Food prices in the United States during COVID-19: generalized facts on price inflation and volatility

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Abstract

Purpose – The COVID-19 pandemic was a shock to the food supply chain without modern precedent. Challenges in production, manufacturing, distribution and retailing led to the highest rates of food price inflation in the US since the 1970s. The major goal of this paper is to describe statistically the impact of the pandemic of food price inflation and volatility in the US and to discuss implications for industry and for policymakers.

Design/methodology/approach – We use Bureau of Labor Statistics data to investigate food prices in the US, 2020–2021. We apply 16 statistical approaches to measure price changes and volatility and three regression approaches to measure counterfactuals of food prices, had the pandemic not occurred.

Findings – Food price inflation and volatility increased substantially during the early months of the pandemic, with a great deal of heterogeneity across food products and geographic regions. Food price inflation was most pronounced for meats, and contrary to expectations, highest in the western US Forecasting approaches demonstrate that grocery prices were about 7% higher than they would have been without the pandemic as of the end of 2021.

Originality/value – The research on COVID-19 and the food system remains in its nascent stage. As findings on food loss and waste, employment and wages, food insecurity and more proliferate, it is vital to understand how food prices were connected to these phenomena and affected. We also motivate several ideas for future work.

Keywords Supply chain, Food industry, Prices, COVID-19, Retail trade

Paper type Research paper

Introduction

The COVID-19 pandemic was a shock to the US food supply system without modern precedent. The last pandemic of comparable scope to affect the USA was the 1918 Influenza Pandemic, which took place a century earlier. The food supply chain 100 years ago effectively bore no resemblance to our modern food system, which is tasked with feeding hundreds of millions more people across the country and world. Subsequently, during the first half of 2022, the US has experienced the highest levels of price inflation in over 40 years, as measured by the Consumer Price Index (CPI). COVID-19 is unquestionably among the factors that have contributed to rising prices across spending categories since 2020.

Much has been written about the impacts of COVID-19 on food prices in the popular press (ABC, 2021; NBCNews, 2021; Reuters, 2021), the blogosphere (Johasson, 2021a, b; Vos *et al.*,

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2022), trade publications (FMI, 2020; NGA and IGA, 2022) and other outlets. The consensus on the topic is that the pandemic resulted in higher food prices due to higher costs throughout the supply chain, increased regulation, labor shortages and turnover, food loss and surging consumer demand. We do not establish causal impacts of the COVID-19 pandemic on either upstream costs, e.g. transportation and labor, or directly on food prices. Rather, our study is the first to take a comprehensive and exploratory look at the dynamics of food prices in the US throughout the supply chain during the COVID-19 pandemic and to draw systematic conclusions about the nature of food price volatility and inflation in 2020 and 2021.

To assess the price impacts of the COVID-19 pandemic on food prices throughout the supply chain, we analyze data from the Bureau of Labor Statistics (BLS). The Consumer Price Index (CPI) measures retail prices and is the most widely used tool for measuring price inflation for consumer goods in the US (BLS, 2022). The US Census Bureau uses the CPI to measure changes in the cost of living (Shrider *et al.*, 2020). The Producer Price Index (PPI) measures prices paid by companies and businesses throughout the supply chain, and therefore is effective for measuring changes in upstream costs that affect retail food prices.

We find that COVID-19 was associated with significant food price inflation and volatility. The effects were generally strongest for animal-based foods, including meats, eggs and dairy. Other food categories showing significant impacts included soybean-based foods such as fats, oils and butter, and fruits and vegetables. Grocery prices generally increased more than restaurant prices, and the impacts on alcoholic beverages were relatively small. The impacts of COVID-19 were heterogeneous throughout the US and we estimate the strongest impacts in the west. This seems counterintuitive, but we also find that upstream transportation costs did not increase as much as other supply chain-related goods and services.

The COVID-19 pandemic generated significant interest in evaluating the resiliency and adaptability of the food supply chain, in the US and globally. We discuss the importance of our findings for understanding food choices and dietary quality in the US since the onset of the pandemic. Our findings also have policy implications, as food price volatility and inflation have impacts on food access, food insecurity and food assistance programs in the US To the extent that retail food prices continued to diverge from historical trends through the end of 2021, as was the case for multiple categories, it is worth considering the specific drivers of inflation and steps that can be taken by both public and private interests to address soaring food prices. The rest of the paper is as follows: we discuss the extant literature and findings on the impacts of COVID-19 on the food supply chain, we discuss our data and methodology, we present our findings and discuss their implications and conclude with suggestions for future research.

Background: the impacts of COVID-19 on the food supply chain

The economic and social impacts of COVID-19 have been vast and remain largely unquantified. Based on our review, most of the academic literature on the food-related impacts of COVID-19 are global in scope or are focused on developing countries. For example, Bairagi *et al.* (2022) showed the prices for staple foods increased substantially in India in 2020 and Agyei *et al.* (2021) found that the price of maize increase during the pandemic in sub-Saharan Africa. Dietrich *et al.* (2022) used the World Programme Review data to study food prices in 44 developing countries and found evidence that the intensity of COVID-19 containment efforts was positively related to inflation. Jaworski (2021) measured highly granular food price inflation in Poland using screen scraped data, a technique that shows promise for future studies on price dynamics. Bai *et al.* (2022) used the CPI for 181 countries and showed that food price inflation was positively associated with total COVID-19 case counts. Carrière-Swallow *et al.* (2023) showed that COVID-19 led to global shipping disruptions and soaring shipping cost, which significantly increased the PPI in many countries, especially those rely more on the imports.

Research on food price inflation due to COVID-19 in the USA is scarce, perhaps in part because the pandemic is ongoing at the time of writing. Our focus in this paper is on food price dynamics through the end of 2021. Hillen (2021) is the only published paper of which we are aware that measures US food price changes during COVID-19. The author studied Amazon's online grocery prices through June 2020 and found few significant increases in the early months of the pandemic. Given the dearth of research on the topic, in what follows we review literature on the supply chain impacts of COVID-19 and consumer behavior, to gain insights that lead to expectations for our own study and factors to help explain variation in food price behavior across categories.

The extensive shutdown of the foodservice sector led to enormous amounts of food waste in US agribusiness. The value or quantity of food waste attributable to the pandemic is not known, particularly by commodity. Ellison and Kalaitzandonakes (2020) discuss multiple factors that contributed to food loss during COVID-19 and highlighted examples of commodities most susceptible to waste due to their perishability and heavy use in foodservice, including milk and chicken. Chenarides *et al.* (2021) discuss this phenomenon in the context of supply chain rigidity, showing that food waste during the pandemic could have been reduced if more growers and producers were flexible in selling to multiple marketing channels.

It is also worth considering other upstream drivers of food price inflation that arose during the pandemic. Several studies, including Hobbs (2020) and Richards and Rickard (2020) identified labor as a major challenge that increased supply chain costs and restricted supply. We may therefore expect to see bigger price impacts for more labor-intensive foods. Hobbs (2020) discussed the impact of labor and argued that consumer stockpiling was driving inflation for some foods. Gray (2020) and Gray and Torshizi (2021) focused on issues related to transportation and showed that, especially early in the pandemic, bottlenecks and capacity shortages affected intermodal food routes via disruptions. Aday and Aday (2020) noted the role of imports in shaping food prices and food supply during the pandemic, suggesting that inflation may be more pronounced for those foods affected by trade disruptions. Goeb *et al.* (2022) interviewed millers to investigate impacts on the rice supply chain and found widespread evidence of disruptions to due to labor and transportation issues.

Finally, a handful of studies have examined the impact of COVID-19 on food insecurity in the US Wolfson and Leung (2020), Niles *et al.* (2020) and O'Hara and Toussaint (2021) all found significant increases in food insecurity in different parts of the country, including both rural and urban areas. Litton and Beavers (2021) found a marked decrease in access to fruits and vegetables during the pandemic, with implications for dietary quality. These studies are relevant to our work because measuring the nature of food price inflation due to COVID-19 is vital for understanding the scope of the impacts of the pandemic on food insecurity and for ensuring that our food system and food assistance programs are best equipped to feed the nation in the event of future shocks and disruptions.

Data and methodology

We measure food price inflation and volatility using the CPI and PPI, two data products of the BLS. Most CPIs and PPIs are updated monthly, and we use the monthly data for each index. Our goal is to measure statistically inflation and volatility during the COVID-19 pandemic for these indexes. We develop a series of 16 metrics for capturing price increases and changes, to develop generalized facts about the impacts of the pandemic on prices throughout the food system. The metrics are as follows:

(1) The average 1-month percent change March – May 2020

(2) The average 1-month percent change June – August 2020

(3) The average 1-month percent change September – November 2020

(4) The average 1-month percent change December 2020 – February 2021

(5) The average 12-month percent change March – May 2020

(6) The average 12-month percent change June – August 2020

(7) The average 12-month percent change September – November 2020

(8) The average 12-month percent change December 2020 – February 2021

(9) The percent change between the average value for March – May 2019 and the average value for March – May 2020

(10) The percent change between the average value for June – August 2019 and the average value for June – August 2020

(11) The percent change between the average value for September – November 2019 and the average value for September – November 2020

(12) The percent change between the average value for December 2019 – February 2020 and the average value for December 2020 – February 2021

(13) The average 12-month percent change March 2020 – February 2021

(14) The monthly coefficient of variation (CV), calculated as the sample standard deviation over the sample mean, March 2020 – February 2021

(15) The percent change between the CV for March 2020 – February 2021 and the CV for March 2019 – February 2020

(16) The average absolute value of the 1-month percent change March 2020 – February 2021

We apply these metrics to four sets of BLS indexes. These are the CPIs measuring national average food prices, the regional and geographic CPIs measuring average food prices for specific areas, the industry PPIs measuring average prices for the major industries and processes in agribusiness, and the commodity PPIs measuring average prices for specific foods and food groups at intermediate points in the supply chain.

For each index, we calculated each metric, then assigned a ranking among all CPIs. We then calculated the average ranking, across the 16 metrics, for each index. There are 125 national food and beverage CPIs for which monthly data were available to calculate all 16 metrics. The average rankings ranges from 17.13 for Uncooked Beef Steaks to 105 for Wine at Home. For ease of interpretation, we attributed monotonic rankings to each CPI, normalizing the rankings from 1 to 125. We also performed these steps separately for the inflation metrics (1–13) and the volatility ranking. This process was then repeated for the geographic CPIs, and industry PPIs, and the commodity PPIs. Among the series for which we had sufficient data, there are 205 regional and geographic CPIs, 130 commodity PPIs and 47 industry PPIs.

To achieve estimates of the impact of the pandemic on food prices, we used monthly CPI data from January 2011 through February 2020 to forecast values to December 2021. These forecasted values can then be compared to the actual values observed. Our dataset begins in 2011 to ensure that we use enough historical data to establish long-term trends in food prices, and the forecasts end in 2021 to avoid capturing food price inflation caused by international phenomena, including record-high oil prices and the conflict in Ukraine.

The forecasts were conducted in three ways to assess the robustness of the estimates. The first method is a traditional autoregressive moving average (ARIMA) process. We used the

Dickey-Fuller unit root test for all the CPI series and the z-statistics were smaller than the critical values, indicating that the CPI series contain a unit root. After we first-differenced the series by one month and re-conducted the Dickey-Fuller test, the null hypothesis of non-stationarity was rejected, suggesting that we should pick lag one for nonseasonal differencing. Examining the autocorrelation and partial autocorrelation plots, we identified one for the moving average term and one for the autoregressive term for the ARIMA estimation, i.e. ARIMA(1,1,1).

$$\Delta \boldsymbol{CPI}_t - \Delta \boldsymbol{CPI}_{t-1} - d = \phi_1(\Delta \boldsymbol{CPI}_t - \Delta \boldsymbol{CPI}_{t-1} - d) + e_t + \Theta_1 e_{t-1} \quad (1)$$

The second approach is regression based and univariate. We modeled each CPI as a function of a linear trend and monthly dummy variables using the data from January 2011 through February 2020 and then forecasted the monthly CPIs from March 2020 through December 2021 using the estimated regression coefficients. This approach is henceforth referred to as the baseline approach, as the regression does not incorporate any additional variables.

$$\boldsymbol{CPI}_t = \lambda + \sum_{i}^{11} \rho_i M_{it} \quad (2)$$

Where $M_{1t}, M_{2t}, ..M_{11t}$ are monthly dummies.

The third approach is based on a traditional vector autoregression (VAR) regression model, given by:

$$\Delta \boldsymbol{CPI}_t = \boldsymbol{\alpha} + \boldsymbol{\beta}_1 \Delta \boldsymbol{CPI}_{t-1} + \boldsymbol{\beta}_2 \Delta \boldsymbol{CPI}_{t-2} + \boldsymbol{\gamma} \Delta \boldsymbol{PPI}_{t-1} + \boldsymbol{\varepsilon}_t \quad (3)$$

where

$$\Delta \boldsymbol{CPI}_t = \begin{pmatrix} \Delta FoodCPI_t \\ \Delta FAHCPI_t \\ \Delta CerealsBakeryCPI_t \\ \Delta MeatsPoultyFish\_CPI \\ \Delta MeatsCPI_t \\ \Delta BeefVealCPI_t \\ \Delta PorkCPI_t \\ \Delta PoultryCPI_t \\ \Delta FishSeafoodCPI_t \\ \Delta EggsCPI_t \\ \Delta DairyCPI_t \\ \Delta FruitsVegCPI_t \\ \Delta FreshFruitsVegCPI_t \\ \Delta NonAlcoholicBeverageCPI_t \\ \Delta FreshFruitsCPI_t \\ \Delta FreshVegetablesCPI_t \\ \Delta FatsOilsCPI_t \\ \Delta OtherFoodsCPI_t \end{pmatrix}$$

and

$$\Delta \boldsymbol{PPI}_{t-1} = \begin{pmatrix} \Delta GasFuelsPPI_{t-1} \\ \Delta FertilizerPPI_{t-1} \\ \Delta ElectricPowerPPI_{t-1} \\ \Delta FoodWholesalingPPI_{t-1} \\ \Delta FoodRetailingPPI_{t-1} \end{pmatrix}.$$

Using the Dickey-Fuller unit root test for all the CPI, we found that the monthly CPI series contain were non-stationary. After we first-differenced the series by one month, the data became stationary, confirmed by the Dickey-Fuller test. Thus, each first differenced CPI is regressed as a function of lagged values of the other CPIs of interest as well as lagged values of key first differenced PPIs, as determined by the USDA Food Dollar Series. We did the first difference on the monthly PPI series based on the Dickey-Fuller test results as well.

In Equation (3), β_1 and β_2 are both 18×18 matrixes, and Υ is a 18×5 matrix [1]. Like the first two regression approaches, the sample period for this approach is January 2011 through February 2020, and the forecasted period is March 2020 through December 2021. Therefore, none of the forecasts are conducted using data from the pandemic period, which would bias our counterfactual estimates.

The efficacy of the VAR depends on identifying the optimal lag lengths of the explanatory variables. We applied a battery of tests to our VAR models to establish the appropriate lag lengths and to check other conditions that may affect the validity of our findings. We used the likelihood ratio tests on the Akaike information criterion (AIC), the Hannan–Quinn information criterion (HQIC) and the Bayesian information criterion (BIC). In all cases, the optimal lag length was determined to be two. Moreover, we tested for the Eigenvalue stability condition, and found that our VAR estimation satisfies this condition. To check for autocorrelation, which is a concern when using lagged independent variables, we applied the Lagrange multiplier test and found no evidence of significant autocorrelation. Finally, we used the Granger Causality Wald test to confirm that our independent variables explain our dependent variables. The full results and details of our diagnostic tests are available from the authors upon request.

The timing and magnitude of price transmission can vary considerably by food category (Assefa *et al.*, 2015). Despite the battery of tests we applied to VAR to establish the optimal lag lengths, our model formulation has the potential to introduce measurement error via the upstream PPIs. We therefore estimate Equation (3) without the PPI matrix as well, to further establish the robustness of our findings. We compare the results from these different approaches to assess robustness and identify categories for which the approaches diverge.

Results

The empirical results of this study are presented in two sections. First, we establish the extent to which food prices exhibited inflation and volatility during the first year of the COVID-19 pandemic, based on the 16 metrics introduced above. Then we present the results of our in-sample forecast exercises, to discuss the extent to which inflation can be attributed to factors at play during the onset of the pandemic in the US.

Inflation and volatility metrics: consumer price indexes

The USDA Economic Research Service (USDA ERS) maintains the Food Price Outlook (FPO), which provides forecasts for major food CPIs of policy interest (USDA ERS, 2022a). To aid in organizing and interpreting the results, we categorized all national CPIs according to the FPO, using the most granular category possible for each CPI. The summarized results are reported in Table 1. Given that several of the FPO categories are nested, in several cases CPIs

Table 1.
Inflation and volatility rankings for national CPIs

	Avg. overall ranking[a]	Avg. inflation ranking	Avg. volatility ranking	Rankings difference	Count
Food at home	59.11 (11)	59.72 (11)	57.97 (11)	27.94 (10)	109
Meats, poultry and fish	20.54 (4)	23.75 (5)	23.39 (6)	15.71 (19)	28
Meats	17.32 (3)	19.86 (3)	21.55 (4)	15.23 (20)	22
Beef and veal	4.60 (1)	7.60 (1)	3.40 (1)	5.40 (22)	5
Pork	24.14 (6)	31.29 (7)	16.14 (3)	16.57 (17)	7
Other meats	25.75 (7)	21.50 (4)	57.25 (10)	35.75 (8)	4
Poultry	15.40 (2)	16.40 (2)	21.60 (5)	8.80 (21)	5
Fish and seafood	36.40 (8)	42.80 (9)	34.40 (7)	20.00 (14)	5
Eggs	23.00 (5)	30.00 (6)	11.00 (2)	19.00 (16)	1
Dairy products	44.83 (9)	38.33 (8)	77.33 (18)	39.00 (5)	6
Fats and oils	87.29 (20)	89.43 (20)	70.00 (15)	40.57 (3)	7
Fruits and vegetables	69.95 (14)	72.62 (16)	59.14 (12)	35.19 (9)	21
Fresh fruits and vegetables	82.67 (18)	89.08 (19)	54.75 (9)	47.17 (2)	12
Fresh fruits	92.33 (21)	102.83 (22)	41.33 (8)	61.50 (1)	6
Fresh vegetables	66.60 (13)	70.00 (15)	60.00 (14)	38.00 (6)	5
Processed fruits and vegetables	47.75 (10)	45.88 (10)	59.75 (13)	19.38 (15)	8
Sugar and sweets	65.44 (12)	63.78 (12)	70.78 (16)	39.00 (4)	9
Cereals and bakery products	82.38 (17)	83.56 (18)	71.50 (17)	22.81 (12)	16
Nonalcoholic beverages	82.70 (19)	78.30 (17)	79.90 (19)	37.20 (7)	10
Other foods	70.70 (15)	69.20 (13)	80.90 (20)	22.10 (13)	10
Food away from home	76.00 (16)	69.40 (14)	95.60 (21)	26.20 (11)	5
Alcoholic beverages	95.64 (22)	92.55 (21)	98.00 (22)	16.55 (18)	11

Note(s): [a]The reported rankings are the average monotonic rankings of all CPIs within the reported categories, among the 125 national food and beverage CPIs examined
The ranking of each reported category average is reported in parentheses. Hence, (1) indicates the category with the highest overall average rankings
Source(s): Authors' calculations using data from the US bureau of labor statistics

are included in multiple rows. In contrast to the FPO, we do not report the Food CPI, as it includes all CPIs, and we report alcoholic beverages as a separate category, distinct from both food at home and food away from home [2].

Our discussion of the findings in Table 1 focuses primarily on the overall ranking averages across categories, but there are cases for which the inflation and volatility rankings diverge considerably. Food at home (FAH), the vast category that encompasses all grocery prices, exhibited more inflation and volatility during the early stages of the pandemic than did food away from home (FAFH), or restaurant prices. This may be explained, in part, by the surge in grocery demand experienced during the pandemic, as well as associated stockpiling and panic buying on the part of consumers (Amaral *et al.*, 2022).

The prices for animal products exhibited the most inflation and volatility during the early stages of the pandemic. Of the 22 food and beverage categories included in Table 1, the top nine in terms of overall average rankings are all animal based. Slaughterhouses and meat packing plants feature conditions with higher risk of COVID-19 outbreaks, which led to multiple outbreaks among workers and, in turn, temporary closures (Middleton *et al.*, 2020). Hobbs (2020) reviewed the literature and available data and demonstrated the significant extent to which productivity in the meat supply chain dropped in 2020 relative to 2019. It perhaps is not surprising, therefore, that meats are all ranked among the highest overall according to our metrics.

Produce categories also ranked highly, immediately following animal-based foods. Although data on the topic are limited, it is widely understood that the COVID-19 pandemic resulted in large amounts of fresh produce waste and loss, largely due to the highly perishable nature of these commodities and the shutdown of the foodservice sector (e.g. Zia *et al.*, 2021). Processed fruit and vegetable prices were subject to more inflation than fresh prices, which may reflect the impacts of conditions in packing houses and manufacturing facilities, which were subject to shutdowns due to COVID-19 regulations and outbreaks. Aday and Aday (2020) also cite fruit and vegetable markets being affected by shutdowns and disruptions during the early months of the pandemic.

Table 1 also demonstrates that some food and beverage categories diverged somewhat between their inflationary behavior and volatility during the pandemic. This is most clear for fresh fruits, which ranked 8th in volatility but 22nd in inflation during our study period. This suggests that 2020 and 2021 were especially challenging for the fruit supply chain, as growers faced volatile costs, largescale food loss, but were limited in their capacity to increase prices. The soybean supply chain faced a different set of challenges, as the CPI for fats and oils also ranked considerably higher for volatility than for inflation. LMC International (2020) estimated that soybean producers and crushers lost more than $4.7 billion between January and June 2020, due to the slowdown in demand for soybean-based oils and feed, as well as supply chain challenges related to the pandemic.

We also applied our 16 inflation and volatility metrics to the regional and geographic CPIs. There were 205 CPIs for which sufficient data were available for this exercise. Table 2 provides summary rankings for these CPIs, organized by region and by food category. The regional ranking defies expectations somewhat, as the highest average rankings occur for CPIs calculated in the West and Midwest, respectively. Given that so many foods, including animal products and specialty crops, originate in California and the western US, this suggests that transportation costs are not the dominant factor in driving spatial variation in food price inflation. It is worth considering the notion that labor challenges and other supply chain-related issues were most acute in the western US.

The average rankings by food category are useful in corroborating the findings thus far with respect to CPI inflation and volatility. Meats and animal products lead the rankings among the regional CPIs by a wide margin. These categories are followed by nonalcoholic beverages, which may reflect shortages and delays in the aluminum market (Chen, 2020), or the higher prices associated with processed fruits and vegetables that we saw in Table 1, which affected juice and mixer prices. The remaining rankings by category are closely comparable.

Region	Count	Avg ranking	Category	Count	Avg ranking
West	67	90.15	Meats, poultry, fish, and eggs	19	31.11
Midwest	51	98.67	Dairy	19	75.58
South	32	109.97	Nonalcoholic Beverages	19	78.26
Northeast	42	114.83	Food Away from Home	19	104.68
Mid Atlantic	12	141.67	Fruits and Vegetables	19	105.53
			Food at home	37	116.08
			Alcoholic Beverages	19	125.26
			Cereals and Bakery Products	19	127.00
			Other food at Home	19	127.47
			Food	16	131.06

Note(s): Each of the 205 regional CPIs for which we conducted this exercise was ranked monotonically based on their average rankings across our 16 inflation and volatility metrics
Source(s): Authors' calculations using data from the US bureau of labor statistics

Table 2.
Summary rankings for regional CPIs

Inflation and volatility metrics: producer price indexes

Producer Price Indexes (PPIs) arguably provide better insights into the dynamics of food price formation, and are more forward looking, than CPIs. The prices used to calculate PPIs are upstream in the food supply chain, and are paid business to business. PPIs are organized into two categories. Industry PPIs measure price changes as industrial sector averages for goods, processes and services, which are in turn costs for downstream companies. Commodity PPIs measure the prices for goods and services themselves.

Table 3 reports the rankings for all 47 industry PPIs for which we have sufficient data to apply the 16 metrics. The PPIs are reported in order of their overall ranking, which includes both inflation and volatility. In line with much of our discussion thus far, three of the top four PPIs pertain to meat processing. This is direct evidence that the COVID-19 shutdowns, operating requirements and labor shortages led to increased costs in the meat supply chain. Soybean and oilseed processing is third overall, in line with our previous findings and the significant economic challenges faced by the soybean growing and crushing industry.

Several transportation PPIs also rank highly among the industrial sectors. Interestingly, air freight services rank the highest among transportation measures. While Bartle *et al.* (2021) showed that air cargo capacity fell more than demand in the early months of the pandemic, little else is known about the impacts of COVID-19 on air freight. But this industry has important implications for the transport of high-value perishable items and international trade. Several freight trucking PPIs also rank in the overall top 15 PPIs, reflecting the cost pressures associated with the truck industry throughout the pandemic and recovery.

Several of the rankings align with the CPI results. Both Creamery Butter Manufacturing and Dairy Product Manufacturing show significantly more inflation than volatility during the 2020–2021 period. Most PPIs related to alcoholic beverages are ranked close to the bottom, suggesting that relatively light cost pressures help explain minimal retail price inflation in this category. Interestingly, fruit and vegetable preservation ranks 31st out of 47, meaning that the relatively high ranking of the Processed Fruits and Vegetables CPI is likely due to commodity cost pressures, rather than the costs associating with processing.

To better understand the relative importance of the different categories of costs, we calculate average rankings by BLS description for the 130 Commodity PPIs with sufficient data. We also map the PPIs with obvious linkages to CPI categories to calculated average rankings by the food categories tracked in the USDA FPO. The results are reported in Table 4.

Corroborating our findings for the dairy and processed fruit and vegetable categories, farm commodities rank higher in the metrics than any other broad category of Commodity PPI. The results throughout this paper make clear that the production sector faced unique challenges during COVID-19 and through 2021, resulting in cost pressure driven downstream by increased farm production costs and higher agricultural commodity prices. Energy ranks second, reflecting the cost pressures of surging crude oil and electricity prices during COVID-19, which affect every stage and segment of the food supply chain. The compounding effect of energy prices on food prices throughout the supply chain has been established globally (Chen *et al.*, 2010; Kirikkaleli and Darbaz, 2021) and specifically for the US (Lambert and Miljkovic, 2010; Beckman *et al.*, 2021) The next three categories, in order, are processing, intermediate foods and finished foods. This represents a decrease in inflation and volatility as food moves downstream in the supply chain, and further suggests that the impacts of COVID-19 on the food system are mitigated as value is added.

Forecast results

The in-sample forecast approaches estimate the counterfactual value for CPIs, should the COVID-19 pandemic not have affected the US food system. Table 5 reports the results for the

	Overall ranking	Inflation ranking	Volatility ranking	Rankings difference
Rendering and meat byproduct processing	1	1	6	5
Animal, except poultry, processing	2	13	1	12
Soybean and other oilseed processing	3	3	4	1
Animal Slaughtering and Processing	4	12	3	9
Domestic nonscheduled air freight services	5	18	5	13
Beef, not canned or made into sausage, slaughtering	6	16	2	14
Cheese manufacturing	7	14	13	1
Grain and oilseed milling	8	2	16	14
International nonscheduled air freight services	9	25	9	16
General freight trucking, local	10	15	10	5
General freight trucking	11	21	11	10
Grocery stores	12	9	26	17
Nonscheduled air freight chartering	13	31	12	19
General freight trucking, long distance	14	22	14	8
Pork, processed, not made into sausage, slaughtering	15	34	23	11
Food and beverage stores	16	8	27	19
Primary Products	17	17	19	2
Flour milling and malt manufacturing	18	4	28	24
Food manufacturing	19	20	18	2
Creamery butter manufacturing	20	46	7	39
Truck transportation	21	26	15	11
Plastics packaging film and sheet manufacturing	22	23	21	2
Fruit and veg canning	23	5	38	33
Dairy product manufacturing	24	39	17	22
Air transportation	25	47	8	39
Fluid milk manufacturing	26	38	22	16
Fruit and veg canning, picking and drying	27	10	36	26
Poultry processing	28	27	24	3
Warehousing and storage	29	28	25	3
Inland water transportation	30	44	20	24
Fruit and veg preserving and specialty food Mfg	31	19	31	12
Wines, brandy and brandy spirits	32	6	44	38
Data processing and related services	33	7	43	36
Wineries	34	11	45	34
Frozen food manufacturing	35	30	34	4
Deep sea freight transportation services	36	43	29	14
Deep sea freight transportation	37	45	30	15
Refrigerated warehousing and storage	38	33	33	0
Water transportation	39	42	35	7
Rail transportation	40	35	37	2
Perishable prepared food manufacturing	41	37	40	3
Line-haul railroads	42	36	39	3
Breweries	43	24	41	17
Specialized freight trucking	44	40	32	8
Canned beer and ale case goods	45	29	46	17
Wines, white, red and rose grape and other fruit	46	32	47	15
Advertising agencies	47	41	42	1

Note(s): Each of the 47 industry PPIs for which we conducted this exercise was ranked monotonically based on their average rankings across our 16 inflation and volatility metrics
Source(s): Authors' calculations using data from the US bureau of labor statistics

Table 3.
Inflation and volatility rankings for industry PPIs

Table 4. Summary rankings for commodity PPIs

Description	Count	Avg ranking	CPI category	Count[a]	Avg ranking
Farm Commodity	27	34.41	Fats and Oils	4	21.25
Energy	12	61.33	Eggs	2	41.00
Processing	37	66.78	Meats	13	45.54
Intermediate Foods	10	68.10	Fruits and Veg	21	49.29
Finished Foods	25	74.24	Cereals and Bakery Products	3	66.00
Advertising	9	90.33	Dairy	7	85.71
Transportation	10	102.90			

Note(s): Each of the 130 commodity PPIs for which we conducted this exercise was ranked monotonically based on their average rankings across our 16 inflation and volatility metrics

[a]Not all commodity PPIs can be mapped to food and beverage CPI categories, and therefore the category counts do not add up 130

Source(s): Authors' calculations using data from the US bureau of labor statistics

Table 5. In-sample forecast results by CPI

Category	Baseline 12–21[a]	ARIMA 12–21[b]	VAR1 12–21[c]	VAR2 12–21[d]	Avg.[e]	CV[f]
Food	7.17%	6.19%	3.47%	6.68%	5.88%	0.28
Food at home	8.01%	7.21%	2.64%	8.02%	6.47%	0.40
Meats, poultry, fish	13.11%	12.85%	6.01%	13.76%	11.43%	0.32
Meats	14.91%	14.18%	5.48%	15.50%	12.52%	0.38
Beef and veal	16.12%	16.90%	4.14%	18.25%	13.85%	0.47
Pork	19.29%	14.77%	8.06%	16.87%	14.75%	0.33
Poultry	10.50%	11.73%	8.70%	11.74%	10.67%	0.13
Fish and seafood	9.43%	9.42%	5.44%	9.63%	8.48%	0.24
Eggs	2.01%	10.63%	−2.67%	16.00%	6.49%	1.29
Dairy	6.02%	1.63%	−6.56%	3.85%	1.24%	4.45
Fats and oils	8.84%	7.43%	1.28%	8.58%	6.53%	0.54
Fruits and vegetables	5.18%	5.28%	6.97%	7.48%	6.23%	0.19
Fresh fruits, vegetables	4.22%	6.44%	9.18%	7.65%	6.87%	0.30
Fresh fruits	2.75%	9.45%	2.16%	10.32%	6.17%	0.70
Fresh vegetables	5.86%	3.60%	17.79%	4.77%	8.01%	0.82
Cereals and bakery products	6.23%	5.54%	0.75%	5.69%	4.55%	0.56
Nonalcoholic beverages	9.81%	8.57%	3.48%	7.41%	7.32%	0.37
Other foods	6.30%	5.99%	2.90%	6.73%	5.48%	0.32

Note(s): [a]The percentage difference between the CPI value in December 2021 with the forecasted value for December 2021 using the regression method

[b]The percentage difference between the CPI value in December 2021 with the forecasted value for December 2021 using the ARIMA method

[c]The percentage difference between the CPI value in December 2021 with the forecasted value for December 2021 using the VAR models with PPIs

[d]The percentage difference between the CPI value in December 2021 with the forecasted value for December 2021 using the VAR method without PPIs

[e]The average of a, b, c, and d

[f]The coefficient of variation for all three forecast estimates, calculated as the standard deviation divided by the mean

In some cases, the index names are abbreviated to conserve space and improve readability

Source(s): Authors' calculations using data from the US bureau of labor statistics

CPIs tracked by the USDA FPO as calculated for all US urban consumers, by all methods. For six national urban CPIs, which represent small shares of household spending according to the BLS weights, the available data were insufficient to conduct ARIMA or VAR forecasts.

The complete set of forecast results, for all food CPIs with sufficient data, is available from the authors upon request.

The results indicate that the COVID-19 pandemic had substantial impacts on food price inflation in the US. In our discussion of the forecast-based findings, unless otherwise noted, we use the average estimates of the three approaches. We estimate that overall food prices were 5.9% higher in December 2021 than they would have been, absent the pandemic. The average estimate for FAH is 6.5%, indicating a stronger impact on grocery prices, relative to restaurant prices. This corroborates the findings of the inflation and volatility metrics, and overall our results indicate that the pandemic narrowed the price gap between FAH and FAFH for US households. The methodologies draw closely comparable conclusions with respect to the overall impacts of the pandemic period on food prices. We report the coefficient of variation (CV) for all CPIs to assess the variability of estimates by approach. The estimates for food and FAH have CVs of 0.28 and 0.40 respectively, indicating limited variation. Table 5 is organized following the FPO for ease of readability and to aid discussion. Additionally, the CPIs also included in the FPO are highlighted.

Among major categories of US household food spending, we estimate the largest price impacts for meats, which ended 2021 12.5% higher than their predicted levels as a category, absent COVID-19. The estimated price impacts for the beef and pork categories are 14 and 15% respectively, which also corroborates the earlier finding that beef and veal was the top ranked category overall according to the inflation and volatility metrics. The meats category includes poultry and fish and seafood, both of which are estimated to have ended 2021 about 10% higher than their predicted levels and are also ranked highly according to the averages in Table 1.

Fruits and vegetables, exhibit a considerably lower pandemic effect. We estimate that produce prices increased slightly more than 6% above expected levels through 2021. This may be due, in part, to the fact that outdoor farms were less impacted by COVID-19 protocols and fields are less favorable for virus transmission than indoor spaces. Additionally, the US imports more fruits and vegetables, by value, than most other food categories (USDA ERS, 2022b). Thus, the supply of fruits and vegetables may have been less affected by labor issues and domestic supply chain issues during the pandemic, relative to other foods.

Our forecast approaches deviate considerably for dairy and eggs. Both CPIs feature CVs that exceed 1, which indicates a high degree of variation. Notably, the VAR approach using the PPIs yields negative estimates for both CPIs, suggesting that retail prices would have been higher for both categories, absent the pandemic. These are two of the most volatile food price categories tracked by the FPO, and some degree of divergence among the approaches is to be expected. But the egg and dairy supply chains featured specific challenges during the pandemic, as discussed above, casting doubt the pandemic resulting in deflation for these categories. It is probable that the PPIs are introducing measurement error into the VAR forecasts, possibly due to the high transportation costs and rapid perishability of both. This finding calls for caution in future efforts to forecast prices for these foods, and future research on the topic.

To investigate spatial differences in estimated pandemic effects on food prices, we also applied the regression approach to the regional CPIs. The performance of ARIMA approach was not ideal for the geographic CPIs because they either have not been collected for a long enough time series, or they are reported intermittently, or both. There were 230 CPIs for which we conducted this exercise, and therefore we do not report the full set of results. These are available from the authors upon request. As before with the metrics results, we report average rankings by region and by series category in Table 6 [3].

The regional CPI rankings broadly corroborate the regional CPI rankings, reported in Table 2. In terms of both measured inflation and volatility during the pandemic, as well as estimated regression impacts, the western US ranks the highest among regions and animal

Region	Count	Avg ranking[a]	Series name	Count	Avg ranking
West	64	98.20	Meats, poultry, fish, and eggs	19	11.16
Midwest	62	106.98	Food at home	35	80.4
Mid Atlantic	14	116.14	Other food at Home	19	81.47
Northeast	58	130.26	Nonalcoholic Beverages	19	112.68
South	32	139.56	Fruits and Vegetables	19	119.16
			Food	25	120.96
			Food Away from Home	28	143.18
			Dairy	19	148.47
			Cereals and Bakery Products	19	151.79
			Alcoholic Beverages	28	173.14

Note(s): [a]Each of the 230 regional CPIs for which we conducted this exercise was ranked monotonically based on the estimated inflationary impact as of December 2021

Table 6. Summary forecast rankings for regional CPIs

products rank the highest among food categories. The regression impacts rank FAH higher than FAFH, and have the south ranked the lowest among regions. Importantly, the regional regression rankings further support the notions that there were important spatial variations in the impacts of COVID-19 on food prices, and that not all food categories were affected equally.

Discussion: policy and supply chain implications

When reviewing the results of this study, it is perhaps most important to keep in mind that our analysis is not causal and that not all inflation or volatility occurring in 2020–2021 was due to the pandemic. One factor potentially affecting food prices during this period include the drought in the American West, which grew in intensity throughout 2021 (NOAA, 2023), and likely had impacts on crop prices in California and beyond. Crude oil prices increased throughout 2021 for reasons largely unrelated to the pandemic, which translated into higher energy prices for all stages of the food supply chain. Our in-sample forecasts are intended to serve as a counterfactual for the pandemic, but they cannot account for other exogenous factors affecting food prices during the time period of interest.

The varied rates of inflation during the pandemic, as measured by both our 16 metrics and the forecasts, suggest important changes in the relative prices of food. The implications of our results with respect to US household shopping behavior and dietary quality are not clear. But we argue they are worth exploring. On one hand, we demonstrate that food price inflation during the pandemic was likely stronger for grocery prices than it was for restaurant prices. Research has shown (e.g. Todd *et al.*, 2010) that FAFH reduces dietary quality, and the pandemic may have resulted in restaurant food becoming relatively (though not absolutely) more affordable. But on the other hand, the strongest estimated inflation during the pandemic was concentrated for foods that Americans overconsume on average, including meats and other animal products (USDA and HHS, 2020).

The forecasting approach indicates that the impacts of COVID-19 on food prices extended well beyond the lockdowns. We estimate that as shelter in place orders ended and foodservice establishments reopened, retail food prices continued to climb faster than would be expected, given normal conditions. This may be the result of continuing operational challenges, including labor issues and strong consumer demand. This finding is also consistent with many food companies, including retailers, achieving record profits in 2021. However, it is also worth noting that we find evidence of margin compression in the food supply chain. Across food categories, PPIs increased more than related CPIs in percentage terms, and in many cases inflation and volatility moderated as food moved downstream. This calls for the study of margins and profitability for food companies during the pandemic, the findings of which will have both practical and policy implications.

We find significant spatial variation in inflation and volatility throughout the US. Perhaps our most surprising finding in this respect is that the western US, which includes Colorado and points west according to the BLS definition, saw the highest average inflation during the pandemic of all major regions of the country. Given that a large share of US agriculture production is concentrated in California, this suggests that transportation costs are not a dominant factor in driving this spatial variation. And relatedly, among major categories of Commodity PPIs, transportation ranked the lowest in inflation during the pandemic, behind farm commodities, energy and other cost sources. We argue that labor constraints, energy prices and consumer stockpiling behavior may have been more acute in the west, and this possibility is worth investigating quantitatively.

Concluding remarks

The COVID-19 pandemic was a shock to the food supply chain without precedent in modern history. The press, trade publications and interviews with both industry practitioners and consumers are replete with stories about food price inflation during the pandemic. But our study is the first of its kind to measure comprehensively how food prices behaved in the US during the pandemic, and to use a counterfactual to estimate the impact of COVID-19 on food price inflation. We find that the impacts of the pandemic on food prices were large in magnitude, driving substantial inflation and volatility. Moreover, these effects show a great deal of variation across food categories and geographic regions of the US.

Our study is exploratory and descriptive in nature and, accordingly, features several important limitations, which motivate a rich set of possibilities for future research on the impacts of COVID-19 in the food supply chain. This study does not assign causality to the pandemic, and in several cases, food price inflation in 2020 and 2021 was likely caused concurrently by other factors, e.g. the drought in the American West. Relatedly, we do not decompose the factors behind food price inflation during the time period of interest, nor are we able to explain differences in inflation or price volatility across consumer spending categories. Our study cannot speak to the respective roles of consumer demand, upstream costs, regulatory changes, or labor shortages. Future work using farm-to-retail price spreads or inferred margins can estimate the impact of the pandemic on profitability throughout the supply chain and investigate the potential role of market power in price transmission during the pandemic. Finally, we are unable to measure price dynamics as they relate to store formats, urban vs rural areas, food access, or local household demographics. Future research using resources such as store scanner data may investigate these granularities and potential associations.

Notes

1. The complete set of regression results, for all coefficients, is available from the authors upon request.
2. The mapping of CPIs to FPO categories is available from the authors upon request.
3. The regional CPIs are reported only by selected categories, and we therefore do not map these results directly to the USDA FPO categories.

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