn in the US South and in much of the Corn Belt. These data, while far from perfect, have broad coverage both temporally and spatially. For all the crops affected by aflatoxin, these insurance claims data are available at county level for each year at https://www.rma.usda.gov/SummaryOfBusiness/CauseOfLoss.

For more than 25 years, most corn acres have been enrolled in the federal crop insurance program. However, a claim is only made when the loss exceeds the deductible, a choice variable made by the farmer. In large part because insurance subsidies have become more generous over time and newer contract forms have become available, the deductible taken out by farmers has generally fallen over time such that the number of recorded claims has likely increased over time. Figure 1 shows the number of acres for which mycotoxin claims were made in Iowa, Illinois, and Indiana each year between 1989 and 2021. This figure also includes acreage claims made for mycotoxin in corn over the Central and Southern Great Plains states of Kansas, Nebraska, Oklahoma, and Texas. In the Corn Belt, the drought year of 2012 saw the most acres claimed, but claims have declined in recent years. In the Central and Southern Great Plains, 2017 saw a large number of claims but otherwise claims activity has declined since about 2014 in comparison with the 2004–2022 period. Not coincidentally, a new plant-incorporated toxin, *Bacillus thuringiensis* (*Bt*) became available around 2010. This *Bt* trait—Vegetative Insecticidal Protein (Vip)—proved very effective in preventing the sort of insect damage to the corn plant that allows for colonization by *A. flavus*. Unfortunately, evidence has emerged that resistance to these proteins is occurring in the field (Yang et al. 2021).

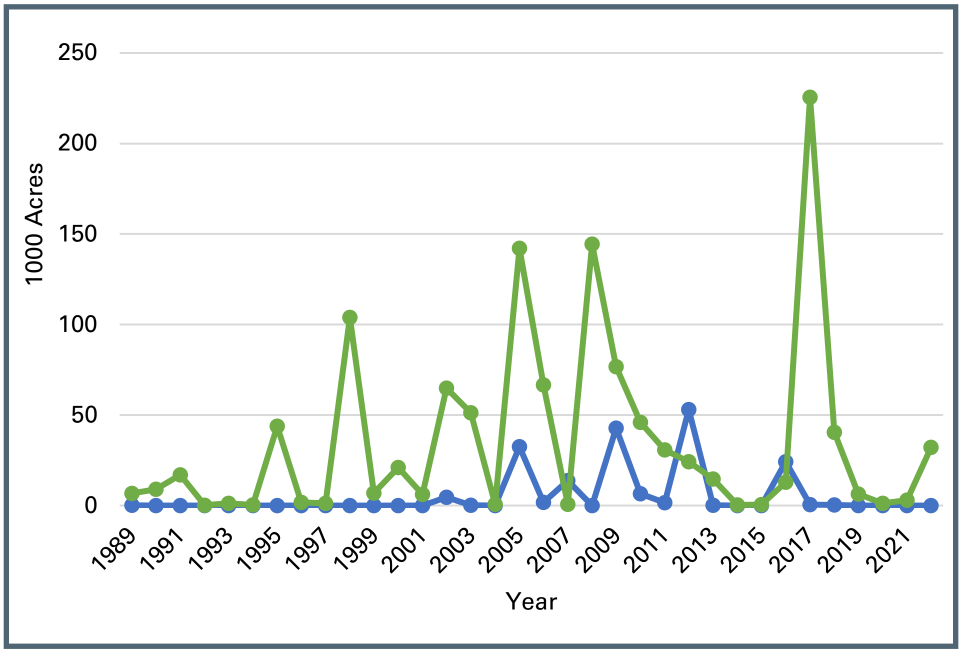

Figure 1. Acres reporting mycotoxin-related insurance claims in Iowa, Illinois, and Indiana (blue), and Kansas, Nebraska, Oklahoma, and Texas (green), 1989–2021.

Weather/climate projections

The relationship between a year's weather patterns and aflatoxin prevalence in that year is involved and somewhat challenging to identify because plant growth-stage during weather events is more relevant than calendar date. However, insights that have been well-established from laboratory and experimental trial work, as well as from the one existing study on commercial data (Yu et al. 2020) are that drought conditions in midsummer dispose a crop to colonization and that high temperatures in July are particularly problematic.

Figure 2 provides historical mean hours per day exposure to temperatures in the 30°–40° C interval over five-year historical periods, which we obtain for each county and then average across Iowa, Indiana, and Illinois. We also obtain projected future values of these variables from climate forecasting models. The represented values are from the MPI-ESM-LR climate model under the highest greenhouse gas (GHG) emission scenario, which Yu et al. (2022) use as a baseline model. The key point is that values are projected to rise (i.e., hours in which corn is exposed to hot temperatures that will render it more susceptible to *A. flavus* infection and subsequent aflatoxin contamination are expected to increase).

More generally, according to the Fourth National Climate Assessment, Midwest summers are expected to become hotter, wetter, and more humid, with more drought and flood extremes (Reidmiller et al. 2018), ideal conditions for the spread of *A. flavus*. One should bear in mind that adaptation in crop production will take place, and that some of these adaptations may reduce the impact of aflatoxin incidence. For example, the Midwestern corn growing season has already been shifting earlier because of climate change as well as altered tillage practices. In addition, irrigation is known to mitigate the incidence of aflatoxin and, water availability allowing, this may become a more common practice in Corn Belt corn production.

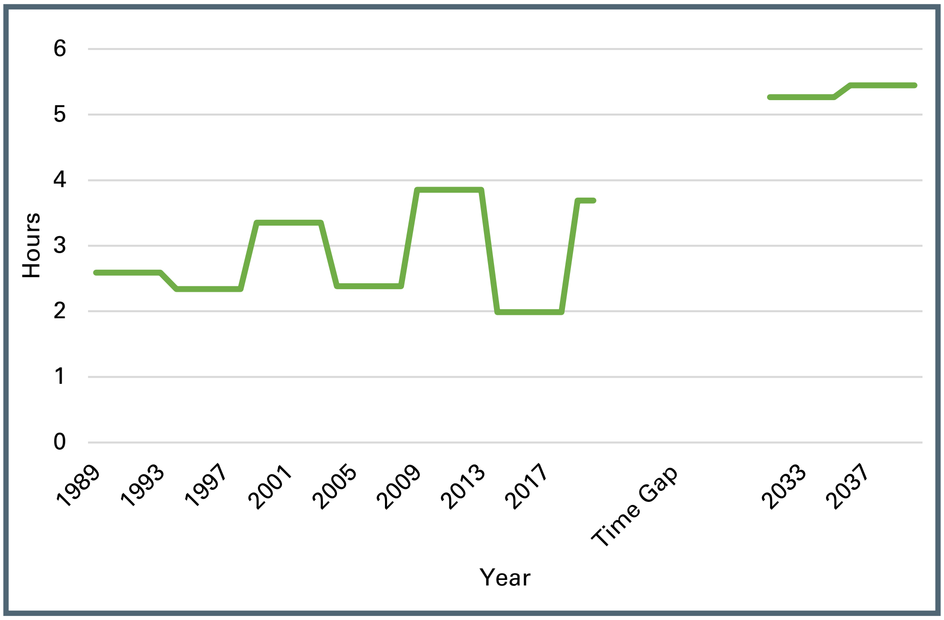

Figure 2. Temperature (30°–40° C) variations in July that are critical to aflatoxin accumulation in corn.

Note: Values show average actual or projected hours of exposure to 30°–40° C in Iowa, Indiana, and Illinois.

Table 1. Aflatoxin-related Indemnity and Loss per Year by State in 2031–2040

	2012–2021		2031–2040	
	Indemnity per year ($1,000)	Loss per year ($1,000)	Indemnity per year ($1,000)	Loss per year ($1,000)
Arkansas	773	1,105–1,545	138	197–275
Illinois	1,127	1,611–2,253	8,626	12,335–17,252
Iowa	132	189–264	1,564	2,236–3,128
Kansas	958	1,370–1916	11,764	16,823–23,528
Mississippi	696	996–1,393	457	654–915
Missouri	553	790–1,105	4,938	7,062–9,876
Nebraska	52	75–104	1,089	1,557–2,177
Oklahoma	720	1,030–1440	450	644–901
Texas	4,557	6,516–9,114	2,313	3,307–4,626

* MPI_ESM_LR model with RCP85 scenario was used as the base model in Yu et al. (2022).

Note: We multiplied Markup (1.43-2) by predicted indemnity amounts. We use MPI-ESM-LR climate model with RCP 85 scenario for prediction.

Policy issues and discussions

A long list of inquiries has been made into how climate change will affect corn production levels in the United States. Food quality consequences of climate change have received less attention than have quantity consequences, perhaps in part because quality measurements are harder to assess. It may also be true that in the United States, corn quality is not as climate-sensitive as quantity produced. Furthermore, the large majority of US corn production is destined for livestock feed and biofuel production, and not directly for human consumption in either domestic or international markets. In addition, the United States has a strong science and regulatory infrastructure to call upon to detect and regulate issues as they emerge. Nonetheless, our view is that more attention should be paid to quality and safety implications for grain production as these relate to near-term climate change.

Yu et al. (2022) use crop insurance claims data to place a monetary value on losses due to aflatoxin arising from climate change. For 15 states in the US South, Southern and Central Great Plains, Iowa, and Illinois, Yu et al. (2022) regress indemnity per premium dollar in a county on weather variables for that year as well as on a variety of controls. The approach uses Tobit analysis to account for the fact that most counties in most years saw no acres reported for mycotoxin loss. Yu et al. (2022) then insert climate projections as weather variables so as to establish how, all else fixed, changing weather patterns would affect mycotoxin claims. One adaptation allowed for was a shift in the corn growing season. Adjustments, through a markup, were then made for the fact that a claim will not be made when losses exist but are small. Table 1 reports estimates for states whose proximate locations allow for comparison with the

Corn Belt.

The model identifies a monetary loss of about $225,000 per year for Iowa over the 2012–2021 period. In constant dollar terms, this amount is projected to increase tenfold from 2031 to 2040. Illinois—the majority of which is further south than Iowa—has always had greater risk of aflatoxin in its corn crop. We also expect that Illinois will see a large increase in damage done, as will Missouri, Nebraska, and Kansas. States further south that currently have major aflatoxin problems may not see an increase in damage done. In our analysis, this is because temperatures above 40° C are not favorable for aflatoxin production. In addition, but not modeled in Yu et al. (2022), corn production becomes increasingly problematic at higher temperatures so that corn acres in the South may decline for reasons unrelated to aflatoxin.

Our analysis does not address technological adaptation. It is possible that varieties or pesticides will be developed that either directly address the fungus colonization issue or remove stressors that allow for the responsible fungi to establish. *Bt* toxins have provided protection since their commercialization in 1996 (Yu et al. 2020). However, because of high levels of use, insects have become less susceptible to these toxins. Of technologies on the horizon, new *Bt* and Vip proteins and their combinations may emerge to promote continued efficacy of *Bt* corn against insect pest damage and subsequent aflatoxin contamination. Additionally, biotech corn varieties may become available in which aflatoxin cannot thrive or becomes degraded (Wu 2022).

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World Spending on Agricultural Research and Development

Alejandro Plastina and Terry Townsend
plastina@iastate.edu; *terry@cottonanalytics.com*

IN MAY 2020, the US Department of Agriculture reported that China, followed by the European Union (EU), the United States, India, and Brazil spent the most public funds on agricultural research and development (R&D) (Fuglie and Nelson 2022). US public expenditures on agricultural R&D were about one-third lower in real terms in 2019 than at their peak in 2002 when spending, in 2019 dollars, was $7.64 billion (Fuglie and Nelson 2022). In contrast to the decline in US public expenditures since 2002, China's public expenditures on agricultural R&D (deflated by national GDP indexes) rose by a factor of approximately five in the two decades since 2000. EU expenditures rose by about one-third, India's approximately doubled, and Brazil's rose by about half. The USDA report carries an alarmist tone, suggesting that the reduction in US public spending on agricultural R&D will lead to a reduction in competitiveness in agricultural production and lower social welfare in the long term.

Public R&D vs. value of ag production

Organization for Economic Cooperation and Development (OECD) data demonstrate the relative size of public sector expenditures on agricultural research and development (OECD 2022). Between 2000–2002, annual average spending on agricultural knowledge and innovation systems rose about $1 billion (in nominal dollars) per country in the United States,[1] India, and Brazil. In contrast, China's public sector expenditures on agricultural R&D leapt by a factor of approximately five, growing from around $1.3 billion per year to $6.6 billion. In 2019–2021, China's annual average public sector expenditures on agricultural R&D were larger than in the United States, India, and Brazil combined (figure 1).

China now has the largest agricultural system in the world by value of production. As of 2019–2021, China's value of production at the farm gate was about $1.6 trillion, compared with $400 billion in the United States and India and about $200 billion in Brazil (figure 2). The structure of China's farm economy is different from the structures in the other countries because China does not have an abundance of arable land. Except for the far-West region Xinjiang, farmers in China operate relatively small farms producing high-value products such as meat and vegetables. In contrast, the United States and Brazil have larger arable areas and much smaller populations and can afford to produce huge swaths of row crops. India has a population as large as China but has more arable land and can afford to produce lower value products.

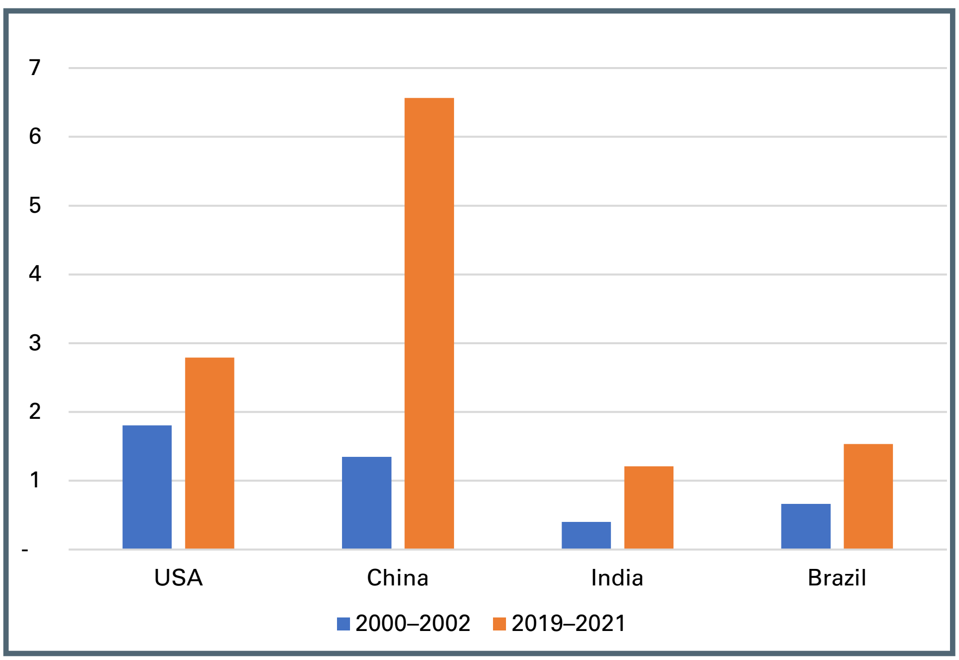

Figure 1. Spending on agricultural knowledge and innovation systems ($US/billion), 2000–2002 and 2019–2021.
Source: OECD (2022).

1. According to the OECD, investments in agricultural knowledge and innovation systems (i.e., R&D) include budgetary expenditure financing: (1) R&D activities related to agriculture, and associated data dissemination, irrespective of the institution (private or public, ministry, university, research center or producer groups) where they take place, the nature of research (scientific, institutional, etc.), or its purpose; as well as (2) agricultural vocational schools and agricultural programs in high-level education, training and advice to farmers that is generic (e.g., accounting rules, pesticide application), not specific to individual situations, and data collection and information dissemination networks related to agricultural production and marketing.

As a share of the value of agricultural production at the farm gate, Brazil's public sector expenditures on agricultural R&D were the largest in 2019–2021 at 0.9%, compared with 0.7% in the United States, 0.4% in China, and 0.3% in India (figure 3). Public sector expenditures on agricultural R&D declined as a percentage of the value of agricultural production in all countries between 2000–2002 and 2019–2021, mainly because the value of production rose.

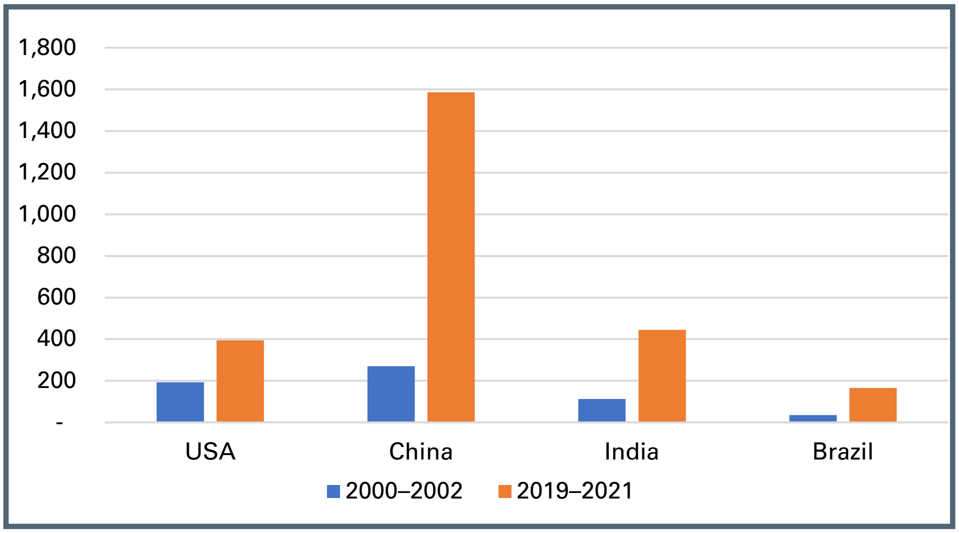

Figure 2. Value of agricultural production at the farm gate ($US/billion).
Source: OECD (2022).

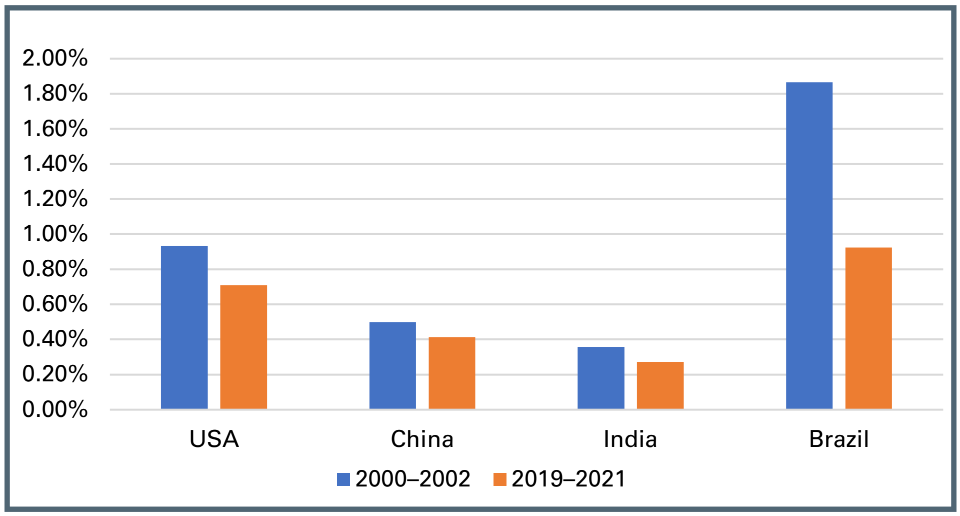

Figure 3. Spending on agricultural knowledge and innovation systems as a percent of value production.
Source: OECD (2022).

The role of private R&D

Private sector spending may offset the United States' lower public spending on agricultural R&D (Fuglie and Nelson 2022). Between 1970 and 2008, the public sector funded about half of the agricultural R&D directly used by US agriculture. However, by 2013, the publicly funded share fell to 40%–45% because real (inflation-adjusted) public agricultural R&D fell by about 20%, while real private R&D spending increased around 50%. Furthermore, if we exclude private sector expenditures on R&D for food manufacturing (figure 4), the average share of private agriculture input industries R&D increased from 38% between 1970 and 2010 to 55% between 2011 and 2014.

When we consider private sector spending, the United States is probably still the world leader in funding for agricultural R&D.

Beginning in the 1800's, the federal government funded most agricultural research in the United States because private sector firms did not have the means and because agricultural research generates significant externalities with significant public benefit. Over time, specialized firms in the farm machinery, agricultural chemical, crop seed, and other agricultural input industries grew large enough to make considerable investments in R&D. Between 1970 and 2013, private sector expenditures on agricultural R&D in the United States rose by a factor of three to about $6 billion, while public spending on agricultural R&D in the United States grew very little.

As a result, by 2013, private sector expenditures on agricultural R&D (not counting food manufacturing R&D spending) accounted for nearly 60% of total agricultural R&D expenditures. Data on private sector expenditures on agricultural R&D in the United States are not available for recent years, but the upward trend apparent between 2008 and 2013 has probably continued. By 2020, it is likely that US private sector agricultural R&D spending was between two and three times that of the public sector, meaning that total agricultural R&D spending in the United States was between $15 billion and $20 billion.

In contrast, private sector expenditures on agricultural research and development in China are, almost by definition, zero, and private sector expenditures on agricultural R&D in the EU, India, and Brazil are, at best, modest. Accordingly, total US expenditures on R&D related to agriculture are still the largest in the world, albeit by a shrinking margin as public expenditures in China, the EU, India, and Brazil rise.

There is a distinction between public and private agricultural R&D expenditures, but such expenditures tend to be complementary, rather than substitutes. Therefore, the fall in US public sector agricultural R&D spending and rise in private spending does not necessarily presage a decline in the growth rate of agricultural productivity.

Since WWII, improvements in genetics, chemicals, fertilizers, agricultural machinery, and farm management techniques have transformed US agriculture. As agricultural productivity has increased, public sector research has tended to focus on environmental impacts, animal welfare, farm worker welfare, farm structure (i.e., farm size, organization, and management), and other issues of broad public interest. Meanwhile, privately funded R&D has tended to focus on the development of marketable inputs and services eligible for patent protection.

Recent research suggests that over the last seven decades it has taken about 20 years for usable technologies to reflect advances in basic agricultural science (Clancy 2020). Given that agricultural R&D expenditures by the US private sector began exceeding public expenditures only about a decade ago, it may be another decade before the implications of reduced public sector spending become apparent.

Total Factor Productivity

Nevertheless, USDA data on total factor productivity (TFP)[2] suggest that the decline in US public sector spending on agricultural R&D may be affecting productivity growth. An index of agricultural TFP (2015 = 100) peaked in the United States at 106 in 2009 (figure 5). As of 2019, the US TFP index was 100, meaning that input use efficiency per unit of output (or output production efficiency per unit of input) in the United States actually declined by about 6% during the decade ending in 2019.

In contrast, China, India, and Brazil's TFP indexes increased between 2009 and 2019, meaning that the agricultural industries of those countries became more input use efficient (or output production efficient).

These indexes of TFP cannot be compared from one country to another. Therefore, we cannot say that as of 2019, India was the most efficient agricultural producer among the countries shown. However, we can say that productivity grew faster in India than in China, the United States, and Brazil during the past decade, rising from an index value of 81 in 2009 to 115 in 2019. Brazil's TFP index (2015 = 100) grew from 85 in 2009 to 107 in 2019, and China's rose from 89 to 105 over those same years.

Curiously, productivity growth among the countries shown was the greatest in India between 2009 and 2019. Spending on agricultural knowledge and innovation systems during 2000–2002 and 2019–2021 was lower in India than in China, the United States, and Brazil, both in absolute dollars and as a percentage of the value of agricultural production. India's TFP index probably rose faster than those of Brazil, China, and the

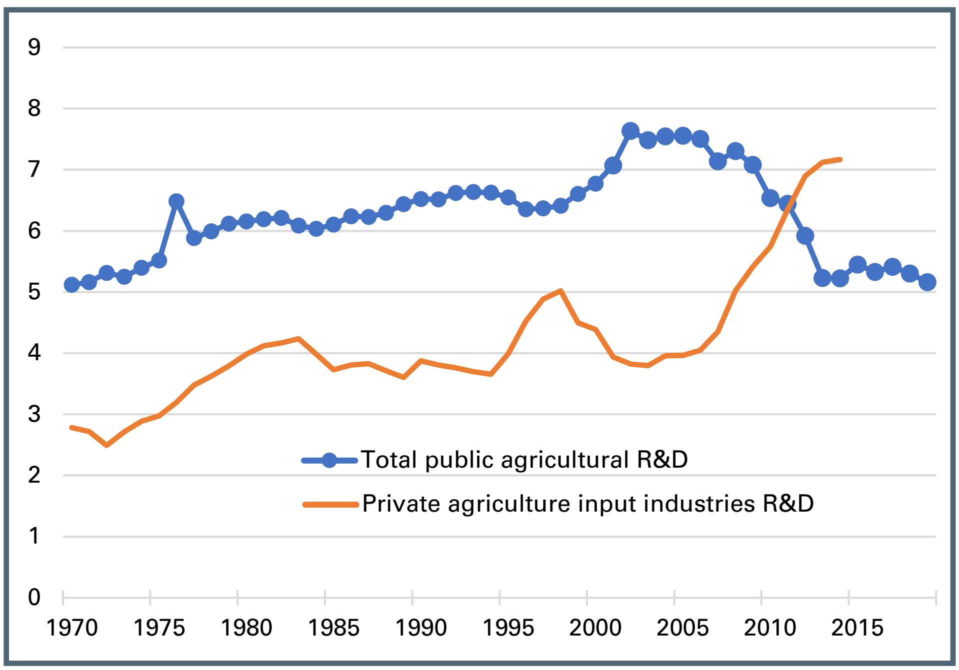

Figure 4. Real agricultural R&D funding, 1970–2019 ($US/billion, 2019 inflation-adjusted).

Source: Fuglie and Nelson (2022).

2. Total factor productivity—usually measured as the ratio of aggregate output to aggregate inputs—is a measure of productive efficiency.

United States during the last decade because India was starting from a smaller base. Nevertheless, India's TFP growth between 2009 and 2019 is still a significant achievement.

The decline in the US TFP index between 2009 and 2019 might be a result of reduced public sector expenditures on agricultural R&D after 2002, as is implied in Fuglie and Nelson (2022). With public sector spending on agricultural R&D declining, enhancements to productivity in the agricultural sector of the US economy are increasingly coming from private sector investments, which may not be sufficient to maintain growth in US agricultural input use efficiency.

However, the reduction in productivity could also reflect that a rising proportion of US public sector spending on agricultural R&D is oriented toward welfare and environmental issues, rather than traditional productivity-enhancing topics like soil science and breeding. Therefore, the decline in US agricultural input use efficiency after 2009 could reflect not just a decline in public sector R&D spending but also a shift in spending to topics that, while important, have little impact on traditional measures of productivity.

The reduction in the US TFP index could also derive from factors unrelated to agricultural R&D spending. Reduced productivity could reflect reduced investments in agricultural infrastructure in response to better opportunities for the use of capital in other segments of the US economy such as cell phones, electric cars, or space tourism.

Regardless of what caused the decline in US TFP after 2009, it is self-evident that more investment on agricultural R&D would result in more input use efficiency, other things equal. Therefore, while the

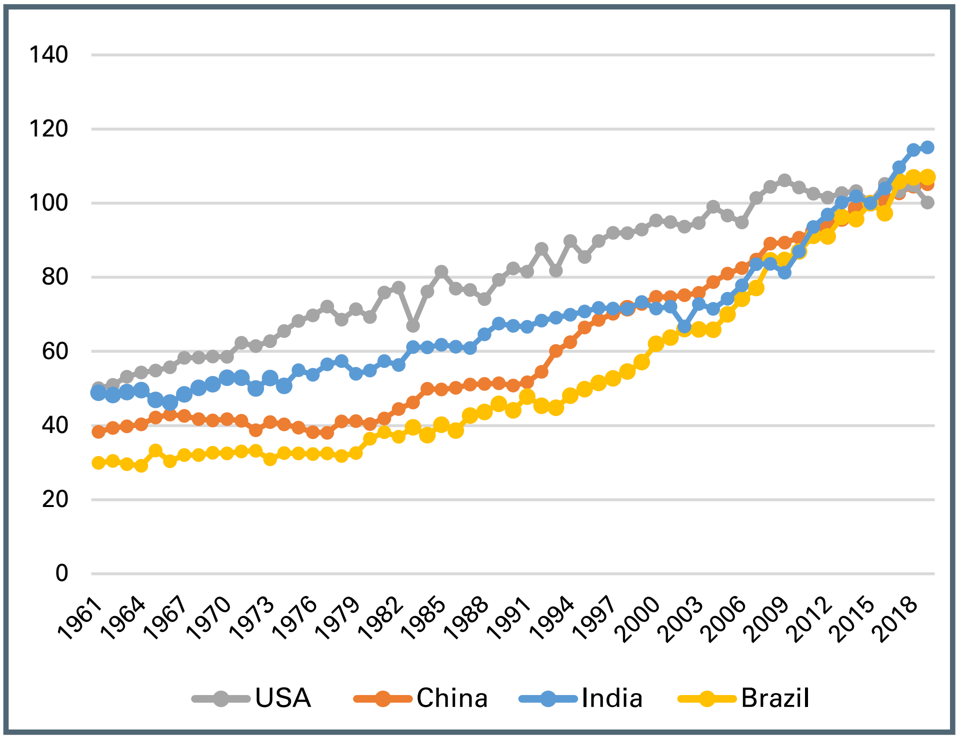

Figure 5. Total factor productivity indexes, 1961–2019.

Notes: This graph does not track relative TFP across countries, only TPF for each separate country. For each country, 2015=100.

Sources: Fuglie (2015) and Fuglie, Jelliffe, and Morgan (2022).

reduction in US public sector spending on agricultural R&D since 2002 may not in-and-of itself be a cause of a decline in agricultural productivity, it nevertheless is a subject that warrants more study.

Conclusions

US public sector spending on agricultural research and development has been declining since the early 2000's. However, US private sector spending on agricultural R&D has been climbing, and total US agricultural R&D spending (public plus private) is probably still larger than in other countries.

China's public sector spending on agricultural R&D during 2019–2021 was roughly double the level of US public sector spending and four to six times that of India or Brazil. As measured by TFP indexes, US agricultural productivity declined between 2009 and 2019; however, India, Brazil, and China's TFPs rose. Accordingly, the United States' advantage in agricultural productivity is less now than a decade ago.

It is not clear what caused the decline in US TFP between 2009 and 2019. Most likely, a multitude of factors including a reduction in public expenditures on agricultural R&D and a shift in public sector spending away from topics having a bearing on input use efficiency toward welfare and environmental issues caused the decline.

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USDA's Outlook for 2023

Lee Schulz and Chad Hart
lschulz@iastate.edu; chart@iastate.edu

EVERY FEBRUARY, the US Department of Agriculture (USDA) provides its outlook for the agricultural year ahead at its annual conference, the Ag Outlook Forum. During the forum, USDA brings together industry, academic, and government experts to discuss the major agricultural issues of the day and examine the near-term market outlook for agriculture. This year's forum follows two of the best years ever for net farm income. Farmers across the nation captured higher prices and returns for most commodities. The markets were supported by strong domestic and international demand. But with concerns about recession and inflation dominating the general economic discussion, the projections for 2023 highlight some challenges for agriculture in the year ahead.

Table 1. Cattle/Beef Statistics

		2021	2022	2023
Cattle and Calves, Jan. 1	(mil. head)	93.8	92.1	89.3
Cattle on Feed	(mil. head)	14.7	14.7	14.2
Beef Production	(bil. lbs.)	28.0	28.3	26.5
Beef Exports	(bil. lbs.)	3.4	3.5	3.1
Beef Imports	(bil. lbs.)	3.3	3.4	3.4
5-Area Steer Price	($/cwt.)	122.40	144.40	159.00

Source: USDA.

Table 2. Hog/Pork Statistics

		2021	2022	2023
Hogs and Pigs, Dec. 1 (previous year)	(mil. head)	77.3	74.4	73.1
Pork Production	(bil. lbs.)	27.7	27.0	27.4
Pork Exports	(bil. lbs.)	7.0	6.3	6.3
Pork Imports	(bil. lbs.)	1.2	1.3	1.0
National Base 51%–52% Lean Live Hog Price	($/cwt.)	67.29	71.21	66.50

Source: USDA.

Table 1 outlines some of the basic numbers for cattle/beef. For the cattle sector, producers started shrinking their cattle herds in 2020. That reduction in herd size has continued over the past three years. Within the past two years, the national herd shrank by 4.5 million animals, with most of that reduction occurring in 2022. The drought throughout the western United States over the past few years has forced a significant reshaping of the cattle industry. The lack of high-quality pasture put pressure on cattle producers to shift more heifers into feedlots and speed up the movement of cattle to slaughter plants. The result was an increase in beef production in 2022, even though the cattle herd was declining; however, that combination cannot be sustained in 2023. This year, the smaller herd will translate into fewer cattle on feed and lower beef production. The 1.8 billion pound drop in beef production will be the largest decrease since 2000. With the combination of lower production and relatively strong domestic consumption, beef exports are projected to fall by 400 million pounds while beef imports remain steady. As the herd shrank, steer prices rose significantly over the past couple of years. The outlook for 2023 shows average steer prices reaching nearly $160 per hundredweight.

Much like the national cattle herd, the national swine herd has been shrinking over the past couple of years. Over the past two years, the swine herd fell by 4.2 million head. While the drought did not directly impact the swine industry (as it did cattle), the indirect impact of higher feed costs has limited expansion opportunities. Despite the decline in animal numbers, pork production has remained above 27 billion pounds; and, just as the beef sector has experienced, domestic consumption of pork has held strong while export demand has retreated. For pork, the export decline hit in 2022, and the 2023 projection shows that decline will remain. While pork exports are still at historically high levels, the industry is feeling the retreat from the records set in 2020 and 2021. Hog prices are projected to decline, based on the higher production and smaller exports.

In total, USDA's projections are mixed for the livestock industry. The cattle sector continues to contract, leading to lower beef production and higher prices. The swine sector is also contracting, but productivity

Table 3. Corn Statistics

Marketing Year (2022 = 9/1/22 to 8/31/23)		2021	2022	2023
Area planted	(mil. acres)	93.3	88.6	91.0
Yield	(bu./acre)	176.7	173.3	181.5
Production	(mil. bu.)	15,074	13,730	15,085
Beg. stocks	(mil. bu.)	1,235	1,377	1,267
Imports	(mil. bu.)	24	50	25
Total supply	(mil. bu.)	16,333	15,157	16,377
Feed & residual	(mil. bu.)	5,718	5,275	5,600
Ethanol	(mil. bu.)	5,326	5,250	5,250
Food, seed, & other	(mil. bu.)	1,440	1,440	1,440
Exports	(mil. bu.)	2,471	1,925	2,200
Total use	(mil. bu.)	14,956	13,890	14,490
Ending stocks	(mil. bu.)	1,377	1,267	1,887
Season-average price	($/bu.)	6.00	6.70	5.60

Source: USDA.

Table 4. Soybean Statistics

Marketing Year (2022 = 9/1/22 to 8/31/23)		2021	2022	2023
Area planted	(mil. acres)	87.2	87.5	87.5
Yield	(bu./acre)	51.7	49.5	52.0
Production	(mil. bu.)	4,465	4,276	4,510
Beg. stocks	(mil. bu.)	257	274	225
Imports	(mil. bu.)	16	15	15
Total supply	(mil. bu.)	4,738	4,566	4,750
Crush	(mil. bu.)	2,204	2,230	2,310
Seed & residual	(mil. bu.)	103	120	126
Exports	(mil. bu.)	2,158	1,990	2,025
Total use	(mil. bu.)	4,464	4,340	4,461
Ending stocks	(mil. bu.)	274	225	290
Season-average price	($/bu.)	13.30	14.30	12.90

Source: USDA.

gains have offset that contraction and pork production is slowly increasing. The increasing production and lower exports are projected to lead to lower prices. The challenges within international markets are a common thread across livestock and crops.

For the crop sector, the 2020 and 2021 marketing years were record setters. The 2020 marketing year set the record for export quantities, as both corn and soybeans saw the largest numbers of bushels shipped outside the United States. The 2021 marketing year set the record for export values. While the number of bushels exported fell, the price those bushels captured increased by more than enough to offset the bushel loss and increase export value. The challenge for the 2022 and 2023 marketing years is that export quantities have continued to fall, but the price changes have also not made up the difference. Combine that with projected increases in production in 2023 and the crop outlook is for lower prices and smaller returns.

For corn, the 2021 marketing year not only set the record for export value, but also for production. While drought did take a bite out of corn production across the western United States, an overall increase in corn plantings nationwide and good yields in the eastern Corn Belt led to record production. Corn prices increased, despite the record production, due to strong domestic and international demand. In 2022, corn plantings decreased due to planting problems—mainly wet conditions during April in the Northern Plains. The continuing drought lowered yields in the Central and Southern Plains and corn production fell by 1.3 billion bushels. Corn usage retreated as well, with feed usage declining as the cattle herd shrank and export sales pulled back. The fall in production exceeded the drop in usage, so corn ending stocks tightened and corn prices rose again. The outlook for 2023 is for an increase in plantings and yield, leading to a projection of record production topping the 2021 level. Corn usage is also expected to rise, but not enough to match production. With ending stocks rising, the projected price for corn in 2023 is set at $5.60 per bushel, over a dollar lower than the average price for the 2022 corn crop.

The general pattern for the soybean market follows that of corn. The 2021 crop was a record crop and saw very strong demand. The 2022 crop was smaller as the drought brought down the national average yield and international sales shrank. Ending stocks for 2022 were lower and soybean prices increased by a dollar. The projections for 2023 show soybean plantings remaining steady at 87.5 million acres, but with soybean yields based on the historical trend, soybean production is expected to reach a record 4.5 billion bushels. Domestic usage of soybeans is expected to increase due to growth in biofuel production. Export sales are projected to increase as well, but by a smaller amount. So, as with corn, 2023 ending stocks grow and prices fall.

The full set of projections show higher production and lower prices for crops and pork, with the opposite for beef, which shows lower production and higher prices. While domestic usage for all of the commodities is still quite strong, the weakness in exports is setting the stage for lower farm revenues in 2023. The past couple of years have been lucrative for farmers as many agricultural products captured their best prices over the past 10 years, if not longer. But that run looks to be at an end.

Suggested citation

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Declining Firm Entry and Self-Employment in Small Markets

Peter F. Orazem and John V. Winters
pfo@iastate.edu; winters1@iastate.edu

THE PACE of new firm entry has declined in the United States over the past 30 years. As shown in figure 1, the entry rate, measured as the share of establishments that newly entered in the year, fell from an average of 15.6% in 1978 to 10% in 2000, and to 8.2% in 2019. The declining pace of firm entry has important consequences for employment and economic growth. New establishments are responsible for about one-third of new job creation (Decker et al. 2014). New establishments are also prone to shut down. The survivors are atypically productive, and so a high rate of firm entry and exit is credited with faster productivity growth (Decker et al. 2017). Consequently, slower pace of firm entry is blamed for the slowing of employment and productivity growth since 2000.

Figure 1 also shows that the rate of firm entry has decreased at all county population levels. However, the pace of decline is smallest in the most populous counties. In 1978, the establishment start-up rate was nearly identical in the smallest and largest counties. By 2019, the entry rate had fallen 5.5 percentage points in the smallest counties, but only 4.4 percentage points in the largest counties. As a result, more densely populated markets have the relative advantage in attracting new start-ups over rural areas.

It is possible that the greater decline in entrepreneurship in less populated markets is due to the type of businesses that atypically locate in rural areas. For that reason, we check the relative decline in entrepreneurship by sector in metropolitan and non-metropolitan markets from 2000 to 2022. We change to data on self-employment rates, which

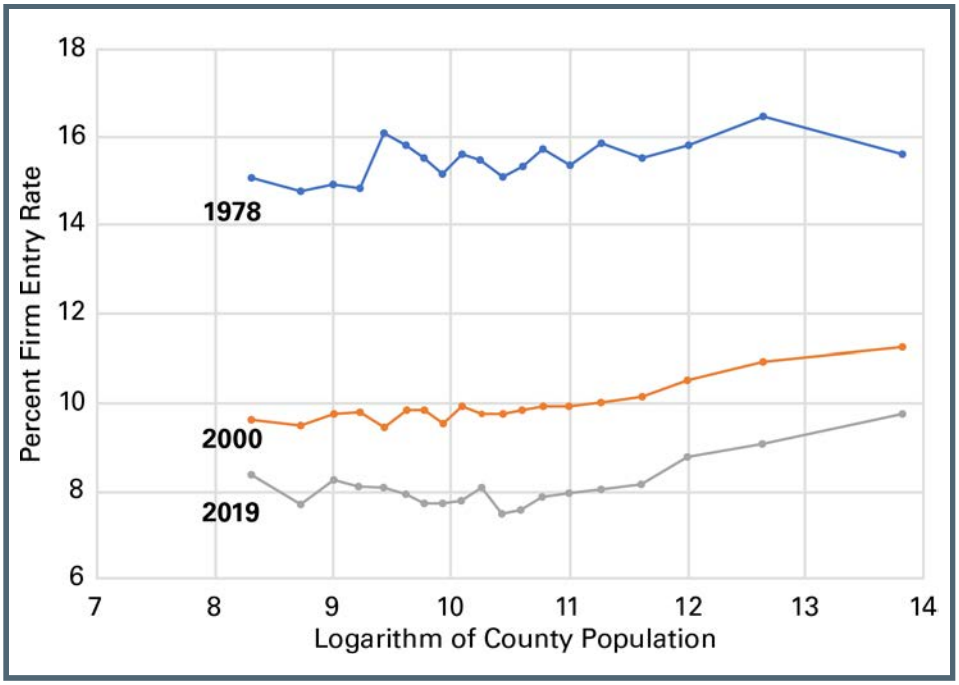

Figure 1. Firm entry rate by county population, 1978–2019.
Source: Authors' analysis of US Census Business Dynamics statistics.

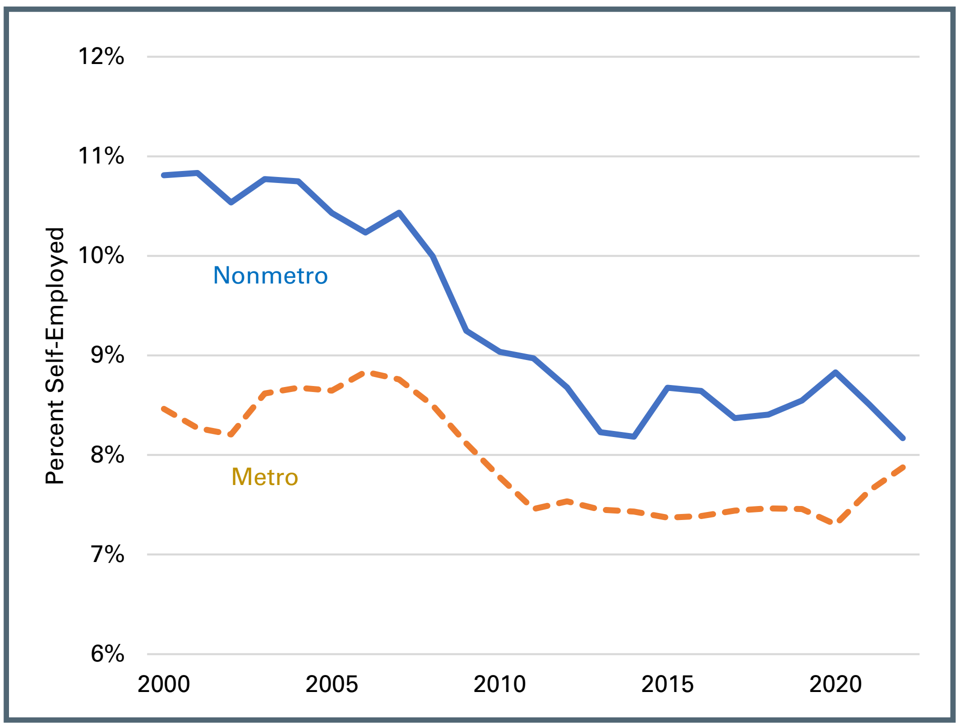

Figure 2. Metro and non-metro self-employment rates, ages 25–64, 2000–2022.

shows self-employment rates overall and in agriculture, services, and wholesale and retail trade. We restrict the data to ages 25–64 to focus on the employment decisions of individuals after leaving school and who have not retired.[1]

Figure 2 shows the pattern of self-employment rates since 2000 for population in metropolitan statistical areas (MSAs) and outside metropolitan statistical areas (non-MSAs). Consistent with figure 1, both metro and non-metro markets experienced decreasing entrepreneurship after 2000. However, the non-MSA markets had higher self-employment rates than did the MSAs.[2] As we will see, both the data on establishments in figure 1 and the data on self-employed in figures 2–5 reveal faster declines in entrepreneurship in the less-populated markets.

In 2000, the self-employment rate was 10.8% for non-MSAs and 8.5% in MSAs. The non-MSA self-employment rate began consistently declining after 2004. The MSA self-employment rate began declining in 2008. Both declined significantly during the Great Recession and the slow recovery thereof, but the cumulative decrease was more pronounced for non-MSAs. Self-employment rates appear to have leveled off by 2019 before the onset of the pandemic—the rate was 8.5% for non-MSAs and 7.5% for MSAs. However, 2020 saw notable changes in self-employment rates. The MSA self-employment rate decreased while the non-MSA self-employment rate increased in 2020. This may partially reflect preferences by footloose entrepreneurs to locate in areas less densely populated to better avoid virus exposure and/or lockdowns. It may also reflect increased

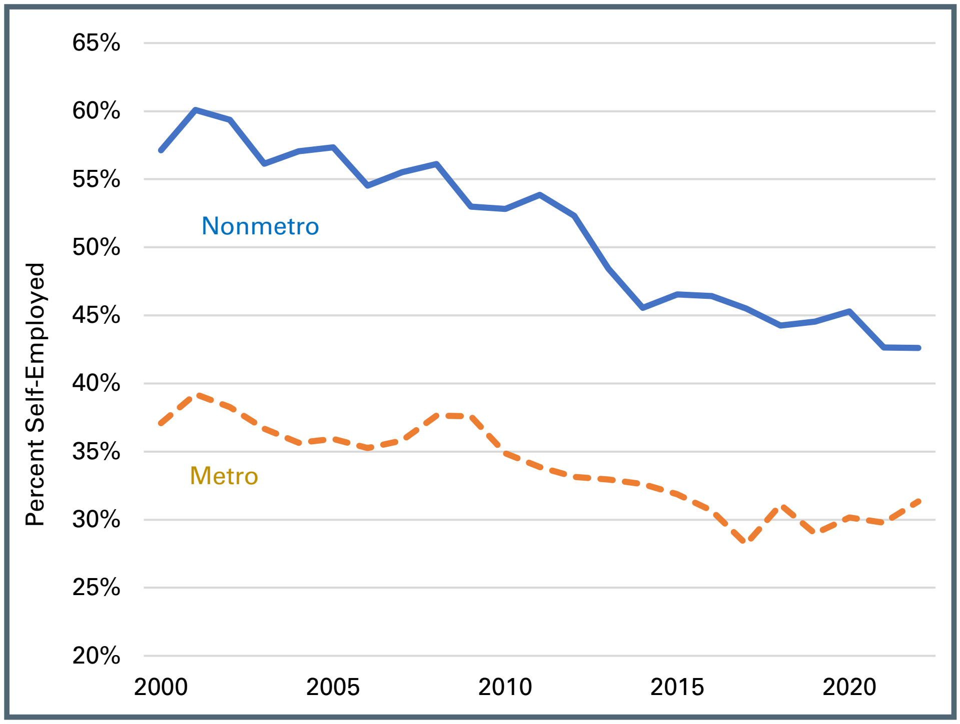

Figure 3. Agriculture self-employment rates, 2000–2022.

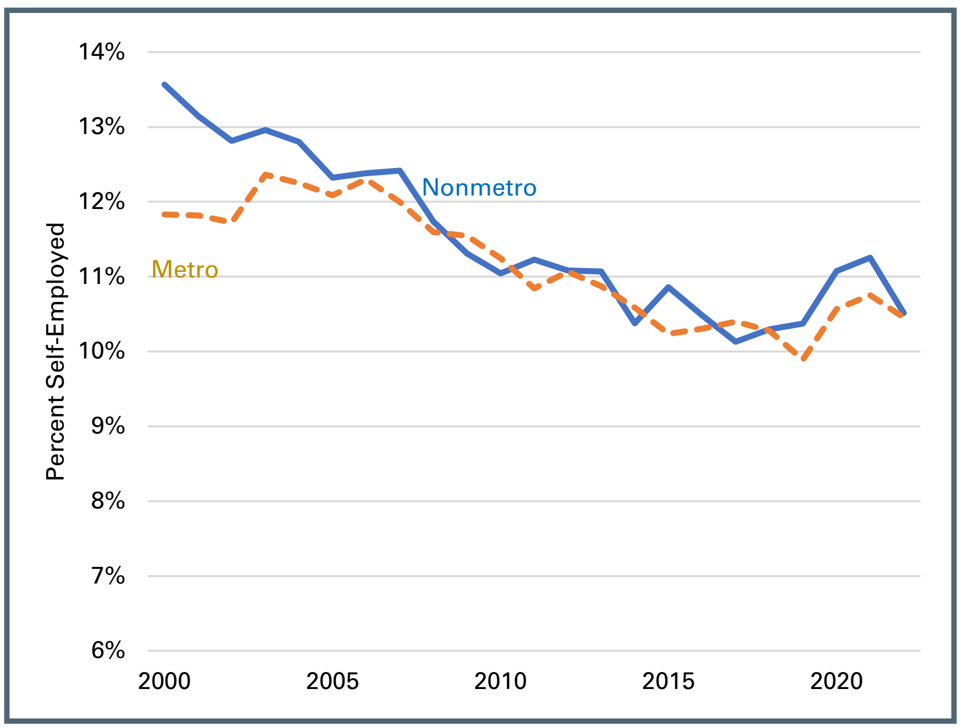

Figure 4. Services self-employment rates, 2000–2022.

1. The estimates are weighted annual averages computed by the authors from the monthly Current Population Survey (CPS) conducted jointly by the US Bureau of Labor Statistics and US Bureau of the Census and accessed via IPUMS (Flood et al. 2022). We focus on self-employment rates since 2000 because of reduced geographic precision in earlier data. We compute self-employment rates in figure 2 as the percentage of the relevant population that is self-employed, which includes persons not in the labor force.

2. The data underlying figure 1 excludes sole-proprietorships without employees. It is possible that less-populated markets have more of these sole-proprietorships.

opportunities to work from home and reduced need for face-to-face interaction. However, the rural entrepreneurship gain was short-lived. From 2020 to 2022, non-MSA self-employment rates decreased from 8.8% to 8.2%, while MSA self-employment rates increased from 7.3% to 7.9%. Thus, 2022 was a historic year for non-metropolitan self-employment rates—they reached the lowest level in recent history and the positive gap in non-MSA to MSA self-employment rates shrank to its lowest level. This has been driven by both persistent long-run declines and recent changes since 2020.

The decline in self-employment rates are somewhat of a puzzle, and we are unable to provide a full explanation. One possibility is that industrial structure may play some role. Compared to MSAs, non-MSAs have larger employment shares in agriculture, manufacturing, and mining, and less in services. Potentially, growth in service sectors related to the sharing and gig economies could increase self-employment and perhaps much more for MSAs than non-MSAs. Similarly, agricultural consolidation could reduce self-employment, with effects heavily concentrated in non-metropolitan areas.

Figure 3 shows metropolitan and non-metropolitan self-employment rates for persons employed in the agricultural industry, broadly defined to include crop production, animal production, forestry, horticulture, and agricultural services. While agriculture is relatively more important in non-metropolitan areas, there is still considerable agricultural employment in metropolitan areas, both self-employment and paid-employment.[3] However, the share of agricultural workers who are self-employed varies—it is historically higher in non-MSAs than MSAs, but agricultural self-employment rates have declined for both and the self-employment gap between non-MSAs and MSAs has shrunk. The agriculture self-employment rate in non-MSAs fell from 60.1% in 2001 to 42.6% in 2022; whereas the rate for MSAs fell from 39.2% to 31.3%.

Agriculture is not the only industry driving self-employment trend differences between non-MSAs and MSAs. Figure 4 shows that self-employment rates in services have typically declined for both non-MSAs and MSAs, but the decrease is steeper for non-MSAs. We broadly define services here to include business, professional, personal, and other services but exclude agriculture, transportation, wholesale, retail, and government.[4] Services account for roughly half of all employment in 2022. The self-employment rate in services for non-MSAs shown in figure 4 decreased from 13.6% in 2000 to 10.5% in 2022 and from 11.8% to 10.5% for MSAs during this period.

Finally, figure 5 shows self-employment rates in retail and wholesale trade.[5] The non-MSA self-employment rate fell from 15.7% in 2000 to 7.5% in 2022, a steep drop. The MSA self-employment rate fell from 12.3% to 8.8% over the same period. The change since 2019 is also especially pronounced. From 2019–2022, the self-employment rate for retail and wholesale decreased from 10.4% to 7.5% in non-MSAs and increased from 8.1% to 8.8% in MSAs.

We also examine self-employment rates in other industries and find them to be more stable over time. Self-employment trends for non-MSAs appear to be driven by agriculture, services, and retail and wholesale trade. It is not clear why exactly these industries are driving

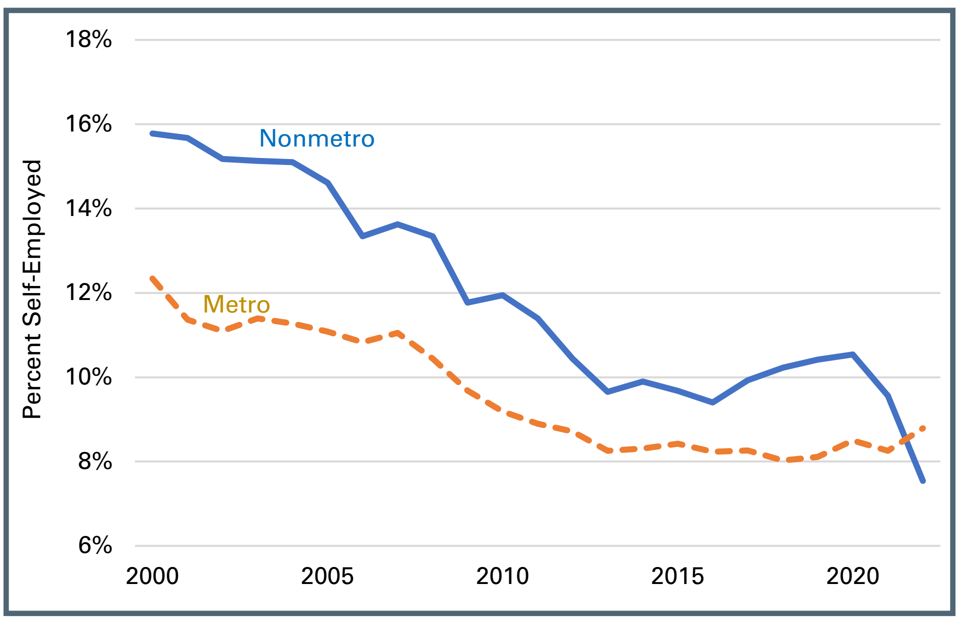

Figure 5. Wholesale and retail self-employment rates, 2000–2022.

3. In 2022, agriculture accounted for 5.8% of total employment in non-MSAs and 1.9% of employment in MSAs. Note that MSA employment includes many rural workers and farmers who live on the periphery of a metropolitan county. The data do not allow us to distinguish more specifically between urban and rural status, and we usually do not know the specific county.

4. We designate industrial codes (CPS variable ind1990) 700-893 in the IPUMS as services. In 2022, 51.8% and 40.7% of employment was in services for MSAs and non-MSAs, respectively.

5. In 2022, these industries combined to account for 13.5% of non-MSA employment and 13.0% of MSA employment. These employment shares have changed only slightly since 2000.

the change, but we can speculate. For agriculture, increased mechanization and returns to scale have led to larger farm operations and fewer small self-employed farmers. This is a long-run trend that has especially notable influences on non-MSA self-employment rates since 2000. For services, perhaps many services cannot be efficiently done at small scale by independent business owners in rural areas, facilitating greater market share for large firms. Some services are also tradeable across areas and these services may be increasingly concentrated in metropolitan areas. For example, better information and communication technology may allow rural residents to utilize financial, legal, and business services in urban areas at lower cost or higher quality and reduce the need for those services to be offered by small business owners in non-MSAs. The major decline in retail and wholesale self-employment in non-MSAs may be influenced by increased pressure from e-commerce. Non-metropolitan residents who can access a cornucopia of goods via Amazon.com and other e-commerce options may see less need to buy locally.

The decline in non-metropolitan self-employment amplifies concerns about the future of these areas and how access to goods and services have changed and will change. To the extent that consumers are using technology to better access high-quality goods and services at lower prices, it may be a good thing. However, losing some local businesses to digital competition may have adverse spillover effects for other businesses that benefit from a strong local economy. When one business shutters, it can have ripple effects to others. Additionally, having fewer non-metropolitan entrepreneurs may pose challenges for small town “main street” areas that often serve as gathering places that strengthen social interactions and are highly valued by local residents. Fewer small business owners and reduced demand for commercial space in non-MSAs may also further erode local tax bases that threaten the ability to provide public services. There is still much uncertainty and a mix of possible futures. Some non-MSAs and their people, businesses, and institutions may adapt and not be worse off, but there are also legitimate challenges and concerns involved. Small businesses are important to local areas and declining rates of local entrepreneurs warrants additional attention.

How can small towns attract new firms? Artz et al. (2021) examine the characteristics of Iowa small towns that have had the highest start-up rates since 1994. The most successful small towns had relatively educated populations, higher per capita incomes, more diverse local economies and local availability of customers and input suppliers. These factors were too important to be counteracted by local tax or subsidy policies, and so small towns cannot significantly attract start-ups by offering special tax breaks or incentive packages.

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