FEDERAL RESERVE BANK OF KANSAS CITY

ECONOMIC REVIEW

Special Issue 2019

Exploring Agriculture's Path to the Long Term

Agricultural Cycles and Implications for the Near Term

The "Normal" Normal: Supply and Demand Drivers over the Next 10 Years

Long-Run Uncertainties for U.S. Agriculture

Transitioning to the Long Term

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Foreword

Agricultural commodity producers are facing a unique challenge. Since 2013, the prices of many agricultural commodities have been low, profits have been limited, and financial challenges have emerged within the sector. Some longer-term trends, however, suggest a more positive outlook may be on the horizon. Global populations and incomes are expected to rise over time, for example, providing a foundation for broad increases in demand.

To fully capitalize on what may be a more profitable future, producers must manage the risks posed by today's low prices while they continue to lay the groundwork for the potential growth period that some predict. Recognizing this challenge, on July 16 and 17, the Federal Reserve Bank of Kansas City hosted a symposium, "Exploring Agriculture's Path to the Long Term," to identify and discuss linkages between current conditions in agricultural markets and longer-term growth prospects.

Articles prepared for this symposium are published in this volume. It is my hope that the thoughts, analysis, and insights in these articles will prove useful to those making long-term decisions within the agricultural sector as well as the many industries affected by economic conditions in agriculture.

Esther L. George
President and Chief Executive Officer
Federal Reserve Bank of Kansas City

Agricultural Cycles and Implications for the Near Term

By Ani L. Katchova and Ana Claudia Sant'Anna

U.S. agriculture has experienced several boom and bust cycles over the last century. During the 1910s and 1940s, demand for food enhanced agricultural exports and farm profitability (Henderson, Gloy, and Boehlje 2011). These booms were followed by busts in the farm economy as the economic and financial conditions changed. In the 1970s, a spike in agricultural exports led to another sharp increase in farm incomes, followed by the largest agricultural bust in recent history, the farm crisis of the 1980s. In 2006, rising commodity prices coupled with strong exports and demand for renewable fuels triggered another boom in farm incomes. Since 2013, however, the farm economy has experienced a period of declining farm incomes, lower commodity prices, and falling (though recently stabilized) land values.

While farm businesses continue to have relatively strong equity positions and historically low leverage, the prolonged period of low farm income since 2013 has eroded working capital on farms and increased financial stress. Although conditions between the two periods are notably different, this recent agricultural downturn has sparked questions about the possibility of repeating the farm crisis of the 1980s.

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The authors would like to thank Robert Dinterman for compiling the data on agricultural delinquencies and bankruptcies. The views expressed are those of the authors and do not necessarily reflect the positions of the Federal Reserve Bank of Kansas City or the Federal Reserve System.

In this paper, we explore the agricultural sector indicators of farm incomes, farm assets and debt, land values, and credit availability that help define and explain the agricultural downturn. While economic conditions have deteriorated and farmers have experienced financial stress, the financial indicators of agricultural loan delinquency rates and bankruptcy rates have remained relatively stable during the recent downturn, making a repetition of the events that occurred during the 1980s farm crisis unlikely. Despite these positive statistics, concerns remain about the duration of this downturn and the ability of farmers to weather a few more expected years of similar conditions.

I. Agricultural Sector Indicators

Several indicators for farm sector financial health are reported and analyzed by the U.S. Department of Agriculture (USDA) (Key, Litkowski, and Williamson 2018). During the last few years, there was a steep decline in agricultural commodity prices, a weaker market for farmland, and a small uptick in interest rates. Lower commodity prices result in lower cash receipts and therefore lower farm incomes. Net farm income and net cash income are important indicators of the financial health of the farm sector (Key, Litkowski, and Williamson 2018). Additional indicators include farm debt and financial solvency that can affect debt repayment capacity.

Net cash income and net farm income forecasts

The USDA's farm income estimates are the official measures of the farm sector's contributions to the national economy and play an important role in the development of agricultural policy (Schnepf 2016). Furthermore, these forecasts serve as an input in various USDA models and in GDP estimates (McGath and others 2009). The USDA farm income forecasts and estimates are widely used by policymakers and media sources to help understand developments in the agricultural economy, and they are a widely used data source for lenders and other agricultural sector stakeholders seeking to understand the magnitude and drivers of farm sector well-being. Net cash income represents the income from cash receipts, cash farm-related income, and government program payments, minus cash expenses. Net farm income is a more comprehensive measure that includes non-cash items such as changes in

inventories and depreciation. The USDA prepares and releases forecasts for the farm economy's net cash and net farm incomes in February, August, November, and February of the following year. Every August, the USDA releases official estimates of net cash and net farm incomes for the prior year. Several recent studies have looked into the accuracy, bias, and efficiency of the USDA net cash and net farm income forecasts.

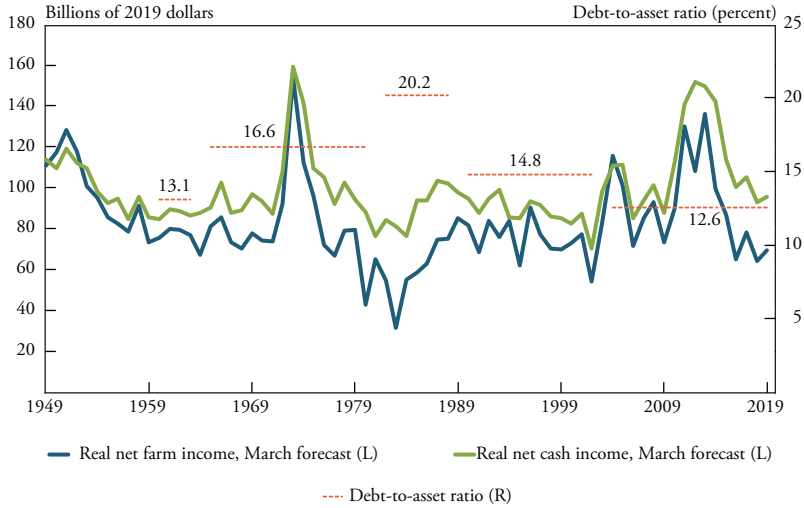
Isengildina-Massa and others (2019) show that the forecast accuracy improved at each forecast horizon over time, with later forecasts being more accurate; however, even the latest forecast made six months prior to the official estimate in August is still significantly different from the official estimate. In addition, forecasts made six to nine months prior to the official estimate are not found to be efficient, meaning that the USDA either smooths (underpredicts) or overreacts (overpredicts) when making forecasts, which later forecasts will need to correct. Bora, Katchova, and Kuethe (2019) show that if it is assumed that the USDA has an asymmetric loss function, then there is a higher cost associated with overpredicting net cash income, particularly in crop cash receipts and government payments. These findings have important implications as the farm income forecasts influence decisions made by farmers, market participants, and policymakers.

Identifying agricultural downturn through net farm and net cash income

The USDA's latest net farm income forecast, released on March 6, 2019, predicts net farm income at the end of 2019 to increase by $6.3 billion (10 percent) from 2018 to $69.4 billion in 2019.[1] If realized, in inflation-adjusted terms, this income would be about 50 percent lower than its highest levels of 2013 and below its historical average across 2000–17, according to the USDA. While there is no formal definition of the term "agricultural downturn," Oppedahl (2017) identifies 2013 as the start of the recent downturn particularly because of the decline in farm income. After farm income declined from 1990 to around 2002, there was an expansion until 2013, after which farm income again declined by about 50 percent. However, this is not the first time that net farm income has fallen in the range of $60 to $80 billion. Net farm income stayed in that range (in real terms) between the years 1959–64, 1967–71, 1976–81 and more recently 1997–2001 (Chart 1).

Chart 1

Real U.S. Net Farm Income, Net Cash Income, and Average Debt-to-Asset Ratios



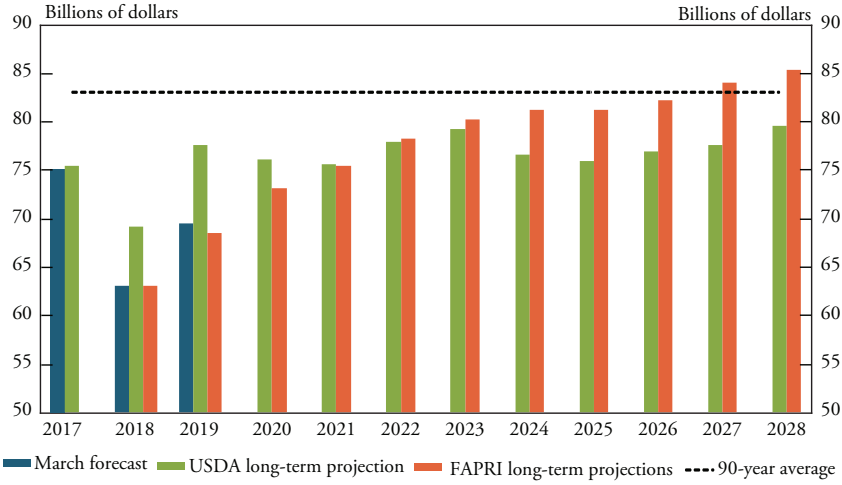
Source: USDA Economic Research Service (USDA ERS).

Is the current 2019 farm income forecast a temporary rebound or a signal of increasing farm incomes to come? Net farm income and net cash income in inflation-adjusted values remain below historical averages from 2000 to 2017, with the percent increase in net farm income still below its last increase in 2016–17. The 2019 final estimate on net farm income may be even higher than the current forecast of $69.4 billion, since the first forecast of the year is generally lower than the final estimate (Kuethe 2018). Nevertheless, for the forecast value to reach the 90-year average of $83 billion estimated by Widmar (2018), an increase of 20 percent or about $13.4 billion would be needed on top of the March 6, 2019 forecast.

The length of time during which net farm income remains below its long-term average is concerning as it may mean financial stress conditions for farmers (Widmar 2018). The year 2019 could mark the fourth consecutive year where net farm income has been below the 90-year average (Charts 1 and 2), and the sixth year of consecutive low farm incomes, indicating an agricultural downturn. Therefore, the current concern should not be whether to expect net farm income to drop to the level witnessed during the 1980s farm crisis, but rather on the length of the agricultural downturn and the toll it might take.

Chart 2

Projected U.S. Net Farm Income, 2017–28



Sources: USDA ERS and the University of Missouri Food and Agricultural Policy Research Institute.

Long-term projections for farm income

Projections from the USDA and the Food and Agricultural Policy Research Institute at the University of Missouri (FAPRI-MU) indicate that it is unlikely for net farm income to surpass the $83 billion 90-year average mark in the near future (Chart 2). FAPRI-MU projects net farm income to surpass the 90-year average mark in 2027, while projections from the USDA estimate 2028 net farm income at $79.5 billion. The USDA projects net farm income to remain in the $75 to $80 billion range, while FAPRI-MU projections are more optimistic, predicting modest increases to net farm income of 1–3 percent from the year 2021 onward.

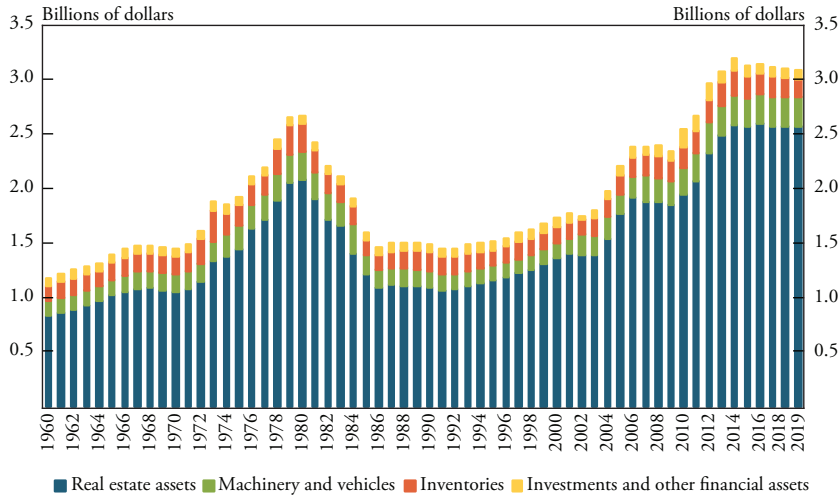
Farm assets and agricultural land values

During the recent downturn in net farm income, land (and more generally farm real estate assets) has continued to account for an important portion of total farm assets (over 80 percent) (Chart 3). The share of land in the total farm assets has increased gradually over time, reducing the relative contribution of other assets such as investments and inventories. This is why trends in land values can provide insights into farm financial stress.

Current land values are the highest seen since 1913 and appear to have stabilized at values above $3,000 per acre (Chart 4). The lowest land values

Chart 3

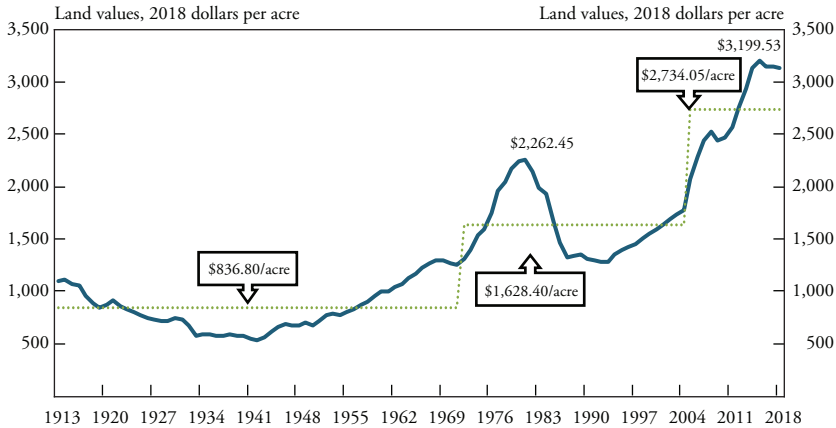
Farm Assets by Type of Asset, 1960–2019



Note: Bar for 2019 represents a forecast value.
Source: USDA ERS.

Chart 4

Land Value per Acre, 1913–2018



Source: USDA National Agricultural Statistics Service.

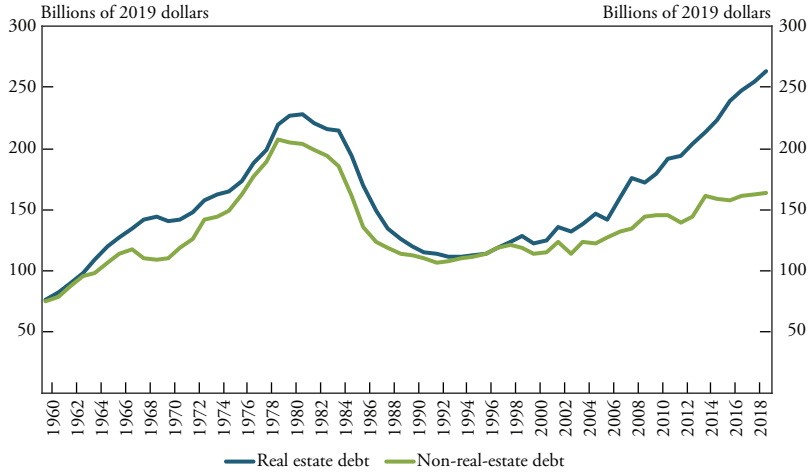
were observed during the 1940s, when land values reached $523/acre. This value was lower in real terms than the sharp reduction in land values witnessed during the 1980s farm crisis. Looking at the period ranging from 1913 to 2018, two major peaks in land values can be identified. The first occurred before the 1980s farm crisis and the second began in 2009. This second peak of high land values is 1.4 times larger than the first one. It would seem that land values are reaching a new plateau, potentially a third one. The number of years it takes to reach each new plateau appears to be getting shorter and shorter. The changes in plateaus could be brought on by 1) higher returns to land due to increases in productivity and increased demand for commodities (for example, the boom in demand of corn for biofuels), 2) greater demand for land brought on by farm consolidation and urban pressures, and 3) a prolonged period of low interest rates. The pattern in ups and downs in land values follows closely the ups and downs in total farm assets.

From 2013 onward, total farm assets have surpassed $3 trillion in 2018 dollars. This is the highest recorded amount. The farm assets portfolio appears to have remained unchanged since the 1960s, although the shares of inventories and investments seem to be slightly smaller than those in the 1980s. These facts suggest that the high land values are the reason for maintaining the high total farm assets values. This could mean a stronger financial resilience of farmers who own their land debt-free. Although in the past 20 years total farm assets have seen increases even larger than those from 1960 to 1980, the pattern of decline in total assets experienced from 1980 to 1986 has not been present recently. In fact, the lowest amount of total farm assets in the period of 1960 to 2019 occurred in 1960 (Chart 3), when land values were also low (Chart 4). Since 2013, total farm assets appear to have stabilized with small declines from year to year. This trend appears more similar to the trend that occurred from 2006 to 2009 than the decline that occurred during the 1980s farm crisis (Charts 3 and 4).

Along with the greater importance and share of farmland in total assets, there has been an increase in the amount of debt that is secured by real estate. In the twenty-first century, real estate debt has increased in larger amounts than non-real-estate debt (Chart 5). Both types of debt were almost the same amount during the couple of years preceding the year 2000. It appears that the non-real-estate debt has stabilized

Chart 5

Farm Real Estate Debt and Non-Real-Estate Debt



Source: USDA ERS.

at a lower level while real estate debt has exhibited constant growth in the twenty-first century. This trend is different from the one witnessed in the distant past. In general, real estate debt has been greater than non-real-estate debt, though they have both followed similar growth patterns. Up until 2008, non-real-estate debt accounted for over 45 percent of total farm debt. The USDA forecast for 2019 is that non-real-estate debt will account for 38.2 percent of total farm debt. Similar to the discussion on the share of land in total farm assets, this points to the greater dependence of farm assets on farmland values, with farmland being used as collateral for real estate loans. As such, agricultural lenders as well as farmers seem to be more dependent on high land values to maintain high total asset values.

Farm debt and financial solvency

In the 1970s, debt increased steadily in response to increases in farm income and land values, from $251 billion in 1970 to a peak of $431 billion in 1980, measured in 2019 values. This meant an increase of 71 percent in total farm debt over 10 years spanning the 1970s. Currently, a similar pattern can be detected, as total farm debt has been increasing steadily since 2009, from $317 billion in 2009 to $426.7 billion forecast for 2019, a 35 percent increase. Hence, the increase in farm debt in real terms was larger in the 1970s ($180 billion) than in the last 10 years ($110 billion).

The smaller growth in total farm debt recently may also be associated with changes in lending practices. Zhang and Tidgren (2018) highlight the changes that have occurred since the 1980s farm crisis: 1) cash flows and repayment rates are given greater consideration than before, 2) loan-to-value ratios are required to be below 85 percent, and 3) collateral land values are estimated based on the returns of the land within a period instead of on current market values.

Rather than the total amount of farm debt, financial solvency (measured by the debt-to-asset ratio) may pose a greater concern for agricultural lenders. As mentioned, the repayment capacity has become an important aspect in agricultural lending since the 1980s. The positive news is that the current low levels of farm income are at times when debt-to-asset ratios have been the lowest since the 1960s (Chart 1). Higher land values may be responsible for the lower debt-to-asset ratios. The highest average debt-to-asset ratio was witnessed during the 1980s farm crisis.

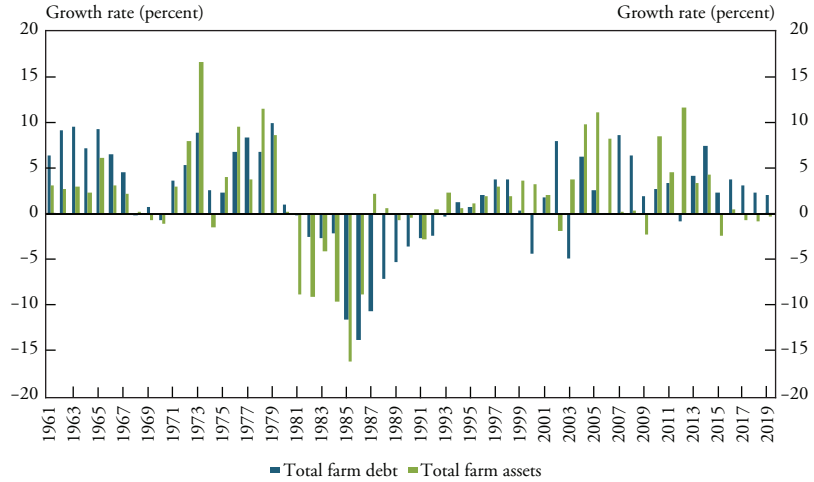
The expectation, however, is for debt-to-asset ratios to increase in the near future, since total farm debt has been growing at higher rates than total farm assets (Chart 6). Variations in total farm debt seem to lag the variation experienced in total farm assets. Since 2015, the growth rates in total farm assets have been mostly negative, while the growth rates for total farm debt have been positive (at least 2 percent). The concurrent negative growth rates in farm assets from 2015 to 2019 coupled with growing farm debt differs from what was experienced during the 1980s, where the growth rates in both farm debt and assets were negative. Among the farm assets components, investments and inventories are probably the cause for lower total farm assets. Inventories have been decreasing since 2015, while investments have experienced declines of 22 percent in 2015 and around 11 percent in 2016 and 2018. Farm real estate continues to be an important component of farm assets (approximately 83 percent), which was also the case during the 1980s farm crisis.

Credit availability

An environment of low interest rates can increase demand for loans as well as demand for farmland. A higher demand for land as an investment may occur as land starts to provide higher returns than other

Chart 6

Annual Growth Rates in Total Farm Debt and Total Assets, 1960–2019



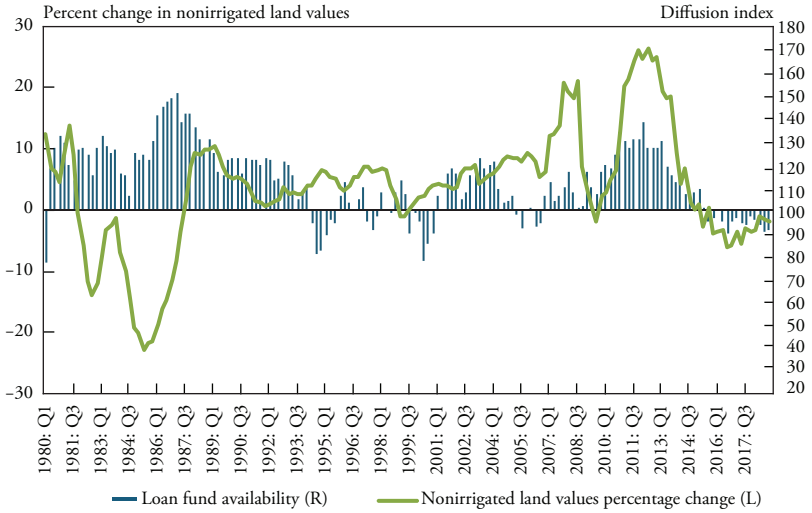
Note: Bar for 2019 represents a forecast growth rate.
Source: USDA ERS.

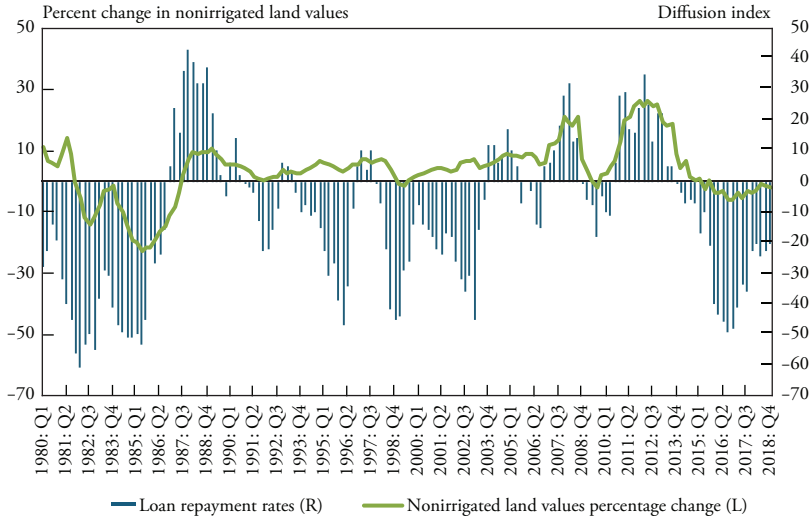
investment opportunities such as stocks or bonds (Zhang and Tidgren 2018). Information on agricultural loans collected from call reports allows for an analysis of total outstanding debt (Devadoss and Manchu 2007; Shalit and Schmitz 1982) but it does not provide information on the amount of loans granted in a given year or quarter. Additionally, information on the total volume of loans does not indicate whether loan requirements are becoming stricter or not. Stricter loan requirements may impact credit access and credit availability. Although credit access and credit availability are different terms, in our analysis we use them interchangeably. Hence, if there is an increase in credit supply through increasing funds in banks, more bank competition, or less strict collateral requirements, there is more credit available and easier credit access.

Credit availability may be vital for land acquisition, but it can also put an upward pressure on land values. Even with the changes undergone in the lending system, it appears that credit availability can still influence land values. Shalit and Schmitz (1982) argue that land prices may be determined by the amount of debt the land can carry. Agricultural lenders' perceptions about lending markets are captured in the Ag Credit survey conducted by the Federal Reserve Bank of Kansas City. Bankers answer questions stating whether they believe the conditions

Chart 7

Land Values and Credit Availability, 1980:Q1 to 2018:Q2





Notes: The top graph shows percentage changes in nonirrigated land values and the diffusion index for loan fund availability. The bottom graph shows percentage changes in nonirrigated land values and the diffusion index for loan repayment rates.
Source: Federal Reserve Bank of Kansas City.

in the current quarter were higher than, lower than, or equivalent to the same quarter a year earlier. In Chart 7, the right vertical axis has the scale of the diffusion index, which is equivalent to the difference between bankers that responded "higher" and those that responded "lower" added to 100. Therefore, values below 100 indicate that the

majority of bankers responded to a decrease in current conditions (that is, in loan repayment rates or in loan fund availability) with respect to last year, while values above 100 indicate the opposite. We would expect increases in loan fund availability and in loan repayment rates to increase credit availability.

Chart 7 shows that, in general, higher loan repayments occurred at times of positive and increasing percentage changes in land values and vice versa. This pattern is particularly clear from 2003 onward and during the 1980s. In the case of loan fund availability and percentage changes in land values, since 2001, increases in loan fund availability have occurred at times when percentage changes in land values are positive and increasing. The difference between now and the 1980s is that in the 1980s, loan fund availability was higher (that is, the diffusion index was above 100), while loan demand and repayment rates were lower (the diffusion index was below 100), and in recent years, loan fund availability and loan repayment rates have been lower, while demand for loans have been higher. This indicates a new type of credit environment than in the 1980s.

Current credit conditions portray an environment of lower credit availability. Around the start of the agricultural downturn, the diffusion index for loan repayment rates and for loan fund availability was below 100. The diffusion index for loan fund availability has been lower than 100 since 2016 and the diffusion index for loan repayment rates has been lower than 100 since 2013 (Chart 7). Not only have we witnessed smaller growth in debt (Chart 6) but also, as mentioned, data from the Ag Credit survey show that an increased number of agricultural lenders indicate lower credit availability than during the previous year as well as lower repayment rates. These credit conditions may have helped to put downward pressure on land values after 2015 (Chart 4). Notice how in Chart 7, negative percentage changes in land values for farmland in the tenth district are associated with lower repayment rates and lower loan fund availability in the past four to five years. Continued periods of lower repayment rates and lower loan fund availability may cause lenders to restrict credit supply, potentially putting further downward pressure on land values and increasing farm financial stress.

Comparing the recent agricultural downturn with the 1980s farm crisis

Could the farm economy repeat the farm crisis of the 1980s? During the 1980s farm crisis, farmers experienced a period of significant increase in debt aligned with declining net farm income and increasing interest rates. The heightened number of bankruptcy filings for farmers prompted the creation of chapter 12 as an exclusive form of bankruptcy reserved for farmers. Land values, which increased sharply in the late 1970s, went into a steep decline in the 1980s. Having taken on loans using their farmland as a collateral, many farmers were faced with increasing financial stress as the value of their collateral deteriorated, making it harder for them to repay their loans or renegotiate loan terms. Debt-free farmers, on the other hand, had the opportunity to acquire cheaper land and expand their farms.

There are similarities and differences between the events that took place before the 1980s farm crisis and the agricultural downturn of the past six years. The similarities could be narrowed down to three points: 1) decreasing commodity prices and net farm income, 2) declining land values following a notable increase in land values, and 3) increasing farm debt. Although these trends are similar, the magnitude of changes was higher in the 1980s than in recent years. A major difference between the two time periods is the solvency of farm businesses. Debt-to-asset ratios are the lowest they have been in past years, whereas during the 1980s farm crisis, debt-to-asset ratios were the highest they have ever been. Currently, the average debt-to-asset ratio is around 13 percent, while in the 1980s it was 20 percent. The data used here refer to sector information and do not reflect the information of farmers individually, as some farmers are still highly indebted and financially vulnerable. Rather, the data provide a collective picture of farm financial stress. The current agricultural downturn conditions may make it harder for farmers to take on new loans, causing them to use their own internal funds (or working capital) to finance purchases.

Interest rates and lender characteristics leading up to the 1980s farm crisis differ from those experienced in recent years. Farm mortgage rates that were 17.5 percent in the 1980s have declined throughout time to about 4–5 percent in recent years. The composition of lenders has also changed. The majority of farm debt is currently held by commercial banks and the Farm Credit System instead of individuals, as was

the case during the 1980s. Additionally, the occurrence of bank mergers may mean banks have greater portfolio diversification, making them more resistant to financial stress (Bunge 2017; Beck, Demirguc-Kunt, and Levine 2003).

Overall, these conditions have been stronger and more favorable during the recent agricultural downturn compared with the 1980s. For these reasons, a repeat of the 1980s farm crisis is unlikely in the near future. What is uncertain, however, is how long the downturn is going to last.

II. The Effect of the Agricultural Downturn on Agricultural Financial Indicators

Information on delinquency rates and bankruptcy can provide an outlook on the current farm financial stress farmers are enduring. Current data show that delinquency and bankruptcy levels are much lower recently than during the 1980s farm crisis. While this does not rule out that highly indebted farmers may be experiencing farm financial stress, it does suggest that a repeat of the 1980s farm crisis is unlikely.

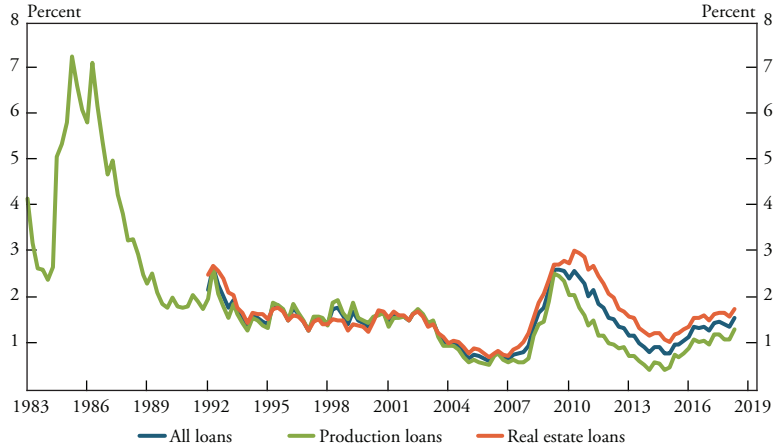
Delinquency rates on agricultural loans

Repayment capabilities can be analyzed by observing trends in agricultural loan delinquencies. Agricultural loan delinquencies constitute loans over 90 days due and loans in nonaccrual status. This information can be acquired from call reports provided by lending institutions. Current delinquency rates are much lower than those experienced in the 1980s (Chart 8). Delinquency rates were over 5 percent during the late 1980s. Since the 1990s, higher agricultural loan delinquency rates of up to 3 percent were experienced in the years preceding the financial crisis of 2008. In recent years, agricultural delinquency rates have been below 2 percent.

Agricultural loans are further analyzed as production and real estate loans. Production loans are taken to finance farm operations (such as purchasing inputs and machinery), while real estate loans are used toward the purchase of farmland and buildings. The repayment lengths and terms for these loans vary, with production loans being shorter term than real estate loans. Delinquency rates for production loans have been smaller than delinquency rates for real estate loans since 2004 (Chart

Chart 8

Agricultural Loan Delinquency Rates for Loans over 90 Days Due and in Nonaccrual Status



Source: Federal Deposit Insurance Corporation.

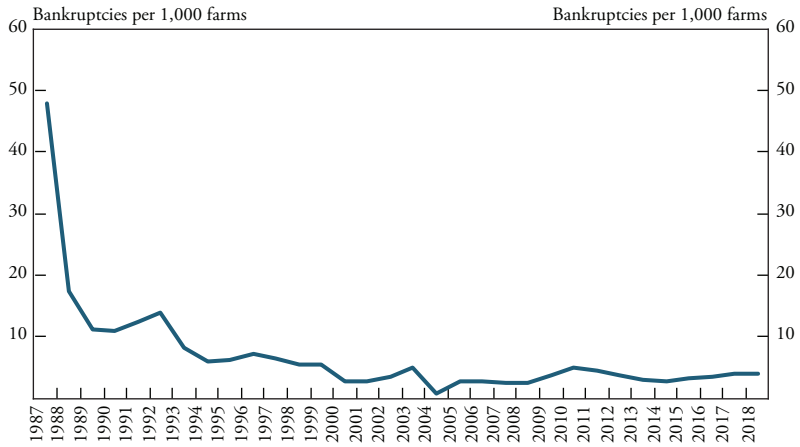
8). The gap between delinquency rates for real estate loans compared with production loans has varied from 0.25 to 1.5 percent, returning to 0.5 percent in 2018 (Davis, Dinterman, and Katchova 2018). This divergence in agricultural delinquency rates may be related to the lower debt amounts of production loans compared with real estate loans.

Farm bankruptcies

In addition to changes in the agricultural lending system, there were also changes in bankruptcy legislation. In 1986, chapter 12 bankruptcies were introduced in response to the farm crisis, allowing farmers to repay their debts in three to five years instead of having to liquidate their farms (as in the case of chapter 7, for example). Chapter 12 was initially a temporary form of bankruptcy and set to expire in 1993, but it was continually extended by Congress until it became a permanent fixture in 2005 with the passage of the Bankruptcy Abuse Prevention and Consumer Protection Act (Dinterman, Katchova, and Harris 2018). Chapter 12 bankruptcy filing is available to farmers who cannot service their debt as long as their total debt is below $4,411,400. Historically, bankruptcy rates since 2000 have been lower than those experienced in the 1980s (Chart 9) (Dinterman, Katchova, and Harris 2018). Therefore, the farm financial stress experienced by farmers during the recent agricultural downturn has a smaller effect on bankruptcy filings than in the

Chart 9

Historical Farm Bankruptcy Rate



Notes: Chapter 12 started in 1986. Bankruptcy rates prior to 1986 cannot be compared directly and were therefore excluded from this chart. Filings prior to 1980 include bankruptcies filed for chapters 7, 11, and 13 by farmers, while those from 1986 onward are chapter 12 filings.
Source: U.S. Courts.

1980s. Once again, there seems to be a period of farm financial stress during the recent agricultural downturn like in the 1980s, but with less influence on farm bankruptcies as a financial indicator.

Although farmers may be facing financial stress during the agricultural downturn with low net farm income, the number of farm bankruptcies has remained fairly stable in recent years. The best way to analyze farm bankruptcy is by looking at changes to chapter 12 bankruptcy filings, though farmers may also file under other bankruptcy chapters if they cannot qualify for chapter 12. In the period in which chapter 12 has been a permanent fixture in the bankruptcy code, the highest levels of chapter 12 bankruptcy filings occurred from late 2009 to mid-2012, with around 700 chapter 12 filings per year. In 2018, chapter 12 filings totaled 498, which was slightly down from 501 in 2017, likely reflecting a greater resilience among farmers. Chapter 12 filings do have regional variation. Recently, Midwestern states have had elevated levels of filings, with the state of Wisconsin having the highest bankruptcy rates in 2018 among all states.

Multiple factors may influence bankruptcy filings (Dinterman, Katchova, and Harris 2018). Among the factors that increase the likelihood of filing for bankruptcy are a lower ability to service

debt and higher unemployment rates. Among the factors that have a negative effect on bankruptcy rates are farm sizes, solvency rates, net farm income, land values, and government payments. Dinterman, Katchova, and Harris (2018) find that the general economy factors such as interest rates and unemployment rates were stronger predictors of farm bankruptcies than agricultural factors such as farm incomes. However, agricultural land values are a strong predictor of bankruptcies because they make up a large share of debt for farmers, and due to the potential for a chapter 12 filing to "cram down" the outstanding debt to the market value of agricultural land in a bankruptcy proceeding.

Conclusion

U.S. agriculture is currently undergoing an agricultural downturn, with many agricultural economic and financial indicators worsening. Farm incomes have dropped by 50 percent since 2013, land values have plateaued in the past three years, farm debt growth has exceeded that of farm assets, and credit conditions have worsened. The downturn has not, however, become a crisis similar to that of the 1980s, as farmers are in a stronger position today than three decades ago.

Although current financial conditions are better than during the 1980s, they may deteriorate in upcoming years. Some positive factors have helped farmers remain in better condition than in the 1980s, such as a higher plateau of land values, low interest rates, net farm income and solvency indicators above 1980s values in real terms, and low agricultural delinquency rates and bankruptcy rates. Nevertheless, the uptick in net farm income in 2017 and expected increase in 2019 are not enough to reach the 90-year average. Several organizations project net farm income to remain below the 90-year average mark in coming years.

Zhang and Tidgren (2018) identify liquidity and working capital as issues related to the agricultural downturn rather than overall solvency. Although farmers still have strong equity positions, less access to credit, lower profitability levels, and deteriorating working capital are elevating farm financial stress. If land values stabilize at higher values, we may see the average debt-to-asset ratio remain lower than it was during the 1980s. The financial stress faced by farmers does appear to be less than that during the 1980s. While we may not expect further declines in land values, due to various factors (such as lending regulation changes)

farmers may still expect to experience an extended period of farm financial stress. Currently, the concern is over the length of the agricultural downturn, which is expected to be prolonged with gradual declines as opposed to the collapse during the 1980s farm crisis (Zhang and Tidgren 2018). As the history of boom and bust cycles tends to repeat itself, it is important to continue to examine the factors that will help boost farm income going forward into 2020 and beyond.

Endnote

[1]This paper was written for the Federal Reserve Bank of Kansas City's Agricultural Symposium in July 2019. At that time, the USDA's most recent forecast for U.S. farm income was from March 2019. In August, the USDA made an upward revision to its expectations for farm income in both 2018 and 2019, which would alter some of the data and discussion that follow, including historical comparisons.

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The "Normal" Normal: Supply and Demand Drivers over the Next 10 Years

By Seth Meyer and Joe Glauber

From 2010 to 2015, farmers saw the longest period of sustained above-average farm income since World War II and its immediate aftermath (Chart 1). In the United States, real net cash and net farm income were above their 1960–2017 average for six consecutive years. By contrast, real net cash and net farm income were only above the 1960–2017 average for four consecutive years in the 1970s (from 1972 to 1975). The run-up in prices in the early 1970s—and the associated brief jump in farm income—originated in oil price shocks and inflationary pressure that set the stage for economic turmoil in the agricultural sector in the first half of the 1980s. The recent period of strong farm income was similarly driven by a surge in producers' crop and livestock prices. As food prices began to rise in 2007 and 2008 and peaked in 2011, U.S. corn, soybean, and wheat prices all hit record nominal prices for the 2012–13 crop year.

The rise in agricultural commodity prices was sparked by falling global grain stocks, weather-related shocks, and policy responses to those shocks. But the rise in prices was also attributed to systematic or nontransitory factors such as population and income growth, energy prices, and demand—including biofuels, falling agricultural productivity, market speculation, and a dated trade policy environment. As a

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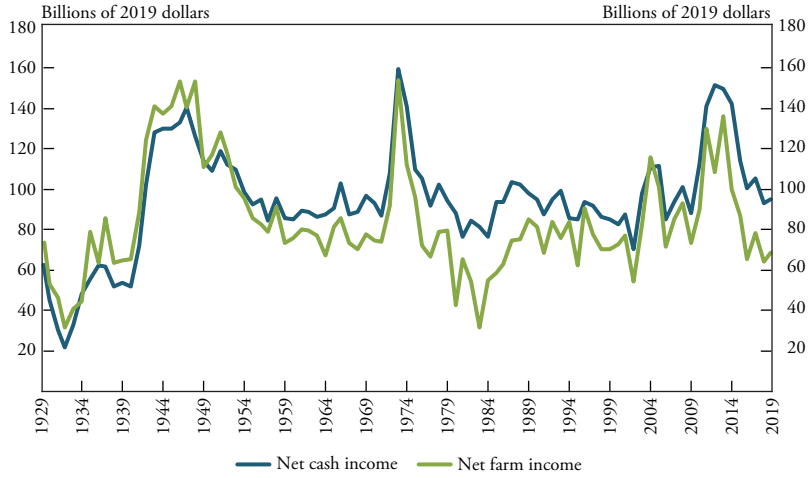
Chart 1

Real Net Farm and Net Cash Income



Source: USDA Economic Research Service (ERS).

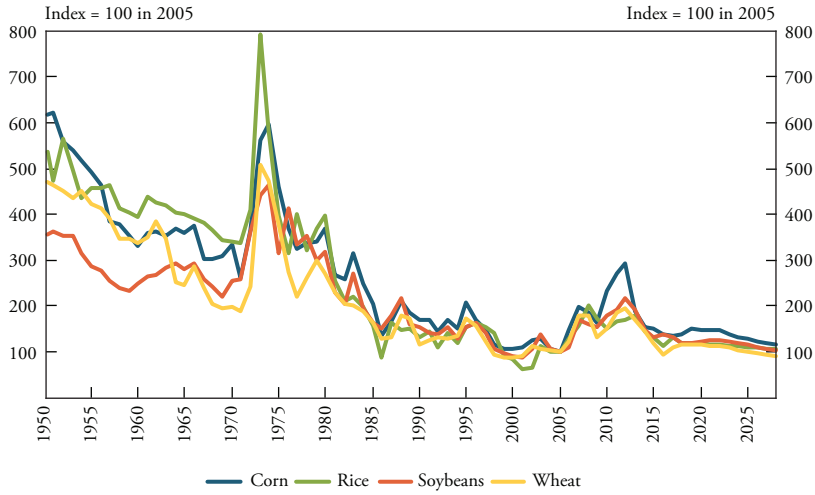
result, there were widespread declarations that global food productivity growth was reaching its limits and that farmers were entering a new phase of prolonged price strength and volatility, perhaps even reversing the long-observed trend of steadily falling agricultural commodity prices (Chart 2).

Since that time, farm prices have moderated, global stocks have rebounded, and farm income has fallen. In the coming decade, in the context of the U.S. Department of Agriculture (USDA)'s long-term baseline—as well as other global scale baselines, such as that produced jointly by the Organisation for Economic Co-operation and Development (OECD) and the Food and Agricultural Organization of the United Nations (FAO)—there appears to be limited scope for such underlying supply constraints or an identifiable spark for demand that would lift farm incomes back to the levels seen in 2011–14.

Analysis of the 2010–15 price surge was extensive both at the time and in subsequent years, with several factors appearing repeatedly in the literature.[1] For example, food demand, particularly for meat, had grown as lower income regions experienced both income growth and population growth. In addition, food prices and energy prices had become more closely tied—and food prices had become more volatile

Chart 2

Real Agricultural Commodity Prices



Source: USDA World Agricultural Outlook Board (WAOB).

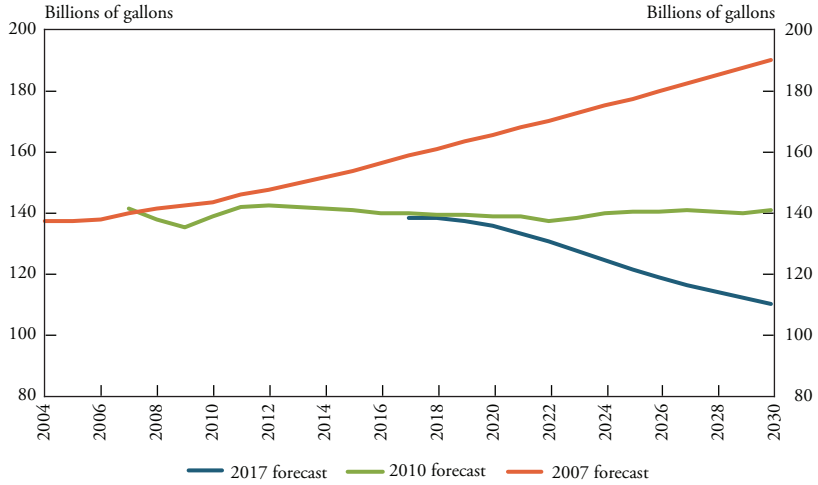
through their diversion into biofuel production. Stagnating or more volatile crop production also featured prominently in discussions of the time. These factors combined with tight stocks and weather-related production shortfalls to set the stage for the observed price surge.

Energy prices and demand as a source of commodity price growth

Rising energy prices coincided with rising grain and oilseed prices and sharp growth in biofuel production. Oil prices, which had been relatively low and stable, began to rise sharply in 2002 and had nearly tripled by 2007. West Texas Intermediate (WTI) prices averaged $72.34 a barrel in 2007, which coincided with a relatively steady weakening of the U.S. dollar over the 2002–07 period. U.S. motor gasoline consumption had risen to over 140 billion gallons per year and was expected to increase steadily by 1.3 percent annually for the next two decades (Chart 3). At the same time, U.S. field oil production had fallen 47 percent since its peak in 1970 and as a result, dependence on foreign oil was rapidly rising (Chart 4). Ethanol production capacity, supported by a blenders tax credit of $0.51 per gallon, reached 6.3 billion gallons by June 2007, with another 6.3 billion gallons of capacity under construction (NEO 2019). Of the corn crop harvested that

Chart 3

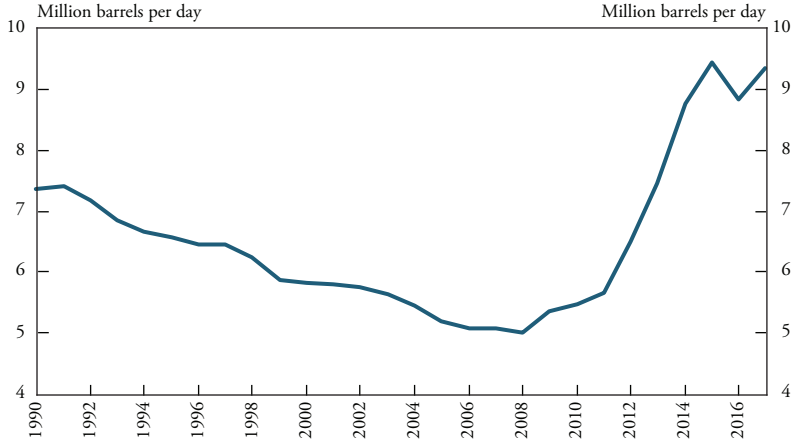
U.S. Motor Gasoline Transportation Consumption Forecasts



Source: Energy Information Administration (EIA).

Chart 4

U.S. Field Production of Crude Oil



Source: EIA.

fall, over 3 billion bushels, or 23 percent of production, went into the ethanol corn grind (USDA Office of the Chief Economist 2010). In this setting, the Energy Independence and Security Act of 2007 (EISA) was passed, which envisioned 36 billion gallons of domestic biofuel use by 2022, the bulk of it from feedstocks other than ethanol from corn starch.

The expansion of biofuel production envisioned under the EISA turned out to be short-lived. Corn ethanol production growth continued to provide a strong direct demand for corn, but the promise of cellulosic ethanol, and its need for agricultural crops and residues, failed to materialize. Biofuel consumption slowed as the Environmental Protection Agency (EPA) began waiving blending requirements for larger volumes. With corn ethanol supported by EISA provisions, industry production capacity has reached 16.1 billion gallons (NEO 2019). In part due to improved fuel efficiency, motorfuel gasoline consumption in the United States also began to stagnate and has begun to modestly decline, with the latest forecast predicting a sharp reduction over the next decade, pulling the blend wall lower and making expansion of ethanol, outside of a growth in mandates, more difficult.

Within the mandated volume structure, the EPA has drastically increased the number of small refinery exemptions granted. By lowering Renewable Identification Number (RIN) prices, these exemptions have reduced the incentives to blend and consume higher level ethanol blends such as E15 and E85 (EPA 2019). Motorfuel ethanol inclusion rates have stagnated as a result. The USDA's World Agricultural Supply and Demand Estimates (WASDE) report for May 2019, the first look at the 2019–20 crop year, forecast that corn and sorghum consumption for the production of ethanol would fall for the first time since 2012 (a year affected by drought), even before the size of the 2019–20 U.S. corn crop was cut in subsequent reports due to delayed plantings under adverse weather conditions. In a look beyond 2019–20, the *USDA Long-Term Projections to 2028* projects that falling motor gasoline use, along with limited mandate pressure, will lead to flat to falling corn-for-ethanol use over the coming decade (USDA OCE 2019a).

Rapid growth in U.S. oil production through fracking has moderated the Organization of the Petroleum Exporting Countries (OPEC)'s control on oil production and prices and is projected to turn the U.S. into a net energy exporter in 2020 (EIA 2019). Corn-for-ethanol

use would likely have declined further in the USDA projections if not for the underlying expectation that ethanol exports, supported by policies abroad, will pick up some of the declining domestic consumption. Ethanol will continue to be a significant use for U.S. corn; however, without growth in mandates, reductions in the number of small refinery exemptions granted, or a sustained increase in energy prices, ethanol production is unlikely to be a major driver in the *growth* of corn demand over the next 10 years. The prospects for biodiesel may be somewhat better given the more stable outlook for distillate consumption in the future, but biodiesel faces similar pressures from small refinery exemptions and stagnant mandates.

Income and population growth

Income and population growth are clear underlying, nontransitory sources of demand growth for food, feed, and fiber from the agricultural sector. While periodic economic downturns can and will shock demand and prices in the future, these two factors have been presented alongside long-run land and water resource constraints as a potential source of future commodity price increases.

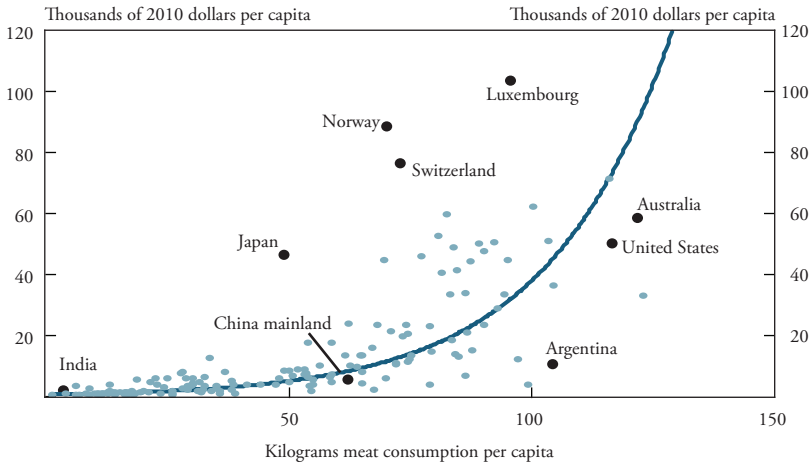
The United Nations (UN) Population Division, in its median population growth variant, predicts global population will rise through 2100. Although the pace of this rise is projected to slow throughout the period, the world population is forecast to reach 10.9 billion people, with the population of Africa more than tripling to 4.3 billion people. While the population of Asia is expected to peak in 2055 and then decline, Asia will remain the most populous region at 4.7 billion people.

Strong population growth rates, together with rising meat demand, suggest strong long-run growth in demand for agricultural commodities. From a 2005–07 base, the FAO projects global meat consumption to increase 27 percent by 2050 and 43 percent by 2080 (Alexandratos and Bruinsma 2012).

However, population projections are presented with a significant range of possible outcomes. For example, the range in population estimates for 2100 between the UN high-growth and low-growth scenarios

Chart 5

Meat Consumption per Capita and GDP per Capita, 2013



Sources: FAO and authors' calculations.

is about 3.3 billion people, with global population levels actually declining after 2060 under the low-growth scenario. Likewise, while the positive relationship between meat consumption and per capita GDP is compelling, consumption varies widely across countries depending on geography, tastes, and religious and cultural preferences (Chart 5).

Will China continue to drive agricultural trade?

Chinese commodity demand, and soybean trade in particular, have provided significant underlying support to the U.S. agricultural sector over the last decade, with agricultural trade growing to 21.2 billion annually for fiscal years 2015–17. Over the last decade, the USDA's annual baseline projections consistently underestimated the sharp and persistent growth in Chinese soybean imports and underlying soybean crush demand for feed.[2] In 2017, China was among the largest export markets for U.S. agricultural products (Anderson 2017; Cooke, Jiang, and Heerman 2018).

China's rapidly growing economy spurred growth in protein consumption, particularly in pork. The growth in pork production was coupled with increasingly industrialized production methods relying on commercial feed rations high in protein meal.

Over the 2000–15 period, China's soybean demand grew at an annual rate of 8.5 percent—over twice the rate of global soybean demand growth over the same period. China met that demand through imports. By 2015, China soybean imports accounted for about two-thirds of the world trade and about 90 percent of the growth in trade over the 2000–15 period. The growth in soybean meal and equivalent (SME) demand grew at a rate well above the growth rate in production of pigs, the dominant animal fed and protein consumed by the Chinese. The divergence in the two growth rates has continued for more than two decades (Chart 6).

The growth in SME use reflected both modest growth in the world's largest pig herd and the steady shift from small-scale, on-farm feeding, including waste feeding to a feed system more appropriate at scale, primarily including soybean meal, corn, and other grains. In addition, the Chinese policy environment enforces "absolute security" as a key factor in rice and wheat supplies and operates a less-than-transparent trade in corn. This distorts grain and oilseed meal prices, and implied meal consumption in animal rations relative to corn appears higher than in the United States as a result.

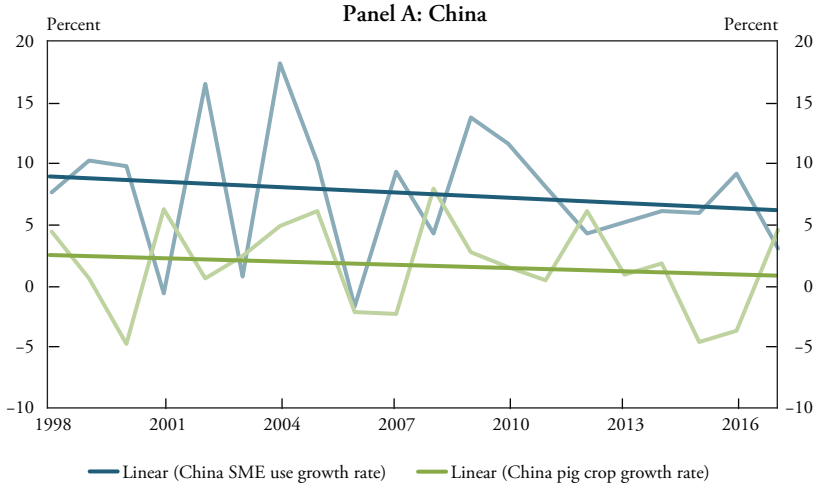
However, growth in the pig herd has slowed as the Chinese pork sector has continued to consolidate—in 2017, more hogs were on large-scale farms than small-scale ones (Inouye 2018). As a result, China's soybean crush, and thus its need for imports, is expected to slow (USDA Office of the Chief Economist 2019a).[3] The USDA projects that China's soybean consumption will grow at an annual rate of 2.7 percent over 2018–28, about one-third the rate of growth seen over 2000–15. More recently, the spread of African swine fever in China, which has primarily affected small producers, may lead to further consolidation, completing the transition to commercial feeding and improving feed efficiency. African swine fever may also result in a shift to other meat production such as poultry, which has greater feed efficiency than pork. As a result, the growth rate in SME use relative to pork production could move more quickly to that observed in the United States (Chart 6).

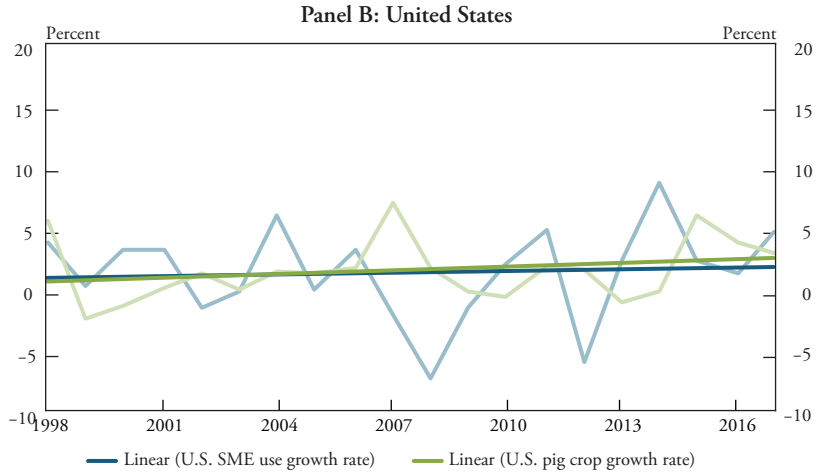
Could other regions spark a growth in demand in the coming decade?

The strength of Chinese demand was not fully anticipated, raising questions about whether demand from another region might also surge

Chart 6

Annual Pig Crop Growth Rate versus SME Use Growth Rate





Sources: FAO and authors' calculations.

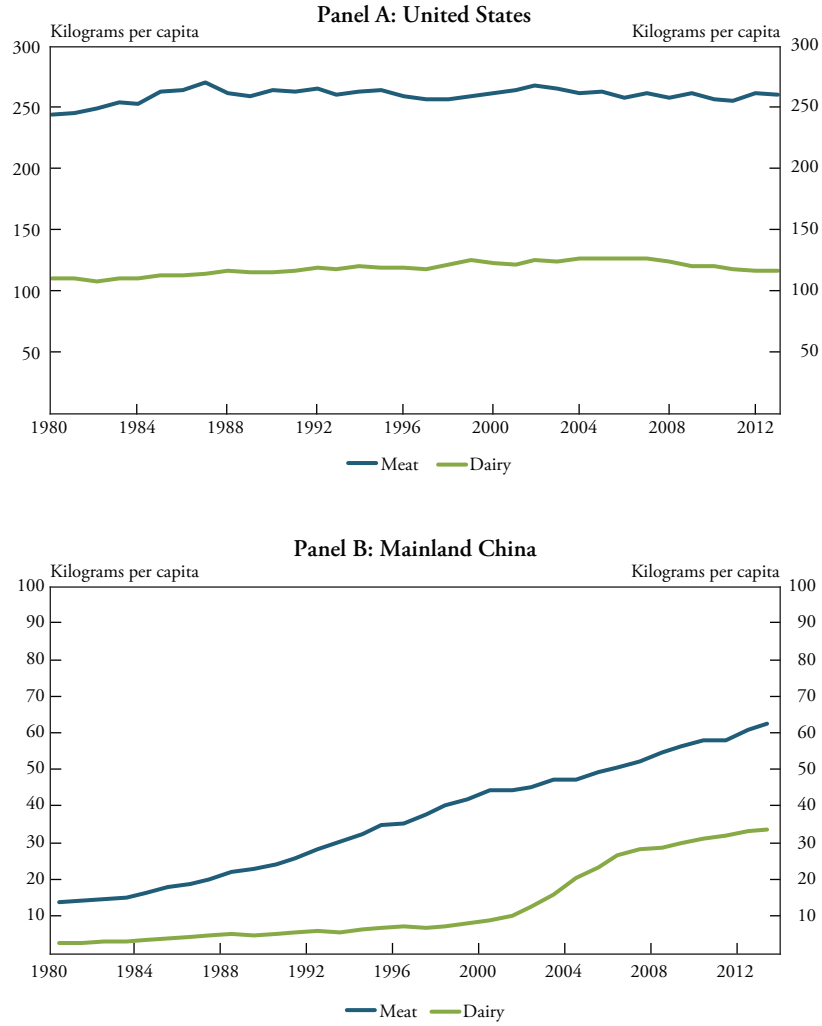
and underpin prices over the next decade. India, for example, seems like a prime candidate: the country's GDP growth has averaged more than 7 percent annually from 1998 to 2017, and its population is projected to exceed China's by 2027.

However, in the context of future agricultural commodity demand, comparing India's growth to China's growth over 2000–15 becomes more tenuous (Chart 7). Despite a three-fold increase in real GDP per capita in India from 1980 to 2013, per capita meat consumption remains low, constrained by cultural factors unlikely to change rapidly over the next decade (for example, Hindu restrictions on beef and Muslim restrictions on pork). In contrast, India has seen rapid growth in dairy product consumption over the same period; moreover, per capita dairy consumption remains lower than in countries such as the United States, suggesting additional room to grow. However, the direct consumption of grains and legumes, and feed efficiency gains in the production of dairy products and even poultry relative to pork and beef, may temper grain and oilseed demand relative to the feed growth observed by China over the last decade (Shepon and others 2016).

Africa represents another potential source of strong demand, as the country has the second largest population base and the fastest population growth rate. But income stagnation has stymied demand in Africa in the past two decades. Sub-Saharan Africa GDP advanced an anemic 3.5 percent per year over the last decade, while the population increased by 2.5 percent per year. Accordingly, per capita income grew by less than 1 percent annually over the last 10 years. In fact, population growth has exceeded GDP growth for the last four consecutive years, reducing per-capita GDP. Near-term forecasts for the region do not suggest significantly brighter prospects that would, combined with population growth, spur a surge in demand (World Bank 2019a). The World Bank notes that structural factors such as public debt and debt risk will continue to pose risks to growth over the coming decade, limiting income growth and its potential contributions to growth in meat consumption (World Bank 2019b). Although aggregate statistics mask the better economic performance of countries such as Kenya, the region as a whole may be a limited driver of demand over the next decade.

Chart 7

Growth in Meat and Dairy Consumption



Sources: FAO and authors' calculations.

High prices of the last decade have invited production competition

Due to the jump in Chinese soybean import demand, the domestic use of corn for ethanol production, and, more broadly, higher prices for agricultural commodities, U.S. grain and soybean harvested areas have increased modestly. At the same time, harvested area growth outside of the United States has increased significantly given the more stagnant growth in global planted area over the previous two decades (Chart 8).

U.S. planted area increased through a combination of market- and policy-driven declines in Conservation Reserve Program (CRP) area and land conversion; however, output gains were also achieved through a change in the mix of crops (Chart 9). With the U.S. comparative advantage in corn and soybean production, areas on the fringe of the Corn Belt, such as North Dakota, South Dakota, and Kansas, have shifted acres out of wheat and minor feed grains and into corn and soybeans. Over the 18-year period from 2000–01 to 2018–19, U.S. production of corn, soybeans, and wheat rose by a combined 166 million metric tons on a harvested area increase of 4.7 million hectares (Chart 10).

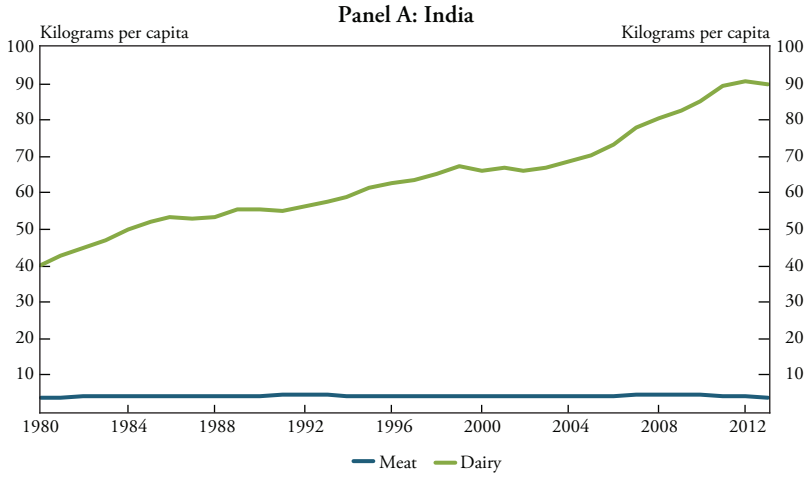
Elsewhere in the world, growth in harvested area and steady growth in yields added significantly to global supplies over the same period. In particular, Argentina and Brazil increased their harvested area for corn, soybeans, and wheat by 39 million hectares and raised production of the three major crops by nearly 200 million metric tons.

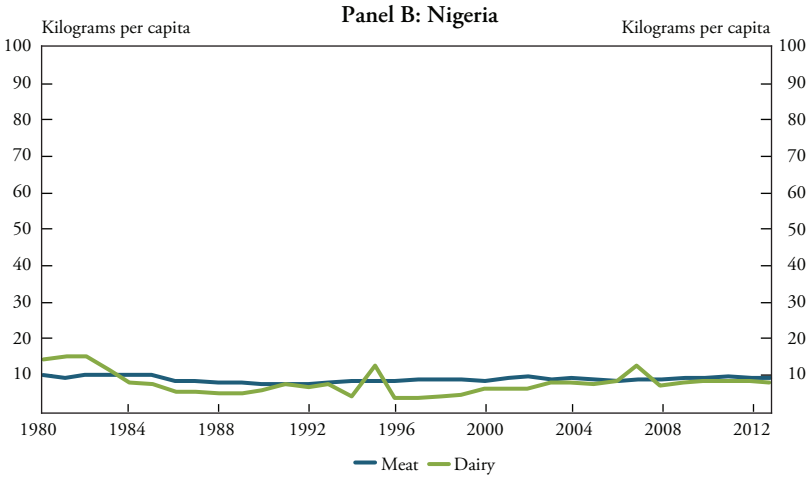
From 2019–20 to 2028–29, a nine-year period in which real crop prices are expected to remain flat or fall, global harvested area expansion is expected to slow outside the United States and contract modestly in the United States for corn, wheat and soybeans. Argentina and Brazil are expected to add a combined 13.6 million hectares of harvested area and 96 million metric tons of production over the same period, with the majority of the area and production changes coming from Brazil.

Harvested area in Brazil is expected to expand by 10 million hectares over the nine-year period, a significantly slower pace than over the prior 18 years. The primary factor in the slowing of Brazil's forecast area growth is the softening of real prices restraining land conversion. However, Brazil has the ability to expand its harvest area even without land conversion. Brazilian farmers have achieved notable area expansion by planting second crops following soybean production in the key

Chart 8

Growth in Meat and Dairy Consumption

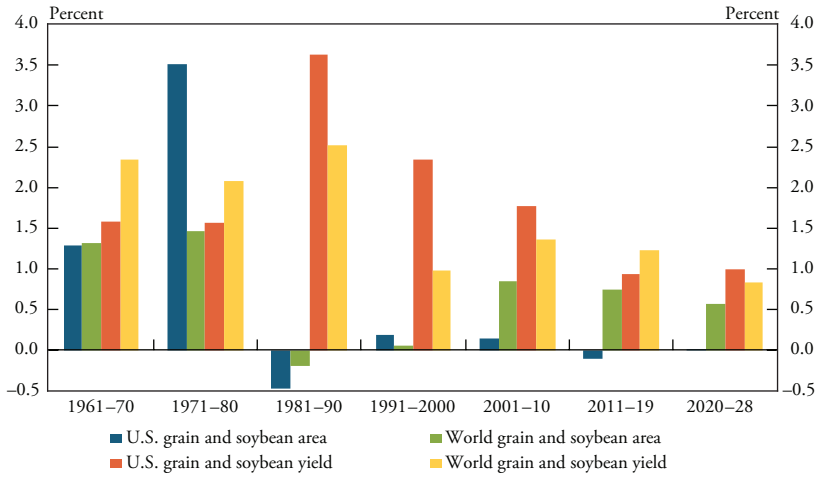




Sources: FAO and authors' calculations.

Chart 9

World and U.S. Grain and Soybean Area and Yield Growth



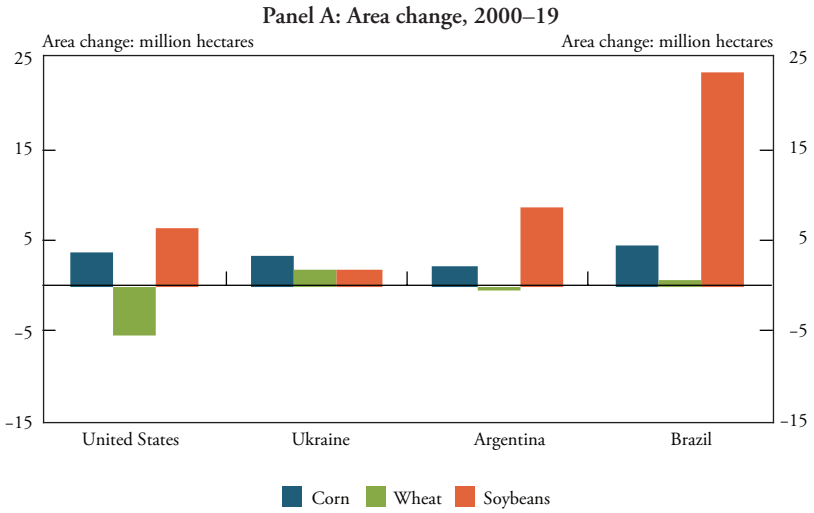
Note: Bars for 2020–28 represent projections.
Source: USDA ERS.

soybean-producing states of Mato Grosso, Mato Grosso do Sul, Goias, and Parana. Within these states, soybeans have pushed out much of the first crop corn. Shorter-season soybean varieties with seemingly minimal yield drag have opened up area for a second crop corn (the *safrina* crop) along with expanding cotton area. Expanding double cropping on existing soybean area in these four states could add the equivalent of nearly 10 million hectares of additional harvestable land (Conab 2019). While this potential increase is equal to the predicted growth in harvested area in the country, the growth is expected to come from a mix of double cropping and new land. The availability of additional land provides a buffer against rising commodity prices.

Although land constraints and drops in productivity through land degradation or climate change may constrain supplies over the next 10 to 15 years, there seems to be sufficient growth in yields, brought on through investment during high-price periods, as well as harvested area for expansion to partially offset any slowdown.

Chart 10

Harvested Area and Production Growth in Key Trading Countries



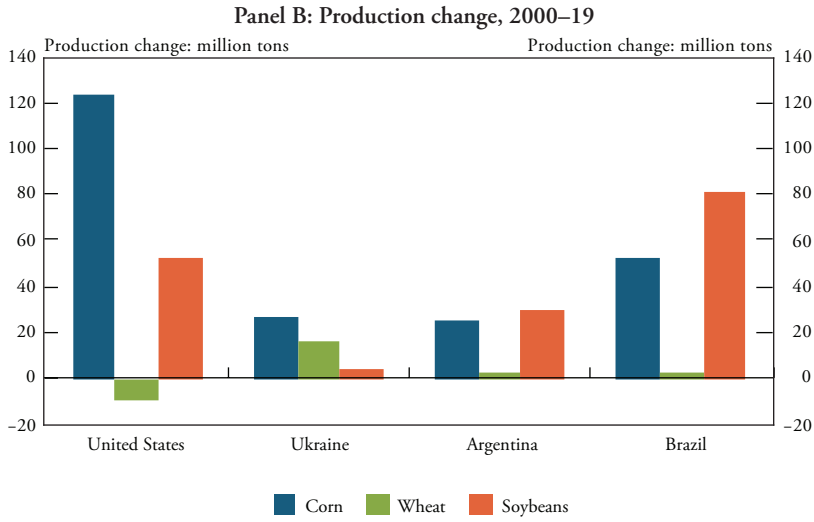
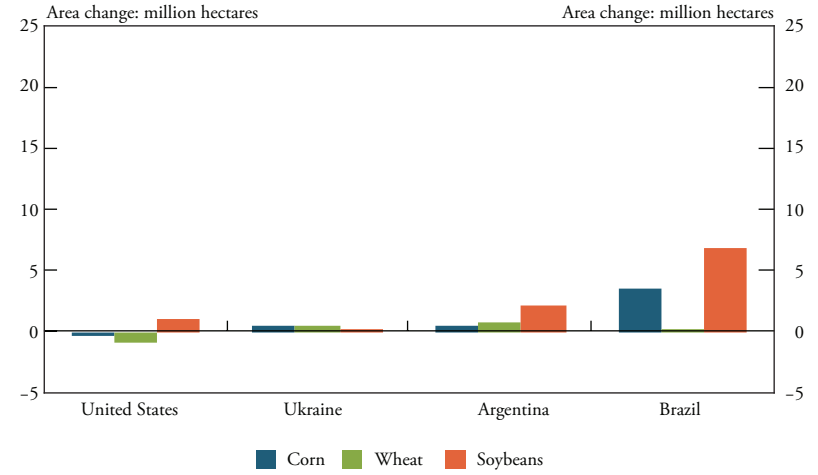
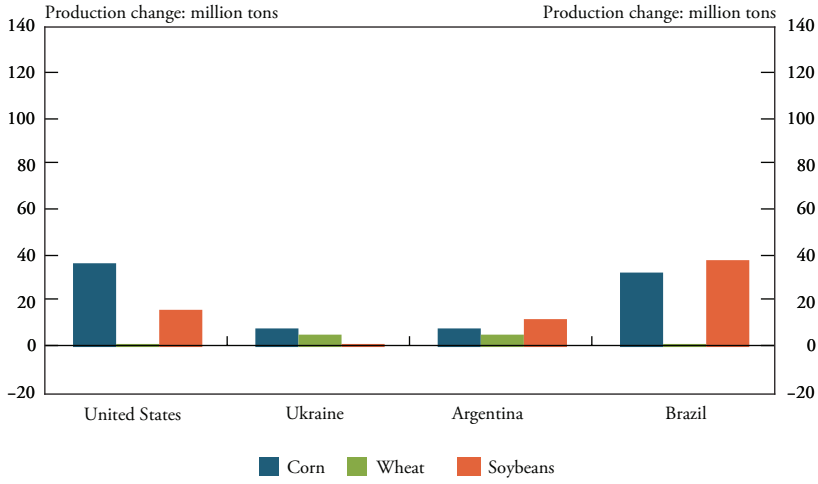


Chart 10 (continued)

Panel C: Area change, 2019–29



Panel D: Production change, 2019–29



Source: USDA ERS.

The changing role of the United States as a residual supplier

With planted area in the United States projected to be flat over the next decade, growth in production will likely come from gains in yield productivity. The share of production overseas is expected to continue to grow and will put steady pressure on U.S. export market share. Within the last two decades, U.S. export shares for corn and soybeans fell below 50 percent, and the share for wheat fell below 25 percent.

The rise in South American soybean production and the lack of farmer storage in the region has created a distinct six-month pattern in China: importers buy U.S. soybeans September through February and soybeans from the southern hemisphere from March through August. The rise of Brazil—and, to a lesser extent, Argentina, which tends to export soybean products—has also altered U.S. export patterns and carry for soybeans and even had modest influence on U.S. corn export patterns at harvest. The other catalyst for this global "just in time" delivery system for soybeans is a common and dominant destination market in China. China accounts for over 60 percent of global soybean imports and depends on imports for more than 90 percent of its soybeans, resulting in significant year-round demand.

With South America accounting for more than 50 percent of global exports and growing, potential importers are increasingly in a position of being only six to eight months from a new global soybean crop or even corn crop, tempering the need for U.S. producers to store and potentially reducing their gains from exploiting carry in the market. The reliance on a dominant single market has also become a source of concern given recent trade friction between the United States and China.

Impacts of trade friction may linger

China's imposition of tariffs on soybeans and other agricultural imports from the United States has had a large influence on U.S. trade, with the value of U.S. soybean sales to China falling by nearly 75 percent year over year for 2018. Trade in soybeans has remained weak throughout the first half of 2019, with other markets not fully offsetting lost trade with China (U.S. Census 2019).

Early in the China-U.S. trade tariff and retaliatory tariff episode, comparisons were drawn to the 1980 U.S.-Soviet wheat embargo, which had limited period effects as trade was rerouted (USDA ERS 1986).

However, the two episodes have some key differences. First, while the United States represented 40 percent of the wheat export market when the 1980 embargo was imposed, much as it does now for soybeans, the Soviet Union represented less than 25 percent of import demand and was transient in its demand from year to year. Moreover, at the time, there were numerous competing suppliers of wheat. The U.S. soybean export ban of 1973 is also cited as the impetus for Japanese investment in soybean production in South America (Almeida 2018).

The current Chinese tariff on soybean imports has left the United States with nearly 1 billion bushels of ending stocks for the 2018–19 crop year (USDA Office of the Chief Economist 2019b). The lingering effects of this trade disruption, if any, will be hard to quantify without a counterfactual. However, if China remains cut off from the U.S. soybean market, the U.S. share in world soybean markets will decline, if for no other reason than that the soybean crush in the rest of the world is growing at a slower rate than in China.

In the fall of 2018, the effective ban by the Chinese on commercial imports of U.S. soybeans led to a sizable price premium for Brazilian soybeans in the global market. The premium on Brazilian soybeans peaked at more than $90 a metric ton before narrowing again as tensions with the U.S. waned and the Chinese made verbal agreements to buy 20 million metric tons of soybeans for the 2018–19 season. The imbalance between Chinese import demand and the availability of non-U.S. soybeans lessened further as Brazilian and Argentine crops progressed well and African swine fever was reported in China, reducing Chinese import demand.

Argentine and Brazilian farmers saw some improvement in prices during this period but had limited opportunities to hedge the coming crop to lock in the price wedge at the time. The Chicago Board of Trade soybean contracts did not reflect the Brazilian and Argentine price premium. Brazil lacks a liquid soybean futures market and thus does not allow its farmers to fully hedge sales, capturing those premiums relative to U.S. markets, or for forward buyers to shed risk from those forward purchases. As a result, it has been difficult for Brazilian farmers to fully incorporate current price premiums into future receipts, blunting the incentive to expand. Under prolonged tensions, Brazilian and Argentine producers would likely capitalize on demand growth by investing

in expanding harvested area, an investment unlikely to quickly fade with an eventual trade agreement.

With the wide spread of African swine fever in China and a tariff on U.S. pork products, the Chinese have also been reported to be opening new import channels for beef, pork, and poultry products around the world. New business relationships may strengthen ties to other exporters even if or when the U.S. trade relationship with China normalizes. At the same time, the effects of African swine fever are likely to be felt for multiple years: China will need to rebuild its breeding stock and sow herd, farrow and finish the resulting pig crop, and bring them to market, all of which can only effectively occur when African swine fever is reasonably contained. The result is a multi-year recovery cycle that may further hinder global soybean demand but enhance Chinese meat trade.

Retaining domestic competitiveness

While it is difficult to identify a persistent demand or supply-side factor in the next decade that would return farm income to the levels seen from 2010 to 2015, other unforeseen factors might still emerge. Transient factors such as short crops in competitor nations may boost farm income, and action in the areas of technology, trade, and competition may be unproductive. Furthermore, factors that have encouraged consolidation among U.S. agricultural producers appear likely to continue.

U.S. producers have historically been active adopters of new technology and practices resulting in higher yields and lower production costs (Brookes and Barfoot 2017). The strength of farm income from 2010 to 2015 in particular drew in additional agricultural sector investment that will likely boost productivity over the coming decade (Alston and others 2000). The cost of production per acre of corn and soybeans is higher in the United States than in Brazil largely due to land costs (Meade and others 2016). However, adjusting for differences in relative corn yields on the farm and inland transportation costs at the port levels the two countries' competitiveness in the export market. Inland transportation costs for locations such as Mato Grosso, Brazil, are significantly higher than for the heartland of the United States. Inland transportation improvements in Brazil could challenge the margins of U.S. producers, requiring them to maintain trucking, rail, and inland

waterway infrastructure as well as consider policy changes to improve distribution (for example, the Jones Act).

Advances in bioengineered products, including both crops and livestock, present an opportunity to increase productivity while improving the sustainability of production by limiting losses and improving input efficiencies. In addition, gene-editing technologies present an opportunity to reduce producer costs and even moderate commodity price fluctuations: the process can be used to protect animals from infectious diseases and make crops more resistant to the vagaries of weather (Zhang and others 2018; Tait-Burkard and others 2018). However, the political regulatory and policy environment may have to change significantly to address technologies that are not well covered under the existing structure.

Given the changes in regional population growth, trade and trade access will continue to be critical in supporting U.S. producer income. As a consequence, the United States has to engage in bilateral and multilateral trade agreements that ensure that access restrictions and controls are scientifically based on internationally agreed-upon terms, such as international agreements on sanitary and phytosanitary measures. Widespread adoption of non-tariff barriers may also present impediments to international competitiveness (Office of the U.S. Trade Representative 2019). While consolidation in the farm sector is likely to continue unabated, it is critical for remaining producers to ensure market access by engaging customers abroad in bilateral and multilateral trade based on these principles.

Endnotes

[1]See, for example, Trostle (2008); Headey and Fan (2008); and Abbot, Hurt, and Tyler (2008).

[2] In addition, the projected surge in Chinese corn imports failed to materialize. Other global forecasters, such as the OECD and FAO, made similar projections.

[3]The 2019 USDA Baseline was completed prior to the outbreak of African swine fever in China.

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Long-Run Uncertainties for U.S. Agriculture

By Rosamond L. Naylor

In 2019, crop and livestock producers throughout the United States confront multiple challenges: trade restrictions, extreme weather events, late planting, low and variable commodity prices, and deteriorating infrastructure. Many conversations in rural America are focused on near-term profits, labor availability, land rental rates, and loan repayments for agricultural machinery. The immediate economic concerns of farm households form the basis for wide-ranging policy discussions at local to national levels.

Virtually all U.S. farmers also face economic and environmental uncertainties over the long term. These long-run uncertainties arise in a globalized food system, where trade policy and linkages between food, feed, and fuel markets work either to stabilize or destabilize commodity markets. Climate change and climate variability—extending beyond just "a year or two of bad weather"—add to the long-run unpredictability of the farm economy.

This paper focuses on three important categories of long-run uncertainty for U.S. agriculture: transitions in global food and fuel demand, the effects of a changing climate, and regional depletion of groundwater resources for irrigation. The definition of "long run" is confined here to a generation in time (approximately 30 years), although the same

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uncertainties would apply throughout the twenty-first century. While a full analysis of each category is beyond the scope of this paper, each section highlights some key areas of uncertainty, reviews recent evidence, and provides relevant examples.

Attention to long-term uncertainties in agriculture is important because farm households manage large amounts of expensive fixed capital, such as land, irrigation equipment, and farm machinery, which places a premium on long-range planning. In addition, understanding long-term uncertainties in agriculture, particularly as applied to climate adaptation and water resource management, is key for creating appropriate policy incentives for farmers through the U.S. Farm Bill and other state-level measures.

I. The Changing Nature of Demand

The future trajectory of global agricultural demand typically provides an overall sense of optimism for U.S. farmers. The world's population is projected to grow by 30 percent over the next 30 years, from 7.6 billion in 2018 to roughly 9.9 billion by 2050.[1] Virtually all of this growth will occur in developing and emerging economies, where per capita incomes are also on the rise. Over the same period, the share of the world's population living in urban areas is expected to jump from 55 percent to 68 percent. These factors, set in the context of a globalized economy, will sustain growth in consumption of wheat- and maize-based products, animal protein, and a wide range of vegetables, fruits, nuts, and other commodities that comprise diversified diets.[2] As one of the world's largest producers and exporters of corn (maize), soybeans, wheat, commercial feeds, and meat products, the United States will likely benefit from these trends in global demand. Economic development in the Global South (a term used by the World Bank to refer to countries in Asia, Africa, Latin America, and the Carribean considered to have low or middle income compared with the Global North) will also lead to increased demand for transportation fuels, including ethanol and biodiesel.

Despite the promise of anticipated growth in global food, feed, and fuel demand for the U.S. agricultural economy, there are three important areas of uncertainty surrounding future consumption patterns that merit careful consideration. The first involves the regional trajectory

of population growth and its implications for global agricultural markets, with a specific focus on Africa. The second encompasses potential shifts in consumer preferences toward nutritious and sustainable foods in both industrialized and developing economies. Finally, the future of the global biofuels market, which has relied to date on a combination of government subsidies, regulations, and targets in all major biofuel-producing countries, remains a large source of uncertainty for the global agricultural economy.

Africa's agricultural demand

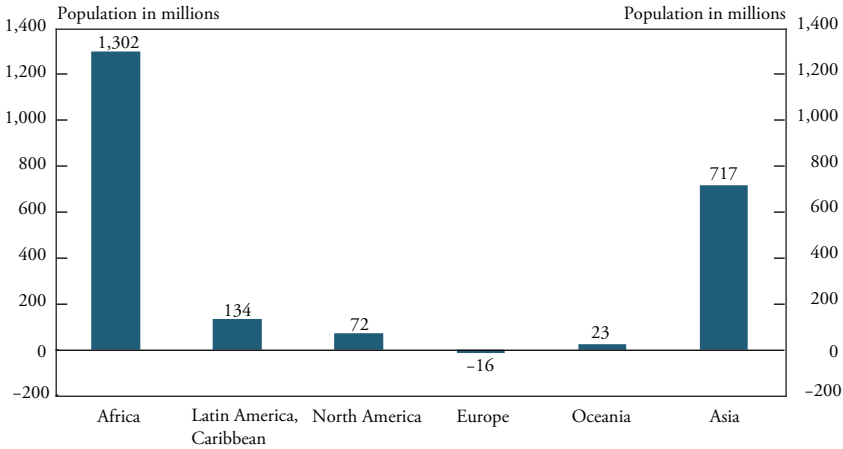
Africa's population is expected to double over the next generation, from 1.3 billion in 2018 to 2.6 billion in 2050, accounting for 58 percent of the global population increase by midcentury (Chart 1). To put this number in perspective, Africa will add 40 percent more people by 2050 than the rest of the world combined. Meanwhile, urbanization on the continent is projected to rise from 40 percent today to almost 60 percent by midcentury. China's population, by contrast, will decline by an estimated 50 million by 2050.

On a global scale, the total fertility rate (TFR) has been falling for decades and now stands at 2.4, less than half the rate of 4.9 recorded in the late 1960s and verging on the replacement level of fertility of about 2.1.[3] Yet throughout the African continent, fertility rates remain well above replacement rates in many countries, failing to follow the rapid pattern of demographic transition experienced in Asia and Latin America at similar stages of economic development.[4] Currently, 17 countries in the world have TFRs above 5, all of which are in sub-Saharan Africa. Niger, with the highest TFR at 7.2, is among the world's poorest countries. Nigeria, a country with greater economic potential, has a TFR of 5.5 and will replace the United States as the third most populous nation by 2050.

What these demographic trends imply for future consumption and trade in cereals, oil crops, animal feeds, and animal products is difficult to predict. Will wheat farmers in Kansas benefit from increased demand for bread and other processed wheat products as African cities expand? Will Louisiana farmers gain from continued growth in per capita consumption of rice in Africa? Will Iowa corn and soybean farmers find new export markets for feeds, meat products, and vegetable oils? Much

Chart 1

Population Change by Major Region, 2018–50



Source: Population Reference Bureau.

of the uncertainty centers on the future trajectory of economic growth for the continent's 54 individual countries. For the past five years, from 2013–18, 30 percent of Africa's economies achieved an average annual rate of real GDP growth at or above 5 percent, but another 30 percent remained economically stagnant (World Bank Group 2019).[5] Large income disparities in many African countries—even in the fastest growing economies—make forecasts of future agricultural demand even more unreliable. In addition, Africa's bulging youth population, estimated to grow by 50 percent by 2050, will generate a precarious balance of youth unemployment and economic growth triggered by innovation and entrepreneurship throughout the continent, depending on each government's economic policies and investments in education and health.[6] For those economies that cannot adequately absorb their expanding youth populations, the risks of civil conflict loom large (Naylor 2018).

Even if Africa's economic trajectory could be predicted with a high degree of certainty, the implications for food, feed, and fuel consumption and trade remain unclear. Which types of animal protein will be most highly demanded in African countries as incomes rise—beef, pork, poultry, fish, eggs, dairy products? Will feeds be sourced internationally or produced and exchanged increasingly within the

continent? To what extent will growth in Africa's transportation fleets rely on regionally versus internationally produced biofuels?

Given the potential scale of Africa's agricultural demand over the next generation, answers to these questions are important for the U.S. agricultural economy. If Africa is, indeed, seen as a target of market opportunity for American farmers, the United States will need to adjust its long-term trade strategy promptly. A decade ago, the United States was one of Africa's main trade partners, along with Europe, Japan, and Brazil. Today, China and India have overtaken the United States and these other countries as Africa's main trading partners and infrastructure investors (*Economist* 2019). Historically, the United States has demonstrated a relatively weak commitment to many African countries due to a myriad of governance and geopolitical concerns; building long-term economic and trade relationships with leading African countries, such as Nigeria, Kenya, and South Africa, will be important for America's agricultural exports going forward.

Food security, health, and the environment

The second area of long-run uncertainty in global agricultural markets pertains to the future trajectory of human nutrition and consumer preferences. Although continued population growth implies "more mouths to feed," the demand for cereals and other starchy staples to meet basic calorie needs is well past its peak (Pingali 2015). The prevailing view that significant growth in staple grain supplies is needed to feed a world that will remain deficient in calories in 2050 is largely misleading. Most low-income households around the world—with the notable exception of those in protracted conflict areas—now have sufficient calories for an active working life in most years (FAO 2017; Naylor 2018). Extreme weather events, natural disasters, droughts, and political upheavals still result in regional food shortages and famines from time to time, especially in parts of sub-Saharan Africa (Devereux 2009; FAO 2018a; FAO and ECA 2018). The level of staple crop demand for direct food consumption has thus leveled off on trend, but the variation in demand persists due to factors largely outside the control of the communities in need. Meanwhile, a rising share of staple grains is being directed toward animal feeds, biofuels, and other industrial demands.

As basic calorie requirements are met for most populations around the world, the focus on global food security is being supplanted by a focus on global nutrition security. Many individuals living in poverty, and even those in low-to-middle-income groups, remain deficient in protein, micronutrients, and essential vitamins—a condition widely referred to as "hidden hunger" (Leathers and Foster 2017). Infants experiencing serious micronutrient and vitamin deficiencies during the first two years of life (including the gestation period in the womb) often suffer from stunting, contributing to permanent physical and cognitive impairments. There are other problems associated with hidden hunger as well: for example, iron deficiency causes anemia, leading to low labor productivity and poor achievement in school, and vitamin A deficiency causes night blindness and poor lung and gut function, particularly in children. Over two billion people worldwide currently suffer from some form of hidden hunger (Gödecke and others 2018).

Global malnutrition is also characterized by excess consumption. Diets rich in carbohydrates, sugar, and saturated fats contribute to serious health problems related to obesity, diabetes, and heart disease in both developing and industrialized countries. Middle-income countries are currently experiencing the most rapid growth in adult and childhood obesity as access to processed foods expands and daily physical activity declines (Leathers and Foster 2017). The global health implications of these trends are staggering, as the majority of the world's population now lives in countries where overweight and obesity-related deaths exceed hunger-related deaths (WHO 2018). With mounting health costs at local to national scales, increased awareness of the links between dietary choices and health outcomes is likely to temper long-term growth in demand for cereals, oil crops, sugar, and meat on a per capita basis. Significant shifts in food preferences, should they occur in the future, would directly affect the U.S. agricultural economy.

Dietary choices are being discussed not only in terms of nutrition, but also in terms of their environmental consequences, particularly among scientific and advocacy groups in Europe and the United States. These discussions present an additional area of uncertainty for future agricultural demand. In January 2019, a report published by the EAT-*Lancet* Commission on "Food in the Anthropocene: Healthy Diets from Sustainable Food Systems" garnered considerable attention within international food and agriculture circles.[7] The report

advocated a rethinking of global food systems and food choices in alignment with the United Nations Sustainable Development Goals and the 2016 Paris Agreement on climate change mitigation. Building on a large and growing body of scientific studies, the report urged a significant shift in consumption and production toward plant-based foods and away from animal-based products, with specific recommendations tailored to countries according to their development and nutritional status. The EAT-*Lancet* report is just one of dozens of recent reports published by international organizations, non-governmental organizations, and scholars during the past decade that raise concerns about the unhealthy, unsustainable, and inequitable dimensions of the global food system.[8] The extent to which sustainability objectives will shape the future of global food systems over the coming decades remains unclear. What is clear, however, is that the international discourse and scientific focus on the health, environment, and equity aspects of food is intensifying.

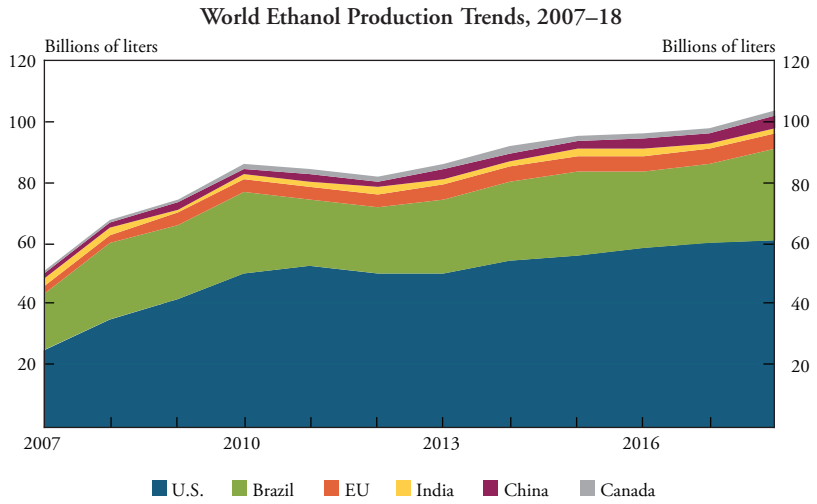
The long-term future of biofuels

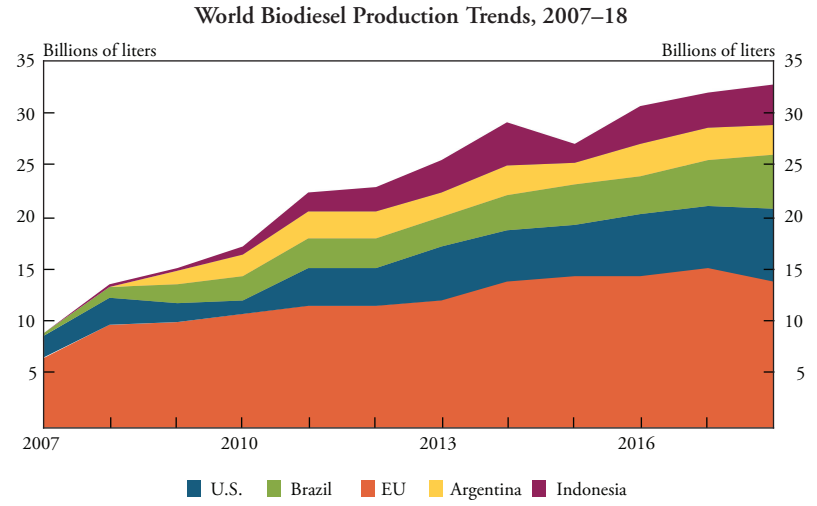
The future trajectory of ethanol, biodiesel, and advanced liquid biofuels presents a third layer of uncertainty for agricultural markets. During the past decade, global ethanol production more than doubled and biodiesel production almost quadrupled (Chart 2). The industry is concentrated geographically, with over 80 percent of global biofuels production and use occurring in the United States, Brazil, and the European Union in 2017 (REN21 2018). The United States has emerged as the world's largest producer of both ethanol and biodiesel, followed by Brazil and more distantly by Germany, Argentina, China, and Indonesia. Ethanol accounts for nearly three-quarters of liquid biofuel production today, but the balance is expected to tip increasingly toward biodiesel as diesel gains market share over gasoline in transportation fuels, particularly in developing countries where commercial truck fleets are expanding rapidly (Naylor and Higgins 2017).[9]

In 2017, the transportation sector accounted for almost one-third of final energy consumption worldwide, but only 3.1 percent of energy used in transportation was from renewable sources (REN21 2018). Biofuels accounted for 90 percent of the renewable portion (2.8 percent of total transportation energy), with electric vehicles constituting the

Chart 2

Growth in Global Production of Ethanol and Biodiesel among Major Producers, 2007–18





Source: Naylor and Higgins (2017) and REN21 (2018).

remainder. Looking ahead, rising incomes throughout much of the Global South over the next 30 years are expected to lead to rapid expansion in all forms of transportation—motorcycles, cars, buses, trucks, planes, boats, and rail. Whether or not biofuels will gain market share within this growing transportation sector will depend on government policies, corporate behavior, and consumer preferences related to energy security, sustainability goals, and relative prices of fossil fuels to biofuels. Crude oil prices have been highly variable during the past 15 years—varying by a factor of four, from roughly $30 to $120 a barrel in real terms—indicating that forecasts of fuel prices out to 2050 have a high degree of error.[10] The future of biofuels is also contingent on technological advances in areas such as cellulosic biofuels and aviation biofuels, which have been relatively slow to develop to date (REN21 2018).

The largest area of uncertainty in long-term biofuel projections is the future role of government policies, both within the United States and in other biofuel-producing countries. U.S. dominance in the global ethanol and biodiesel markets has resulted mainly from the establishment of mandates and other regulations and incentives for biofuel production and use within the federal Renewable Fuel Standard (RFS) legislation (EPA 2019; Naylor and Falcon 2011; Naylor and Higgins 2017). Roughly 40 percent of the U.S. corn crop now goes into ethanol, and with recent low commodity prices and continued trade battles with China, President Trump signed a new executive order in June 2019 to lift the summer season ban on fuels containing higher blends of ethanol (USDA ERS 2019). This ruling will permit an increase from E10 blends (10 percent ethanol and 90 percent petroleum, as currently mandated in the RFS) to E15 blends; the higher blends had been restricted for summertime use due to concerns of increased smog during periods of high temperatures. The United States also provides incentives for biodiesel through tax exemptions and restrictive trade policies, including anti-dumping duties on biodiesel imports from Argentina and Indonesia and a history of complex trade rules with the European Union (Naylor and Higgins 2017). Overall, the direction of U.S. biofuel policies continues to be a moving target, hinging largely on market conditions for corn and soybeans.

The scope of policy interventions on biofuels is global and massive in scale. More than 40 countries had mandates and other regulatory

Table 1

Biofuel Mandates (Ethanol and Biodiesel) for the World's Major Producing Countries

Country	Ethanol mandate	Biodiesel mandate
U.S.	15 billion gallons in 2019	2.1 billion gallons in 2019
EU	B20 in overall energy mix by 2020; B10 in transportation sector; a maximum of 7 percent from food-based biofuels	
Brazil	E27 in 2018	B10 in 2018
India	E20 by 2030	B5 by 2030
China	E10 by 2020	None
Canada	E5; higher in some provinces	B2; higher in some provinces
Indonesia	E20 by 2025; currently no import or production of fuel-grade ethanol in Indonesia	B30
Argentina	E12 in 2018	B10 in 2018

Sources: U.S. Department of Agriculture (USDA), European Commission, U.S. Environmental Protection Agency, and the International Energy Agency. Adapted from Naylor and Higgins (2017).

policies supporting biofuel production and use in 2017 (REN21 2018). Table 1 shows the mandates for the world's major biofuel-producing countries. In most of these countries, including China, Brazil, and Indonesia, biofuel mandates have been aimed at boosting the demand for domestic agricultural feedstocks and promoting a transition from fossil fuels to renewable energy in transportation. In other countries, such as Norway and European Union nations, concerns over the sustainability and climate consequences of feedstock production have weakened biofuel incentives. The complex interactions among policies on energy, agriculture, trade, environment, and climate throughout the world make the future of crop-based biofuels highly unpredictable.

A final area of long-run uncertainty for the biofuels sector is the role of electric vehicles (EVs) in global transportation fleets. Globally, the number of EV sales has increased to record levels each year—albeit from a low base—and car manufacturers continue to roll out new electric vehicle product lines (REN21 2018). Sales of electric cars increased by 58 percent in 2016 alone, accounting for 1.3 percent of total passenger vehicles on the road (IEA 2018). North America is now the third largest market for EVs after Europe and China (REN21 2018).

Although EVs represent a small share of global transportation today, growth in this sector is fueled by policies and initiatives to advance the renewable energy sector. In 2017, five countries announced plans

to ban diesel and petroleum vehicles completely in the coming decades: India, the Netherlands, and Slovenia by 2030, and France and the United Kingdom by 2040. Also in 2017, the Global Electric Vehicles Initiative (EV30@30) was launched, setting a target for 30 percent market share of EVs among passenger cars, light commercial vehicles, buses and trucks by 2030 (IEA 2019). This initiative is backed by a growing list of countries, including Canada, China, Finland, France, India, Japan, Mexico, the Netherlands, Norway, Sweden, and the United Kingdom. Meanwhile, a coalition of corporations from China, Europe, and the United States, assembled by the Climate Group, introduced an "EV100" program to help accelerate a full replacement of petrol and diesel fleets with EVs, including the development of renewable electric charging infrastructure (Climate Group 2017).

The fact that the world's two largest emerging economies—China and India—are among the many countries actively pursuing a transformation from petroleum- and diesel-powered transportation to EVs suggests that the future path of global biofuels cannot be assured. Even in the United States, sustainability concerns focused mainly on climate change have sparked a growing debate on the life-cycle environmental consequences of electric versus biofuel-based transportation, with supporters of EVs and biofuels pitted against each other (Martin 2017b).[11] How these trends and debates over energy, climate, and the environment will affect American farmers over the next few decades remains to be seen.

Ultimately, the 30-year trajectory of global agricultural demand for food, feed, and fuel is ripe with uncertainty. The long-run challenge of ensuring robust demand for staple agricultural products in the United States may even rival the widely declared challenge of producing enough food to feed a global population of 10 billion by 2050. What is clear, however, is that challenges on both sides of the agricultural demand-supply equation will be important for farming communities as they plan for the future.

II. Climate Change and Variability

One of the largest uncertainties for agricultural supplies over the course of the twenty-first century centers on climate change and variability. The best way to think about climate is that it represents the

statistics of weather over time and space, and all farming communities have an eye on the weather. The effects of extreme weather events and natural disasters—heavy rains and floods, unseasonal hailstorms and blizzards, droughts, tornados, hurricanes, and severe heat waves—are experienced regularly by farmers throughout the world today. How the frequency, intensity, and location of such extreme weather events and natural disasters are likely to change in the future with rising mean global temperatures remains uncertain (IPCC 2014).

Climate change, or global warming, is a topic of widespread debate in U.S. society, but one need only look at the actions of the $5 trillion global insurance industry to understand that climate change poses a substantial and increasing risk. In a 2018 survey of the global insurance industry, climate change was ranked for the first time as the leading current risk, emerging risk, and risk combination for 2019, rising above the perceived risks associated with cyber and infrastructure collapse, financial volatility, and price asset collapse (Rudolph 2019). Also in 2018, a survey by the Geneva Association, a major international insurance think tank, found that two-thirds of the companies within their sample have already integrated climate change into their business models, incorporating the full suite of physical, liability, and transaction risks (Golnaraghi 2018).[12] The elevated rank of climate change as a leading insurance risk reflects the rising frequency of extreme weather events and the increasing exposure of people and property to such events worldwide.

Regardless of how farmers in the United States articulate their views on climate change, most are in favor of crop insurance programs through the Farm Bill. A recent report by the Congressional Research Service (2018) shows that the federal crop insurance title of the Farm Bill had the second largest outlays after nutrition programs during the 2007–16 period, a pattern that is expected to persist through 2027.[13] In the 2014 Farm Bill, the federal crop insurance program became agriculture's largest producer support program, providing over $100 billion of insurance protection annually for over 100 crops. Corn, soy, and wheat accounted for roughly 70 percent of enrolled acres and claim payments, with enrollment concentrated in revenue-based policies (which insure against a combination of production losses from natural causes and declines in commodity prices), followed by yield-based policies (which insure specifically against production losses from natural causes, such

as drought, floods, hail, wind, insects, and disease). Although federal subsidies on insurance premiums differ by level of coverage and type of program, the Federal Crop Insurance Corporation paid 61 percent of the premiums in aggregate from 2007 to 2016, while producers paid 39 percent.

Precipitation and extreme events

When asked about future climate uncertainties, farming communities generally talk about rainfall and extreme events, such as floods, droughts, tornados, and hurricanes. Such events have widespread effects on their livelihoods, properties, and personal lives through injury and death. Since the start of 2019, eight Corn Belt states along the Mississippi have experienced record, long-lasting rainfall—more than 2 feet of precipitation in the lower regions and up to 40 inches in some areas—causing historic delays in planting or no planting at all (National Weather Service 2019a; see also Good 2019). In the five months between January and May 2019, the National Weather Service also reported an all-time record of over 1,000 tornados throughout the United States, over half occurring in May alone (National Weather Service 2019b).

The frequency and intensity of heavy precipitation events across the United States have increased more than average precipitation during the past 50 years, a trend that will likely continue well into the twenty-first century (National Climate Assessment 2018).[14] At the same time, surface soil moisture over most of the United States is expected to decrease with greater temperatures over the coming decades, raising the specter of worsening drought conditions in some regions, particularly in the Southwest and Southern Great Plains. As important as these conditions are for the U.S. agricultural sector, long-range predictions of the timing, location, and intensity of extreme weather events cannot be made with much confidence (IPCC 2014).

A related source of uncertainty for farmers over the next 30 years will be the cost of crop insurance premiums and the extent of federal insurance subsidies as the effects of climate change unfold. Between 1980 and 2018, the United States experienced an average of 6.3 extreme weather events per year with damages over $1 billion each (inflation-adjusted); during the most recent five years (2014–19), the number doubled to 12.6 extreme events per year.[15] With the rising number of

extreme weather events per year in the United States, it is highly likely that crop insurance premiums will also increase.

Yield outcomes from rising temperatures

Although farming communities generally focus on risks related to precipitation, climate experts tend to focus on future warming trends for several reasons. First, both the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) have reported rising global temperatures since the turn of the twenty-first century, and the past five years alone have been the warmest since modern recordkeeping began (NOAA 2019; NASA 2019) . In addition, the projected increase in mean temperatures around the world is large relative to historical variability, and there is much greater agreement in the global climate models on future temperature versus precipitation forecasts (Lobell and Burke 2008; Battisti and Naylor 2009; IPCC 2014). In all but the most aggressive scenario for greenhouse gas emission reductions—a highly unlikely scenario given that carbon dioxide emissions continue to rise—the global annual mean temperature is expected to increase by 2 degrees Celsius by midcentury compared with the 1980–99 average (IPCC 2014).[16] Numerous studies have concluded that warming of this magnitude will lead to substantial declines in average crop yields, and that the most serious agricultural consequences will occur in the tropics (Battisti and Naylor 2009; Porter and others 2014; Asseng and others 2014; Zhao and others 2017). For every degree Celsius increase in the global mean temperature, holding all else constant, yields are projected to decrease on average by 7.4 percent for corn, 6 percent for wheat, 3.2 percent for rice, and 3.1 percent for soybeans (Zhao and others 2017).[17]

The effect of extreme temperatures on crop yields depends on the timing of heat or freezing events. High temperatures negatively affect plant development in multiple ways and at different times in the growing season, such as through reduced spikelet fertility, reduced grain filling, and increased respiration (Porter and others 2014; Sánchez, Rasmussen, and Porter 2014). Freezing temperatures can push plants toward dormancy by shutting down tiller formation. In a study that measured wheat yields in Kansas varietal trials against location-specific weather data from 1985–2013, Tack and others (2015) showed that

the largest effects of temperature-induced yield loss were due to freezing temperatures in the fall and extreme heat events in the spring.[18] The net effects of warming were uniformly negative across wheat varieties, even when accounting for lower exposure to freezing. The study highlighted an important trade-off in crop breeding: many new varieties in the field trials have relatively long grain-filling stages to increase yield potential under ideal conditions, but this long grain-filling period makes the plants more vulnerable to heat stress in high temperature seasons. Spring rainfall can ease heat stress in wheat and other crops, and additional irrigation can be used as an adaptation strategy to reduce the effect of high temperatures on yields during the long grain-filling stage. However, the availability of water for irrigation poses additional uncertainties for farmers in the future.

Climate effects on crop pests and pathogens

While many studies of climate effects on agriculture focus on the direct relationships between temperature, precipitation, and crop yields, the indirect effects of climate change on the evolution and spread of pest and pathogens in agriculture may be more serious—and significantly less predictable. Plant species differ in their defense mechanisms to biotic stress under changing climate conditions. These differences are not directional—that is, some crop species demonstrate stronger defense strategies, while others become more susceptible to pests and pathogens under varying climate conditions—and it is difficult to aggregate the varying response mechanisms at regional or global scales. Elevated carbon dioxide can also shift a given plant's natural defenses to favor some types of crop diseases over others (Zhou and others 2019). Climate change affects more than a crop's defense behavior to pests and pathogens; it also affects the evolution and movement of pests and pathogens themselves (Velásquez and others 2018). Overall, the interactions between crops, pests, and pathogens in the context of climate change are highly complex and poorly understood (Gregory and others 2009).

Farmers in temperate regions are likely to be affected by crop pests and pathogens that respond to warmer winters and shorter (or nonexistent) freezing fallow seasons. Wetter and milder winters will increase the survival of certain winter annual weeds, and longer growing seasons will allow summer annual weeds to move northward—patterns that are

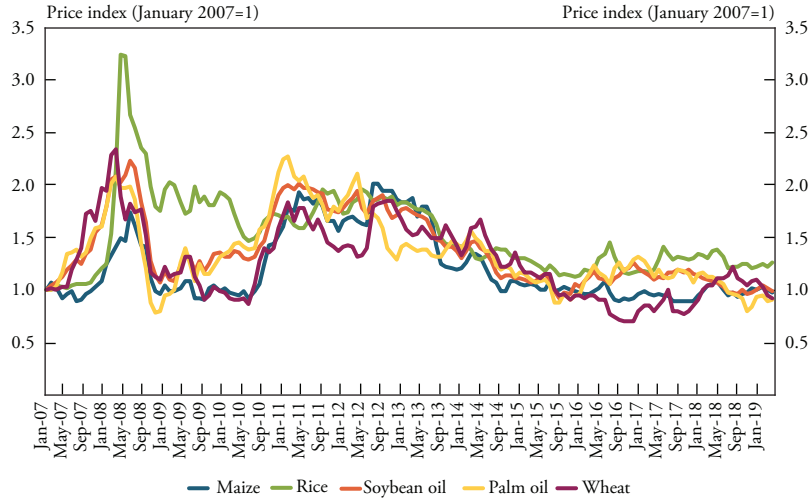
already evident in parts of Europe and North America (Peters and others 2014). Warmer and more humid growing conditions with year-round cropping will also facilitate the spread of fungal diseases, such as leaf rust for wheat. A recent study by Caubel and others (2017) showed that with milder winters in France, wheat rust establishes earlier in the season, augmenting fungal infections and sporulation efficiencies and leading to more virulent leaf rust cycles.

Warmer climates will also increase the metabolic rate of insect pests and allow insects to expand their range into higher latitudes, thus potentially exacerbating plant herbivory as well as the spread of insect-transmitted viruses, bacteria, and fungi. Deutsch and others (2018) modeled these insect dynamics for rice, wheat, and corn on a global scale and projected increases in yield losses of 10–25 percent per degree Celsius of global warming associated with climate-induced pest pressure from range expansion and herbivory, with the highest losses in temperate areas. In tropical areas, the increase in insect pest metabolism is somewhat offset by a decline in growth rate and expansion, as insects in these regions already operate near their optimum temperature range. Scientists at the Universities of Exeter and Oxford have recorded the movement of crop pests toward the North or South Poles since 1960 and have measured a rate of 2 miles (3 kilometers) per year on average for all pests and a northward movement of 12 miles per year for insect pests in particular.[19] Still, there is much to be learned about the dynamics of insect infestations in temperate agricultural systems, particularly regarding predator behavior and natural plant defense mechanisms.

A key question for the next 30 years is whether or not breeding efforts can stay ahead of both direct (abiotic) effects of climate on crop yields due to heat stress, droughts, and excessive rainfall and indirect (biotic) stresses from pests and pathogens. Management strategies for abiotic stresses, such as early planting or increased irrigation, may not be effective at curtailing biotic stresses from pests and disease. Even with new forms of chemical and genetic controls, it is highly possible that crop production in the United States and other temperate zones will become more variable with the spread of overwintering pests and diseases.

Chart 3

Variability in Agricultural Commodity Prices, January 2007– April 2019



Notes: Prices are nominal. Maize: U.S. No.2 Yellow, FOB Gulf of Mexico, U.S. price, US$ per metric ton; wheat: No.1 Hard Red Winter, ordinary protein, Kansas City, US$ per metric ton; rice: 5 percent broken milled white rice, Thailand nominal price quote, US$ per metric ton; soybean oil: Chicago Soybean Oil Futures (first contract forward) exchange approved grades, US$ per metric ton; palm oil: Malaysia Palm Oil Futures (first contract forward) 4–5 percent FFA, US$ per metric ton.
Source: International Monetary Fund.

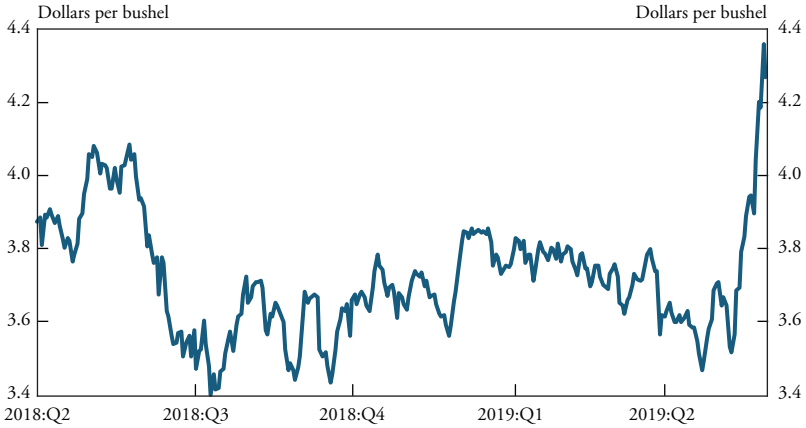
Climate effects on market volatility

Yield variability is a key concern for farmers throughout the United States as it affects farm revenue streams, crop insurance premiums, and in some cases, overall market volatility. International grain and oil crop markets have been highly volatile for over a decade, with peak monthly prices exceeding low monthly prices (in nominal terms) by 200 percent to 300 percent from 2007 to 2019 (Chart 3).

Several factors are contributing to this pattern of volatility, including international financial fluctuations and trade, biofuel, and stocking policies, but climate-induced production shocks also play an important role. As a recent example, record delays in corn planting in the U.S. Midwest due to extreme wet weather caused the Chicago Board of Trade (CBOT) corn price to jump to a three-year high in late May 2019, reversing (at least temporarily) an extended period of low prices for farmers (Chart 4). Severe rainfall, floods, droughts, heat waves, and

Chart 4

Spike in Corn Price in May 2019 with Extreme Wet Weather and Delayed Planting



Note: Nominal price on vertical axis (CBOT, USD/bushel), time on horizontal axis (Feb. 2018–May 2019).
Source: USDA National Agricultural Statistic Service.

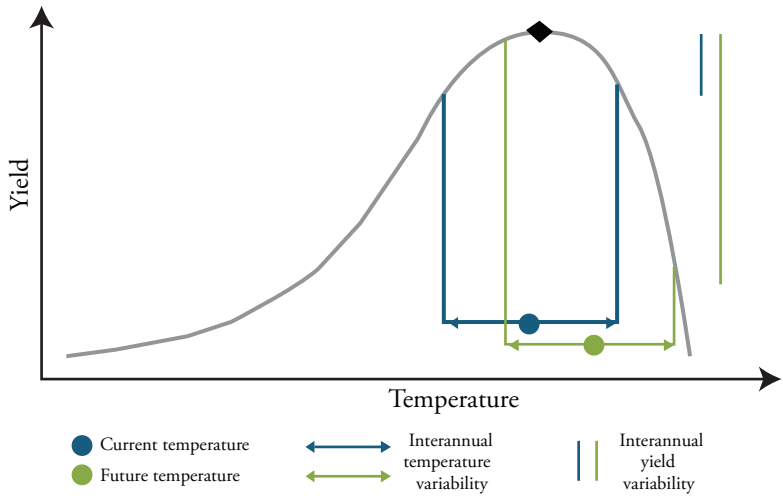
natural disasters that affect yields in the world's major breadbaskets often produce ripple effects throughout the world food economy.

In highly managed, high-yield cropping systems, such as those in North America, climate variability accounts for a relatively large share of the total yield variance compared with low-yield environments, where agronomic and management conditions have a greater influence. Empirical studies of climate change and agricultural yields in the United States indicate that major crops, such as corn, have an optimal temperature for performance, beyond which yield levels rapidly decline (Schlenker and Roberts 2009; Urban and others 2012). As illustrated in Figure 1, an increase in the mean temperature beyond the optimum growing temperature can also result in greater yield variability, even if interannual temperature variability remains the same.

Extreme crop losses in large producing countries are currently rare due to the highly controlled environment and technology under which these crops are grown. However, yield variability is expected to increase significantly under future warming conditions, unless heat-tolerant varieties or other adaptation measures, such as increased irrigation, are adopted. Modeling the potential effects of rising global temperatures on corn yields around the world, Tigchelaar and others (2018) find

Figure 1

Schematic Representation of Temperature-Yield Relationship



Notes: In the absence of breeding for heat tolerance, an increase in mean temperature beyond the optimum temperature (black diamond) will lead to a decrease in mean yield and an increase in yield variability, assuming interannual temperature variability stays the same.
Source: Tigchelaar and others (2018).

that increased yield variability in the world's major producing countries is likely to lead to greater market volatility worldwide.[20] Their analysis shows that the probability of climate-induced yield losses greater than 10 percent for the top four corn-producing countries (United States, China, Brazil, and Argentina) is negligible today but rises dramatically with a 2 degree Celsius increase in growing season temperatures by mid-century (Table 2). The probability of significant yield losses jumps even higher as growing season temperatures rise by 4 degrees Celsius, an outcome that is not farfetched given current trends in global greenhouse gas emissions and carbon dioxide concentrations in the atmosphere (Global Carbon Project 2018).

Assuming that weather varies independently between geographic regions, the chance that maize production will fall by more than 10 percent in all four countries in the same year is zero today but rises to 6 percent under 2 degree Celsius warming and 86 percent under 4 degree Celsius warming. Similar results hold for the world's four largest exporting countries (United States, Brazil, Argentina, and Ukraine). Given that the top four producing countries comprise more than two-thirds

Table 2

Percent Probability of Climate-Induced Yield Losses for Corn-Producing Countries

	Present day		2°C warming		4°C warming	
Country	>10 percent	>20 percent	>10 percent	>20 percent	>10 percent	>20 percent
United States	3.8	0.0	68.6	29.5	100.0	96.9
China	6.6	0.0	46.2	16.8	98.8	89.2
Brazil	1.4	0.0	38.7	9.4	90.5	64.1
Argentina	3.4	0.1	50.0	9.9	96.9	86.9
Ukraine	2.5	0.3	51.8	19.2	98.2	85.0
Top four producing (United States, China, Brazil, Argentina)	0.0	0.0	6.1	0.0	86.6	48.1
Top four exporting (United States, Brazil, Argentina, Ukraine)	0.0	0.0	6.9	10.0	86.1	45.8

Note: Table shows probability that in any given year, the relative yield in a country's most productive region will decline by 10 percent or 20 percent of the present-day mean yield for the top corn-producing countries individually (top), and combinations of the countries that produce or trade the most corn (bottom).
Source: Tigchelaar and others (2018).

of global production—and the top four exporters contribute around 87 percent of global corn exports—this analysis portends substantial volatility in international corn markets over the long term in the absence of significant adaptation. More generally, widespread volatility in corn production has implications for global agricultural markets as a whole, as corn is often considered to be the lynchpin of the world food economy. Corn accounts for around one-third of global cereal production and trade, and it is closely linked to other cereal and oil crop markets through its versatile role in food, feed, and biofuel markets (Naylor and Falcon 2011).

In addition, it is highly likely that agricultural market volatility resulting from climate shocks will be amplified by intervening trade policies. Widespread evidence on the political-economy dynamics of food and agriculture shows that governments around the world tend to restrict cereal trade during times of international price volatility to stabilize domestic food and agricultural markets (Swinnen 2018; Battisti and Naylor 2009). During the 2006–08 food crisis, for example, large maize-exporting countries, such as Brazil, Argentina, and Ukraine, imposed export bans (thus lowering export supply in world markets), while importing countries introduced trade incentives to lower the price of imported grain (thus raising import demand) (Abbott 2012).

The result was a much larger international price shock for cereals than would have been the case had free trade prevailed (Naylor and Falcon 2010; Martin and Anderson 2012).

The upshot is that climate effects on agricultural productivity—combined with government restrictions on trade to stabilize domestic markets—are likely to have multiplier effects on agricultural prices and farm incomes. Synchronous climate shocks among major grain-trading countries will exacerbate global market volatility. Given the current trend toward protectionist trade policies, climate-induced price volatility poses increasing uncertainty for farmers in both the short and long run.[21]

III. Groundwater Depletion for Irrigation

An important adaptation option for farmers facing climate-induced yield volatility is to irrigate their crops with greater intensity in seasons of dangerously high heat and low rainfall. Irrigation increases crop evapotranspiration, allowing the land surface to remain cooler than it otherwise would be under heat- and water-stressed conditions. The main risk that this solution presents is excessive demand for freshwater resources and the depletion of groundwater in regions where extraction exceeds aquifer recharge.[22] Ongoing challenges of groundwater depletion in two of the world's major breadbaskets—the U.S. Ogallala Aquifer region and the Punjab region of India—are presented here to illustrate the potential enormity of the problem.

On a global basis, irrigation already accounts for around 70 percent of freshwater withdrawals and 90 percent of consumptive water use (Siebert and others 2010). With population growth and rising per capita incomes, global freshwater use has expanded six-fold over the past century, and is expected to rise by another 20–30 percent by 2050 (UNESCO 2019). The area currently equipped for irrigation worldwide exceeds 300 million hectares, of which an estimated 38 percent relies on groundwater (Siebert and others 2010).

The Ogallala Aquifer

The risk of groundwater depletion is on the minds of many U.S. farmers as they track the decline in water levels in the Ogallala (High Plains) Aquifer. The annual rate of groundwater extraction from the Ogallala Aquifer is eight to 10 times the rate of natural recharge in some

regions, threatening groundwater depletion over the next 30–50 years (National Climate Assessment 2018). Agriculture accounts for over 90 percent of the water pumped from the Ogallala. The aquifer supplies water for about one-third of all irrigated agriculture in the country, and roughly one-fifth of all wheat, corn, cotton, and cattle produced in the United States come from the High Plains region (Little 2009; Frankel 2018). The potential long-term consequences of depleting the aquifer include a decline in both the quantity and quality of groundwater. Although groundwater tends to be less polluted than surface water, levels of arsenic and other toxins can become concentrated and increasingly dangerous when aquifers recede.

Predicting future water levels in the Ogallala Aquifer is not a simple task. The aquifer spans eight states, each with its own policies and practices for groundwater extraction. Depending on how aggressively farmers throughout the High Plains extract groundwater, the Ogallala could be largely depleted by midcentury, or it could be sustained for well over 100 years (Parker 2016). The lack of coordinated management of surface water and groundwater within and among states limits the region's ability to address potential climate effects on the agricultural sector (National Climate Assessment 2018). For example, the Nebraska state government has been relatively successful in enforcing reductions in groundwater extraction, while the neighboring state of Kansas has little, if any, legislative control over excessive pumping for irrigation, particularly in the western portion of the state (Frankel 2018). Reporting on the situation, Brown (2018) aptly concludes, "Kansas agriculture faces an existential choice: it can cut back water use voluntarily now and face a decline in farm productivity, or it can continue to ignore the problem and face far more dire consequences as the water runs out." Several agricultural communities in Kansas have recently signed on to voluntary groundwater reduction programs and have begun to adopt soil and water conservation practices to sustain agricultural yields well into the future. Farmers' immediate attention, however, appears to be focused more on earning a viable living in the short run so they can survive into the long run.

Groundwater extraction in northwest India

Agricultural communities in the United States will also be affected by groundwater depletion in other regions of the world, particularly those producing crops that compete with the U.S. in international markets. India is a prime example, given its role as the world's second-largest producer of both wheat and rice behind China. In 2018, India produced an estimated 99.7 million metric tons (mmt) of wheat (roughly double the U.S. production of 51 mmt), and 116 mmt of milled rice (about 16 times that of the United States) (FAO 2018b). India was also the world's largest rice exporter in 2018, accounting for 30 percent of global exports. Wheat is a major irrigated crop in India, as is rice in some Indian states. The country's production of both crops has expanded significantly since high-yielding cultivars were introduced in the late 1960s as part of the Green Revolution. Irrigation, fertilizers, and favorable economic incentives have been crucial to making the Green Revolution for wheat and rice so successful.

India's agricultural sector draws water from both surface and groundwater sources, but groundwater has become increasingly important over the past half century. (Groundwater and surface water are linked through conjunctive use; surface water, including leakage from canals, helps to recharge groundwater tables to varying degrees across India's hydrological landscape.) Research by Srivastava and others (2018) shows that the share of irrigation from groundwater has doubled from 30 percent in 1964-65 to 63 percent in 2014-15 for India overall, with variation among states in their extent of irrigated cropped area and groundwater dependency. In the drier, northwestern states of Punjab, Haryana, and Rajasthan, where wheat and rice are widely cultivated, the majority of irrigation comes from groundwater. Groundwater extraction exceeds replenishment in these three states and water tables are declining significantly.

India has become the largest user of groundwater in the world, exceeding the extraction rates of the United States and China combined (Siebert 2010). Agriculture accounts for 90 percent of the country's total groundwater use. More than 20 million wells of various depths provide water for irrigation, and as water tables have declined in some areas of the country, the share of deep tube wells has increased. The estimated number of deep tube wells used for agriculture has risen from

around 100,000 to 2.6 million over the past 30 years (Kishore 2018). The spread of deep tube wells is supported by substantial subsidies on rural electricity, especially in the northwestern states (Srivastava and others 2018).

The rate at which India's groundwater will be depleted in the future depends on climatic conditions controlling growing season temperatures, the South Asian monsoon, and the melting of Himalayan glaciers. Increased growing season temperatures and glacial melt can be predicted with a relatively high degree of certainty, whereas long-run patterns of monsoon onset, intensity, and area extent are much less certain (IPCC 2014). The monsoon supplies around 70 percent of the country's annual rainfall and is thus hugely important for Indian farmers. Parts of India are currently facing one of the worst droughts in history as a result of a delayed and weak monsoon season; the lack of water and extreme heat, approaching 50 degrees Celsius in some western states, has caused widespread deaths and farm abandonment. Meanwhile, India's sixth-largest city, Chennai, whose population now exceeds that of Los Angeles, has essentially run out of water. One need not look far to the future to measure the effects of monsoon variability on the Indian population.

Irrigation provides an important adaptation option for many farmers suffering the effects of low rainfall and extreme heat, at least in the near term, depending on their proximity to surface and groundwater resources. Glacial melt is higher in warmer years, helping to offset drought stress. However, increased glacial runoff from the Himalayas due to warming is expected to peak by 2050, reducing the protection that glacial melt will provide for farmers in India over the long term (Pritchard 2019). Overall, there is a substantial risk of unsustainable groundwater use throughout India by midcentury as a result of both irrigation expansion and climate change, even in areas that experience precipitation increases in the future (Zaveri and others 2016).

In India, the U.S. High Plains, and other irrigated regions where groundwater depletion poses a significant threat to society, the adoption of advanced technologies that improve irrigation efficiency provides a possible remedy. Given that water is essentially free for farmers throughout most of the world, however, they typically have little incentive to improve irrigation efficiency on their own. The solution has been for

governments to provide additional subsidies, which has often proven to be counterproductive; producers may save water at the farm scale but increase water use at the basin scale through area expansion (Grafton and others 2018). Over time, the beneficiaries of these subsidies often lobby for continued support, making the problem even worse. This process has occurred, for example, in India's western state of Rajasthan, where subsidies for drip irrigation have led to the expansion of irrigated area and increased water use in agriculture (Birkenholtz 2017). Without a carefully monitored and enforced cap on groundwater extraction at the basin scale, even the best intentions for water use efficiency may result in groundwater depletion.

For all irrigated agriculture, the role of government policy is paramount. Providing farmers with essentially "free" water and subsidized energy to pump water creates perverse production incentives and conditions for rent-seeking and corruption. In India, the world's largest democracy, rural votes can be won through farm subsidies. The difficulties that the United States has faced in pricing water at its true opportunity cost provide a useful warning of how challenging the task will be for India to align objectives for water resource conservation with incentives. India has the world's largest number of people living under the poverty line, and its need to improve rural incomes and food security in the short run often comes at the expense of sound groundwater management over the long run. How government policy will shape farmers' use of water resources over the next 30 years is daunting and highly uncertain with respect to poverty levels, hunger, rural health, and migration.

Conclusion

This paper has highlighted three important areas of long-term uncertainty for U.S. farmers: the changing nature of agricultural demand, climate effects on crop production and market volatility, and the depletion of groundwater resources for irrigation locally and globally. In all three areas, government policy within large agricultural economies will play a critical role in shaping the economic and biophysical conditions under which farmers will operate. International market conditions for food and agriculture reflect the residual effects of national policies around the world, and it is virtually impossible to predict government policy for multiple countries over the long term.

Despite the difficulty of making future projections on the direction of government policies worldwide, some points of predictability are bound to challenge the next generation of farmers. For example, sufficient scientific evidence shows that global mean temperatures will increase by 2 degrees Celsius or more by midcentury unless draconian geo-engineering efforts are mobilized, which would only accentuate climate uncertainties for all nations in the long run (IPCC 2014; Barrett and others 2014).[23] In a warmer world, how will the location and composition of cropping systems change within individual countries over the next 30 years? Will groundwater resources become more or less stressed? Given current cropping systems, a 2 to 4 degree Celsius warming will have significant effects on crop yield levels and variability. In addition, major grain-producing countries are likely to face synchronous shocks in agricultural productivity that could lead to increased future volatility in world markets.

Experience during the past 15 years has also indicated that governments tend to protect domestic consumers and producers in the face of rising volatility, leading to even greater instability in global markets (Swinnen 2018). Food price volatility hurts poor consumers and urban consumers, but it also raises the level of uncertainty that farmers experience over the long term, which may affect agricultural investments worldwide. Even in countries such as the United States, where crop insurance programs are robust, farmers face uncertainty in insurance coverage and premiums over the long run.

At stake is the future of the rural economy, as well as the future of global food security. What is different about the challenges that farmers will face over the next 30 years, as opposed to their immediate concerns today, is the magnitude of variability and uncertainty that exists along multiple fronts. The risks of increased volatility in agricultural markets, changing demand patterns, and protectionist trade policies make rural communities within and outside of the United States particularly vulnerable to economic hardship. Perhaps the biggest unknown is whether, in the face of such expansive vulnerability, promising young farmers will choose to stay in agriculture over the next generation. If the best and brightest farmers move out of agriculture, global food security will surely be jeopardized.

Endnotes

[1]Demographic data for this section of the paper are from the Population Reference Bureau (2018) and the United Nations World Population Prospects (2019).

[2]Economic principles indicate that the income elasticity of demand for food in the aggregate declines with income growth (Engel's Law), meaning the share of income spent on food in the aggregate declines as incomes rise. At a disaggregated level, Bennett's Law states that the share of calories derived from starchy staples declines as incomes rise, and that individuals diversify their diets into vegetables, fruits, nuts, animal products, and other foods with relatively high income elasticities (Timmer, Falcon, and Pearson 1983).

[3]The TFR is defined as average number of children born to women in the child-bearing cohort, assuming that all women live to the end of their childbearing age. The replacement level of fertility is the average number of children born per woman at which a population exactly replaces itself from one generation to the next (without migration); this rate is approximately 2.1 children per woman depending on mortality rates in any given country. These projections assume current mortality trends and the absence of a pandemic disease outbreak in Africa or other parts of the world.

[4]The demographic transition is defined by a shift from high birth rates and high death rates to low birth rates and low death rates over the course of economic development. The precise pattern differs by country, but death rates typically fall before birth rates, as lower infant mortality ensures a desired family size.

[5]Stagnant economies are defined in this paper as those with average real GDP growth per capita at or below zero for the 2013–18 period.

[6]Africa will have over 360 million young people between the ages of 15 and 24 years by 2050, ready to enter the labor force. For further information on Africa's increasing youth population, see Page (2014) and Sow (2018).

[7]EAT is an independent, nonprofit organization based in Oslo, Norway and founded by the Stordalen Foundation, Wellcome Trust, and the Stockholm Resilience Centre. The EAT-*Lancet* Commission convened 37 leading scientists from 16 countries in various disciplines including human health, agriculture, political sciences, and environmental sustainability to develop global scientific targets for healthy diets and sustainable food production. The report was translated into multiple languages for international access.

[8]For a list of such reports, contact Rosamond Naylor, the author of this paper.

[9]The share of diesel in transportation demand is expected to increase at various rates in all countries, and at a global scale, biodiesel is expected to account for 70 percent of renewable transport fuel demand growth by 2040 (Naylor and Higgins 2017). The biodiesel sector includes fuel from fatty acid methyl esters and from hydrotreated vegetable oil.

[10]One can examine either crude oil or diesel in relation to ethanol and biodiesel, as the correlation between crude and diesel prices was 0.98 between 2000 and 2017 (correlation is between the Europe Brent Spot Price FOB and the Los Angeles, CA Ultra-Low Sulfur CARB Diesel Spot Price).

[11]Scientific consensus indicates that both biofuel- and electric-powered vehicles have environmental advantages over conventional fossil fuel transportation; which of the two has a comparative economic and environmental edge depends on the source of energy for EVs and the feedstocks used in biofuels (Martin 2017a).

[12]The reinsurance industry is even more active in the climate change space; for example, Munich Reinsurance Company, the world's largest reinsurance company, has been addressing insurance-related risks and opportunities associated with climate change for several decades in its risk assessments, asset management strategies, and global partnerships and initiatives (Munich RE, n.d.; *Reinsurance News* 2019).

[13]The federal crop insurance program is permanently authorized and receives mandatory funding; as a result, it will continue to operate even if Congress fails to pass future Farm Bills (CRS 2018).

[14]Data on average and extreme precipitation over the past 50 years are compared with data over 100 years from 1901–2016.

[15]According to data from NOAA's National Centers for Environmental Information (2019), the United States has experienced 246 weather and climate disasters since 1980 where overall damages or costs reached or exceeded $1 billion (including CPI adjustment to 2019). The total cost of these 246 events exceeds $1.6 trillion.

[16]A report by the Global Carbon Project estimated an increase in carbon dioxide emissions of 2.7 percent in 2018, sharply up from the 1.6 percent rise in 2017, and from the plateau in 2014–16. With the exception of the European Union, almost all countries contributed to the rise in carbon emissions, with emissions in China rising by 4.7 percent, in the United States by 2.5 percent, and in India by 6.3 percent in 2018 (Global Carbon Project 2018). Carbon dioxide concentrations in the atmosphere reached a record level of 415 parts per million in May 2019 (Harvey 2019).

[17]Zhao and others (2017) measured the effect of temperature on yields of these four major crops using four different analytical methods: global grid-based models, local point-based models, statistical regressions, and field warming experiments. The study did not look at carbon dioxide fertilization; effective adaptation, such as irrigation or planting dates; or genetic improvements. The authors note that elevated atmospheric carbon dioxide can stimulate crop growth when nutrients are not limited, but it can also increase canopy temperature from more closed stomata. See Long and others (2006) for further evidence on the limited effects of carbon dioxide fertilization on yield growth.

[18]Tack and others (2015) use regressions to measure yields from trials of 268 wheat varieties in Kansas against daily minimum/maximum temperatures and total precipitation pertaining to the specific sites.

[19]The database consists of 612 species of pests and pathogens distributed worldwide. Most of the pests are insects, nematodes, bacteria, or viruses (Nature's Half Acre, n.d.).

[20]The model used by Tigchelaar and others (2018) assumes constant technology (for example, no improvement in heat tolerance due to breeding) and constant management, and thus abstracts from reality. The top four countries for maize production and exports were selected on the basis of average production and trade values over the period 2012–17.

[21]This paper does not focus explicitly on trade policy as a major theme of uncertainty, as international trade was the topic of the Federal Reserve Bank of Kansas City's Agricultural Symposium in 2018, "Agriculture in a Global Economy."

[22]This section of the paper is relatively brief, as it follows from the 2016 Agricultural Symposium hosted by the Federal Reserve Bank of Kansas City on "Agriculture's Water Economy."

[23]Carbon dioxide persists in the atmosphere for over a century; given the current carbon dioxide concentration of 415 parts per million, the atmosphere will continue to warm through midcentury regardless of any change in global carbon dioxide emissions. For more information, see IPCC (2014) and National Climate Assessment (2018).

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Transitioning to the Long Term

By Michael Gunderson

Across the world, agricultural producers and businesses will need to adapt their operations to myriad factors as they seek to position themselves for long-term profitability. Persistent changes in consumer food preferences will continue to play a role in shaping the nature of demand for agricultural products. Production conditions will also continue to evolve alongside effects associated with climate change, and technology will likely play an increasingly prominent role in the structure and operation of agricultural businesses. This paper will explore how the agricultural sector might bridge the gap between its current state, where commodity prices and revenue generally have been low, to a longer-term future with greater economic potential. Using Treacy and Wiersema's (1995) work on the three areas of market leadership—cost leadership, product leadership, and customer intimacy—this paper will attempt to answer how the agricultural sector might transition from its current state to a longer-term state with greater economic potential.

The agricultural and food value chain

The most recent version of the U.S. Department of Agriculture (USDA)'s "share of the food dollar" graphic indicates that farm production receives just 7.8 cents of the nominal food dollar (Figure 1). Indeed, according to the USDA Economic Research Service, the share of the real dollar received by farm production has been declining (Chart 1).

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Figure 1

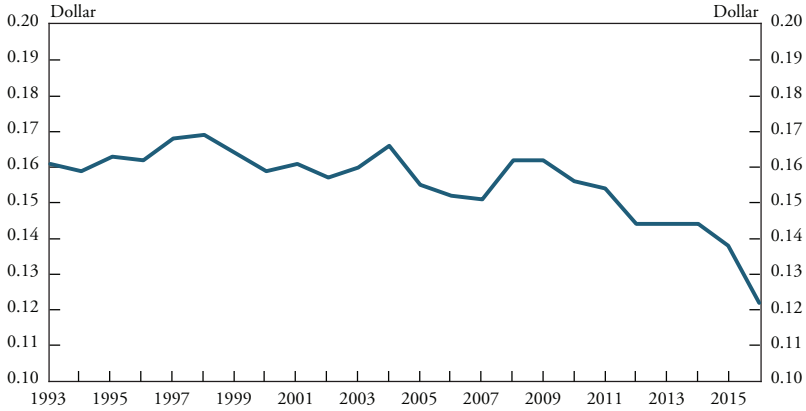
Share of the U.S. Food Dollar

2017 food dollar: industry group (nominal)

Source: USDA Economic Research Service (ERS).

Chart 1

Farm Production Share of the U.S. Food Dollar



Source: USDA ERS.

One common error associated with this food share calculation is that the total revenue generated by farm production must likewise be falling. When end consumers are willing to pay more for value-added activities, the total revenue generated by the value chain will grow faster than population. In fact, the total value (revenue) generated in the agricultural and food value chain is increasing with population, purchasing power, and additional value-added activities. In this environment, any player in the value chain can create additional value and capture premiums as a result.

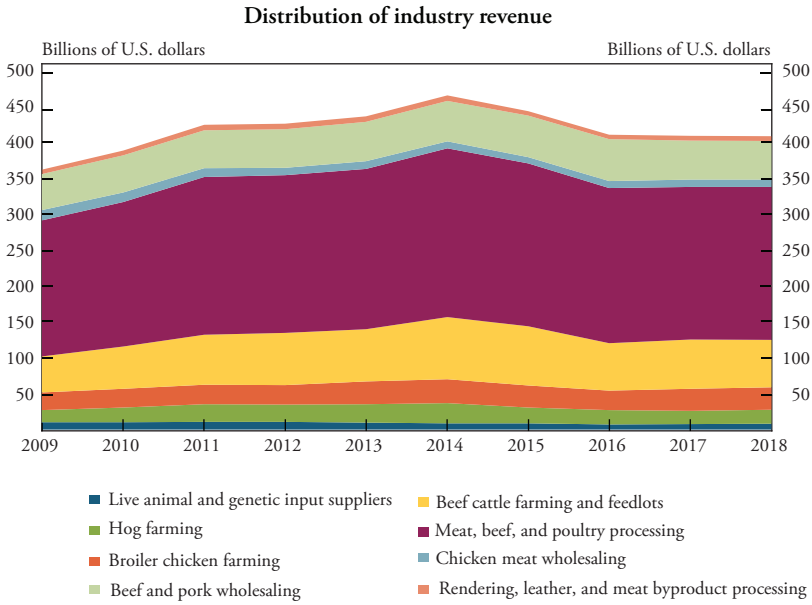
The protein value chains of beef, pork, and chicken illustrated in Chart 2 show where the total value created and captured in the value chain is shared. Several value chain actors coordinate to bring food to consumers' tables. While one might automatically assume that the farmer receives the smallest share in the value chain, the genetic input suppliers receive the smallest share.

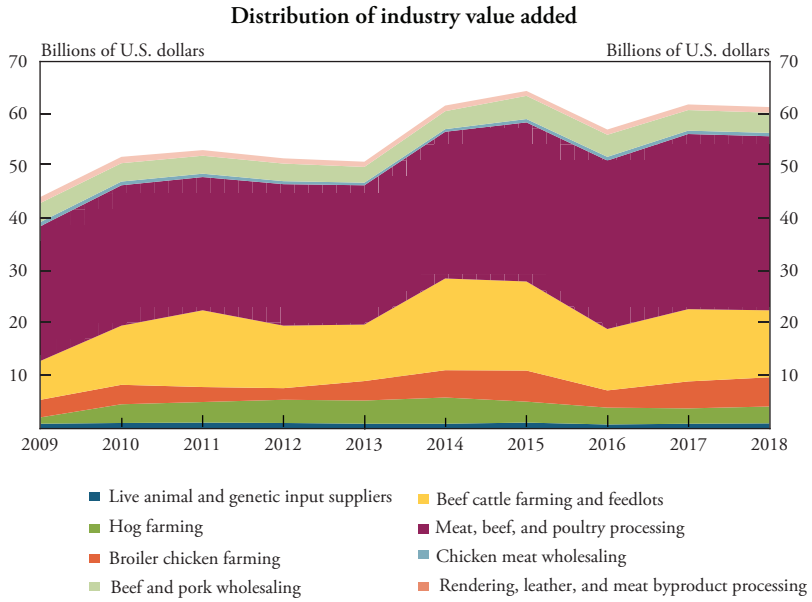
When food processors create new products or innovate packaging to be more convenient, premiums are typically associated with the innovations. Food producers who grow crops meeting USDA organic standards nearly always earn premiums of 20 percent or more (Carlson 2016). In the agricultural and food value chain, one particularly innovative disruption near the consumer has been the delivery of food items. As dining at restaurants has grown, simultaneous growth has occurred in the grocery market (Chart 3). This is likely due to growth in the grocery delivery market, both through online ordering and delivery from local stores as well as the rise of meal kit delivery companies such as Blue Apron and Hello Fresh (Packaged Facts 2016).

A transition from a present state of low commodity prices and revenue to a longer-term future with greater economic potential necessitates a continued focus on reducing per unit costs, greater value creation and capture, or a combination of both. In their work on market leaders, Treacy and Wiersema (1995) suggest there are three areas of market leadership: cost leadership (operational excellence), product leadership, and customer intimacy (Figure 2). Agricultural producers choosing to lead cost per unit (operational excellence) will have to invest in technology that improves productivity and leverages economies of scale. Alternatively, agricultural producers could choose to lead on product quality or customer intimacy to create and capture additional value (revenue).

Chart 2

Animal Protein Value Chain Distribution of Industry Revenue and Industry Value Added

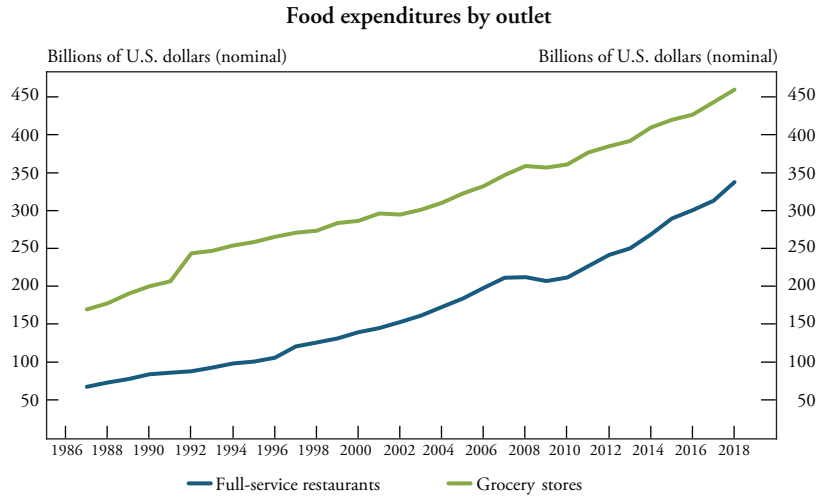




Note: Reproduced from Davis (2019).
Source: IBISWorld and author's calculations.

Chart 3

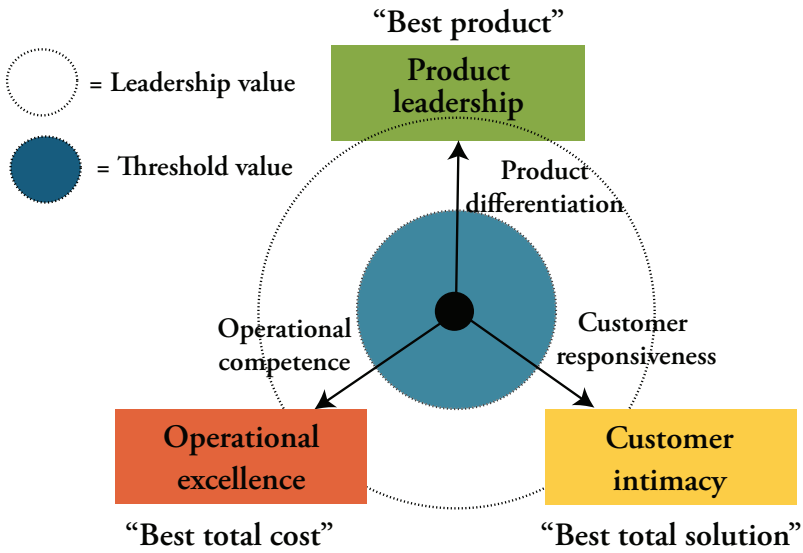
Food Expenditures by Outlet, 1986–2018



Source: USDA ERS.

Figure 2

Value Disciplines



Source: Treacy and Wiersema (1995).

A word of caution on strategy

One strategy suggested for farmers in the short run is to diversify their enterprises by seeking new streams of revenue. This often comes with proposals to find new uses for underutilized resources such as custom harvesting with equipment already owned. Others suggest diversifying across enterprises and raising livestock that can add value to grain crops already being grown. Still others recommend that farmers diversify into adding value by transforming some goods into products for the end consumer.

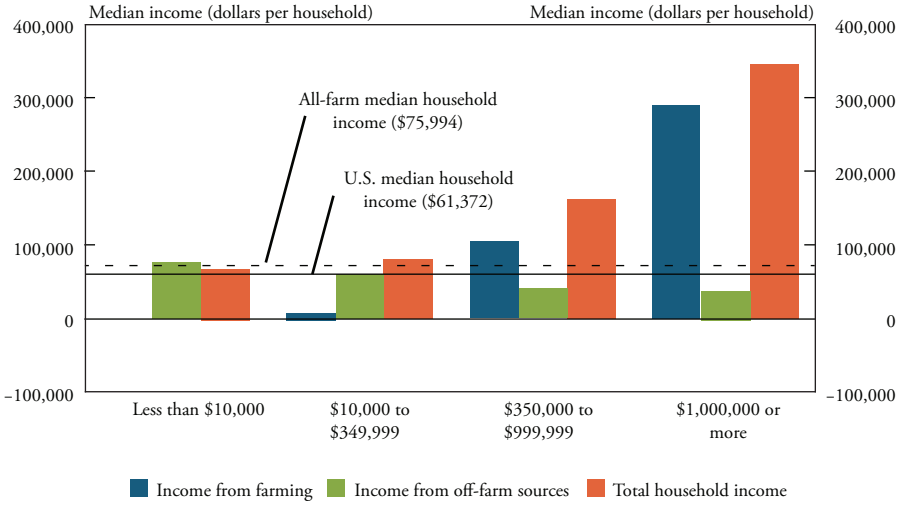
The study of strategy is young relative to other more established fields of study such as economics, biology, sociology, and agronomy (Rasche 2008). Despite its relatively small collection of empirically tested theories, one main conclusion rises above all: strategy requires focus (Rumelt 2011; Lafley and Martin 2013; Christensen 1997; Kiechel 2010). Even in large, sprawling organizations, strategy requires many employees to simultaneously execute a narrowly defined vision and mission. Strategy is as much about what the firm chooses not to do as it is about what the firm will do. Agricultural producers that will be profitable in the long run likely need to transition efforts from excellence in production (for example, agronomy or animal husbandry) to thinking like a chief executive officer or chief marketing officer focused on excellence in delivering value.

Thus, agricultural producers of the future who wish to manage the farm as a business rather than a way of life must face this reality of corporate strategy. Dallying in side jobs to supplement income means the farm may never evolve into a sustainably profitable enterprise. Indeed, the USDA suggests that "most farmers receive off-farm income, but small-scale operators depend on it" (USDA ERS 2019) (Chart 4).

Successful producers are those that focus almost entirely on a narrow set of activities and perform them at the highest level of leadership among cost, product, or relationship. While moonlighting as a custom harvester might be intuitively appealing, and the activity might in fact provide needed short-run cash flow, the hidden costs of such unfocused activity are rarely noted. Producers who focus narrowly and intensely will move to the frontier of leadership across their selected means of competing in the sector more quickly than those distracted by side jobs.

Chart 4

Median Household Income of Farm Operators by Source and Sales Class, 2017



Notes: Sales equal annual gross cash farm income before expenses (the sum of the farm's crop and livestock sales, government payments, and other cash farm-related income). Data as of November 30, 2018.
Sources: USDA ERS, USDA NASS, and U.S. Census Bureau.

This is not to suggest that a farming operation cannot be successful in diversifying across enterprises or running multiple business units. In fact, many of the most successful farms already do. This type of structure, however, is different than the idealized Old MacDonald's farm with a few hogs, a couple of cows, some chickens, and crops grown on a couple hundred acres. A successful diversified operation today is unlikely to do all of those activities, but it is easy to point to large farms with multiple operating units diversified across many commodities. These farms are typically organized with a leadership team, each focused narrowly on an individual enterprise rather than one individual providing leadership to multiple enterprises.

Just as leadership in operational excellence demands narrow focus, so, too, does leadership in product and customer intimacy. It would be foolhardy for a farm that produces undifferentiated commodities at the lowest cost possible to dilute the focus by beginning a small scale agritourism enterprise. Similarly, one choosing to focus narrowly on product leadership should not transition from a focus on low-cost commodity production to a focus on creating value added. Creating

additional value typically requires additional resources. A farm making such a transition should be prepared to commit entirely to the new strategy and transition as quickly as possible.

Operational excellence using the experience curve

If an agricultural producer is intent on leading in a way so many agricultural producers have led in the past, emphasizing operational excellence and low-cost leadership, the path forward is fairly predictable. Gottfredson and Schaubert (2008) describe the experience curve, noting that for all industries, costs per unit always decline. As firms produce more units of product, the accumulated experience results in lower costs per unit. Calculating the experience curve for any agricultural commodity will establish where a farm must have its per-unit cost structure in about 10 years.

The experience curve concept has been applied across a broad array of industries, including those with steep learning curve slopes (such as microprocessors), moderate learning curve slopes (such as airlines), and flat learning curve slopes (such as milk bottles). More mature industries tend to have flatter slopes for the experience curve. For example, the butter experience curve required about 35 years to cut butter prices in half from just above $4 per pound in 1970 to nearly $2 per pound in 2005. Gottfredson and Schaubert (2008) note that to some extent government regulation of and volatility of inventories in the butter markets increased the year-to-year volatility in price declines, but the downward march was steady in the long run.

In agricultural production, experience curves exhibit relatively flat slopes given the large amount of experience already accumulated. The innovations of the twentieth century, such as mechanical planting and harvesting, improved seed genetics and technologies, synthetic fertilizers, and high efficacy crop protection chemicals rapidly increased yields and decreased cost per unit of production. In animal agriculture, improved genetics, nutrition, and animal comfort delivered similar cost savings. This steady march downward in real, per-unit costs is likely to persist. Thus, by calculating the curve, one can reasonably forecast the cost per unit of any agricultural commodity into the future.

Corn production experience curve

Following the method outlined in Gottfredson and Schaubert (2008), I estimate the corn production experience curve using publicly available data on annual U.S. corn production costs, U.S. corn production, and the GDP deflator. Corn price and production data are available from the USDA National Agricultural Statistics Service (NASS), and the deflator is available from the Federal Reserve Bank of St. Louis's FRED database.

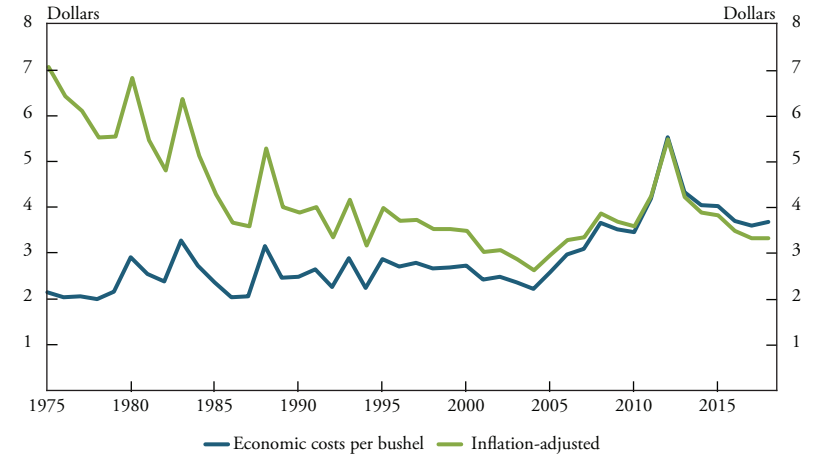
U.S. corn production nominal economic costs appear to have increased over the 1975–2018 period (Chart 5). A noticeable spike in nominal economic costs started around 2006, undoing a 30-year trend of relatively flat nominal values. When adjusted for inflation, the downward trend from 1975 to 2005 is more pronounced, and the spike from 2006 to 2018 is slightly muted. The spike is nearly erased once the U.S. corn experience curve is mapped using the Gottfredson and Schaubert (2008) method (Chart 6). Starting with just fewer than 6 billion bushels produced in 1975 and cumulatively 423 billion bushels produced during the 1975–2018 period, the slope of the 40-year experience curve is about 87 percent. This means that as the accumulated number of bushels of corn produced doubles, the cost per bushel of corn will decline by 13 percent. This is consistent with the slope of many other experience curves, though notably on the flatter end of the distribution of experience curve slopes. What is notable here also is that the experience curve runs such a long horizon.

Dairy production experience curve

To estimate the dairy production experience curve, I use milk statistics from USDA NASS and deflator information from the Federal Reserve Bank of St. Louis since 1980. The variability in the experience curve began to increase more recently, likely due to changes in regulation of the global milk market and the variability in input costs, primarily feed (Chart 7). Despite the variability, the slope of the dairy industry is similar to corn and is flat relative to other industries. If one assumes that milk production has peaked at 2 billion hundredweights (cwts) (an amount produced steadily for the past three years), then in 30 years, milk prices will decline to $13.19 in 2012 dollars.

Chart 5

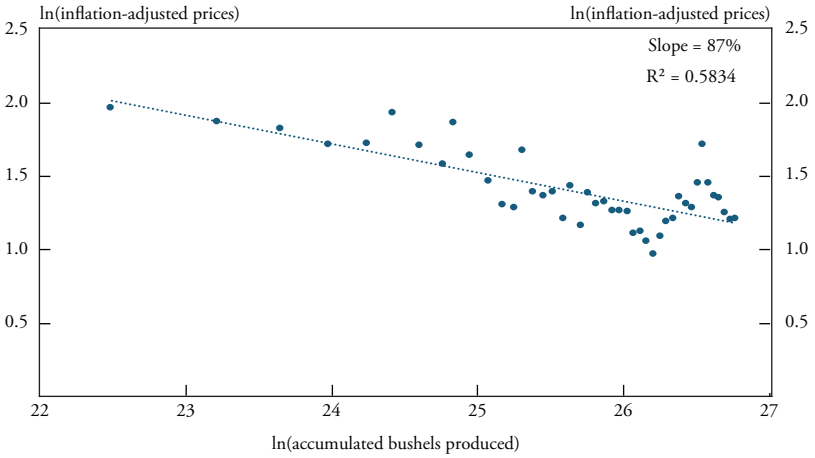
U.S. Corn Production Nominal Economic Costs



Source: USDA.

Chart 6

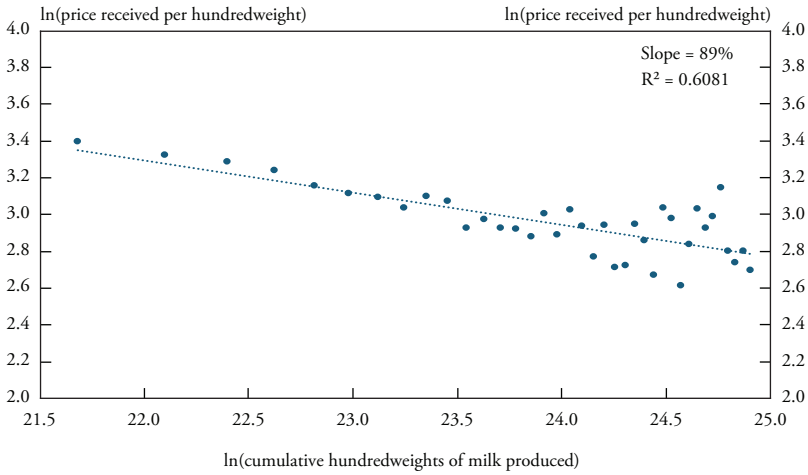
U.S. Corn Experience Curve



Sources: USDA NASS, U.S. Bureau of Economic Analysis, Federal Reserve Bank of St. Louis FRED, and author's calculations.

Chart 7

U.S. Dairy Experience Curve



Sources: USDA NASS, U.S. Bureau of Economic Analysis, Federal Reserve Bank of St. Louis FRED, and author's calculations.

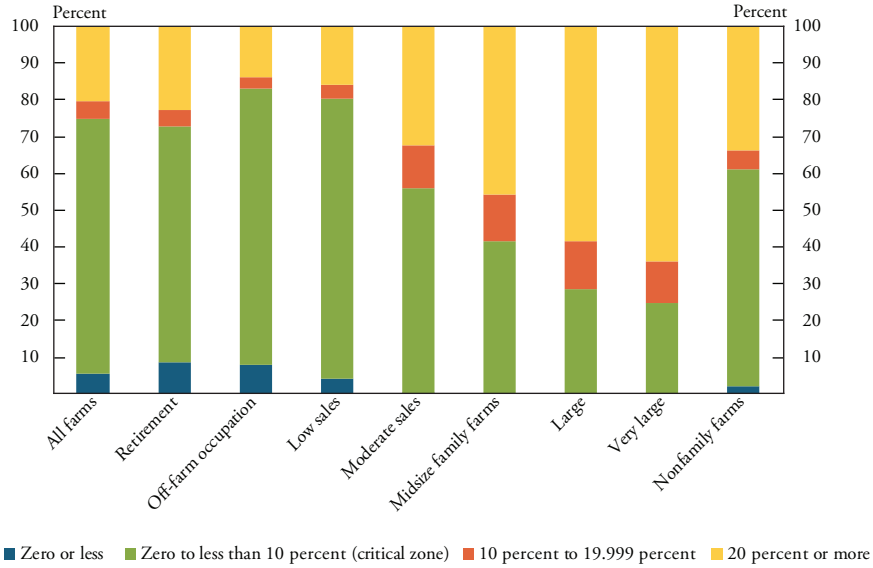
Pursuing low-cost leadership (operational excellence)

Farms that strategically choose low-cost leadership will most likely win with scale. Data from the USDA's Economic Research Service suggests that the largest producers are most likely to have the largest operating profit margins (Chart 8). These firms have the scale to make returns attractive on a per-unit basis when substantial investments are required for new technologies. These same firms will likely also have more access to financial capital at lower rates to be able to commit to investing in technology.

Indeed, the USDA analysis of total factor productivity indicates that total output has grown using more non-land capital and less labor (Chart 9). The analysis also shows that the contribution of the quantity of labor to total factor productivity has declined, while the contribution of the quality of labor has increased. This suggests that agricultural producers will continue a pace of having more formal education to improve decision-making.

Chart 8

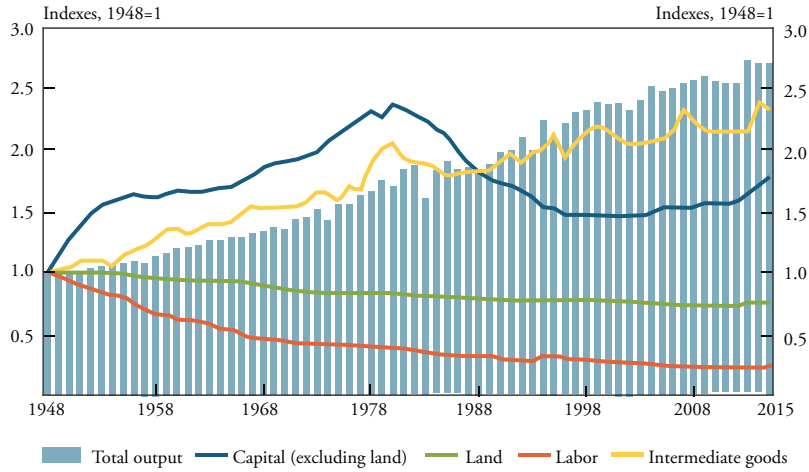
Operating Profit Margin by Farm Typology



Source: Hoppe (2015).

Chart 9

Input Composition of Capital (Excluding Land), Land, Labor, and Intermediate Goods



Notes: Data are expressed with an index calculated relative to the data in 1948, where data in 1948 are set to equal 1. Intermediate goods include feed and seed, energy use, fertilizer and lime, pesticides, purchased services, and other materials used. Reproduced from Wang, Nehring, and Mosheim (2018).
Source: USDA ERS.

Pursuing product leadership as a differentiation strategy

Product leadership could come in several forms for agricultural producers. In crop production, differentiation can happen by appealing directly to the end consumer or producing a crop that aligns more closely with a processor pursuing its own differentiation strategy. Select agricultural producers have provided leadership in products by growing crops for seed companies, producing crops of a specialized quality or type for a particular food grade use, or growing agricultural commodities using methods demanded by consumers, such as organic production or animal welfare certification.

Agricultural producers could provide leadership to product quality by most closely meeting the needs of food processors, retailers, or even end consumers. For example, producers in Indiana have chosen to produce food-grade corn for Frito-Lay. Some even choose to grow blue corn for use in tortilla chips. Some producers are tailoring the growth of soybeans for export to Japan and other countries for use in tofu. Producers in Indiana have chosen to grow tomatoes on contract for Red Gold tomatoes for use in canning and ketchup production. Some producers are leading the way on products that have no established commodity market, such as ancient grains and hemp. In animal agriculture, producers specialize in delivering milk components rather than the largest volume of fluid milk. Dairy producers deliver milk with high butter fat or protein content for use in specialty dairy products. Livestock growers opt into producing Waygu beef because of its quality, not because it is inexpensive to produce.

Pursuing customer intimacy as a differentiation strategy

Customer intimacy is foreign to a commodity business built on spot transactions and standardized products. The standard growing season of many row crops provides little opportunity to differentiate oneself by partnering closely with customers on tasks like inbound and outbound logistics. In the livestock sectors, producers and processors have a relationship that is more frequent and ongoing, which lends itself to an opportunity for greater customer intimacy.

One means of pursuing customer intimacy is to commit to agritourism. Heavily supported by government actions, Italy's *agriturismos* are examples of profitable small-scale farms. This strategy, however,

requires a focus on the needs of the tourist. The farming aspect of this particular tourism is just one component of managing reservations, meals, maintaining lodging facilities, and marketing to customers. In Italy, nearly all of the agricultural production that occurs on the farm must be incorporated into the tourism business to remain certified. Similar enterprises in the United States exist, but are usually day trips rather than overnight stays. "U-pick" orchards and corn mazes are more typical forms of agritourism in the United States.

Besides tourism, there are other opportunities to consider customer intimacy in the food and agricultural value chain. Working closely with end customers has boosted the adoption of the Community Supported Agriculture (CSA) model in addition to more traditional farmers markets. Whereas the farmers markets typically bring the farm closer to the end purchaser (consumer), the CSA often becomes a true intimate relationship. Producers who run CSAs will often invite members to the farm to see the production as it occurs. Some have even invited members to help in peak labor demand seasons such as planting, weeding, and harvesting. The success of CSAs has resulted in rapid growth to over 1,300 as of a few years ago (Eise and Foster 2018).

Some livestock producers in Indiana have chosen to partner with restaurants to provide locally grown meat with attributes that diners prefer. One such farm operation, Fischer Farms in Indiana, markets its beef as "naturally raised." Owners Dave, Diana, and Joseph have established close relationships with restaurants. This results in Fischer Farms branding on restaurant menus and close collaboration with restauranteurs and chefs to provide cuts of meat consistent with fine dining and innovative cooking.

The business model of Loftus Ranches in the Yakima Valley of Washington is an example in specialty crops. Before 2010, this organization largely produced commodity hops for export and national brewers. The boom of the craft brew market meant that the leadership of Loftus ranches chose to specialize production for thousands of smaller craft brewers each looking for its own unique flavor profile. Loftus Ranches has new opportunities to create and capture value for its customers, which comes with additional focus on the relationship. The key to the relationship is connecting to the brewers' passion for flavor.

Conclusion

Agricultural producers who take advantage of emerging technology can differentiate by leading on operational excellence, product quality, or customer intimacy. Some agricultural producers may continue to pursue smaller scale production of agricultural commodities, but they are likely to remain dependent on off-farm income and additional businesses to diversify revenue streams. A transition to an agricultural production system more focused on operating farms as a business rather than a way of life began many generations ago. Family farms continue to dominate agricultural production and are likely to do so for the intermediate future, but they are likely to operate in a more professional manner focused on how external factors influence the farm business and on marketing and controlling costs.

Large-scale agricultural producers stand to benefit the most from spreading the fixed costs of technology across many standardized units to continue to serve a portion of the market looking for safe, low-cost calories. Other agricultural producers should consider leveraging emerging technologies that enable low-cost tracking of differentiated goods. Producers that choose to focus on creating products that more closely meet the specifications of increasingly demanding food processors and end customers could capture premiums for agricultural products. Similarly, agricultural producers who choose to closely align with downstream clients to coordinate outbound and inbound logistics to create strong relationships could share the value created by such coordination.

The diversity of the soils and weather patterns that demand decision-making be done close to the crop's geographic location will slow the pace of farm consolidation. Any technology that enables low-cost, real-time monitoring of geographically dispersed crops will likely accelerate consolidation of farms among the most sophisticated operators who are able to drive down the per unit costs of production. Driverless equipment, including self-powered planters and sprayers, and affordable small-scale sensors are such disruptive technologies.

Consumer demands for local production of agricultural commodities and a desire to have a relationship with the people growing their food offers an opportunity for some producers to maintain profitability at a smaller scale. The consumers' preferences for local and small scale could supersede the need for low-cost, efficient production, allowing

producers with this focus to capture premiums to offset additional per-unit fixed costs.

Similarly, sensing technology will enable a transition from a commodity value chain driven by large volumes and standardization to one driven by differentiation and niche batches of production. Agricultural producers who are nimble enough to react quickly to shifting consumer demands will be well suited to capture premiums associated with the differentiated product. Partnering with additional players in the food value chain such as processors and retailers could have similar effects on farm profitability.

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