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Heterogeneous Effects of COVID-19 on Fruit and Vegetable Markets

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The COVID-19 pandemic caused abrupt changes in food purchases and consumer behavior because of both supply and demand shocks. Stay-at-home orders resulted in large reductions in demand for food consumed in food-away-from-home settings. At the same time, the demand for food purchased at grocery stores and online spiked. We analyze the association between pandemic, related media coverage, and prices of specialty crop commodities. We find that prices of specialty crops consumed mostly away from home exhibited a demonstrative negative relationship with the pandemic and associated media coverage compared to specialty crops consumed mostly at home.

Key words: Food at Home, Food away from Home, Fruits, Pandemic, Supply chains, Vegetables

Introduction

The COVID-19 pandemic had a profound effect on food and agricultural industries due to disrupted supply chains and major food demand shifts. Restaurants and schools shut down impacting the consumption of food away from home (FAFH), and many people engaged in panic buying of food and supplies impacting the consumption of food at home (FAH). Understanding the factors associated with larger disruptions could help in the development of a more resilient U.S. food supply chain. In this paper, we analyze how fruit and vegetable markets were impacted by changes in consumer demand and supply chain issues due to the COVID-19 pandemic. Specifically, we analyze how prices, shipments, and sales of fruit and vegetable crops relate to the COVID-19 pandemic and associated media coverage. We evaluate whether effects were heterogeneous across the selected crops, with a focus on the market channels in which crops are sold. Finally, we examine the extent to which fruit and vegetable crop markets recovered.

The first major wave of disruptions to the food and agricultural sectors was the result of two substantial and abrupt demand shocks. Shutdown and stay-at-home orders resulted in a significant reduction in demand for food eaten in restaurants, cafeterias, and other FAFH settings. At the same time, demand for food purchased in grocery stores spiked (Chenarides, Manfredo, and Richards, 2021; Hobbs, 2020; Kassas and Nayga, 2021). In mid-to-late March 2020, sales in grocery outlets increased 90% relative to the year prior, with the largest gains occurring in

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categories such as toilet paper, frozen foods, packaged foods, and meat. Online food sales rose at the onset of the shutdowns and continued to increase through May 2020 (Chenarides et al., 2021).

The media coverage of COVID-19 regularly reported on shortages of food and other items needed to "hunker down" to endure the effects of the pandemic, which led to prolonging and/or creating additional FAH purchases and shortages. Even if individual consumers were not initially concerned about their own mobility or income, observing other consumers' behavior may have incentivized them to change their behavior. Social media may have also played a direct role in influencing the food purchasing behavior and types of food purchases made by consumers.

More than half of consumer food spending occurs in FAFH settings (Okrent and Alston, 2012; Okrent et al., 2018). A reason for grocery store shortages during the pandemic was that consumers shifted their food demand from FAFH venues to grocery stores, which were unprepared for the demand spike. There is also evidence to suggest that total aggregate demand for some products actually rose (Lusk, 2020). This is consistent with consumers stocking up and possibly also panic buying.

The pandemic shifted both where consumers buy food and what they buy (Chenarides et al., 2021). There was a decrease in FAFH purchases and an increase in purchases of foods prepared and consumed at home.[1] The pandemic led to an increase in sales of processed comfort foods, which were on the decline prior to the pandemic (Bracale and Vaccaro, 2020). A possible explanation is that consumers lacking sufficient cooking skills or time for food preparation were incentivized to purchase ready-to-eat foods or foods requiring minimal preparation prior to eating. Consumers may have been seeking familiar comfort foods, and there is anecdotal evidence that being home for extended periods of time led to consumers eating snack foods more often. Demand for meal kits grew (Janssen et al., 2021; Żurek and Rudy, 2024).

The pandemic created challenges for supply chains globally (Chowdhury et al., 2021) and increased public awareness of delays and extended shipping times (Pujawan and Bah 2022). There were also labor disruptions in planting, harvesting, processing and transportation of crops and commodities. The shutdown orders that restricted the amount of labor companies could employ alongside restricted movement compounded the pressure that supply chains faced (Meyer, Walter, and Seuring, 2021).

Exacerbating these disruptions is the fact that the food supply chain is generally designed and optimized to supply either the restaurant-and-food-service sector or the grocery sector. It is generally difficult in the short-to-intermediate run to alter food processing methods, types, packaging, and transportation modes in order to quickly change distribution channels (Lu et al. 2021). For example, consider the case of potatoes, most of which are used for processing (USDA, 2024a). Processed potatoes are primarily consumed in restaurants and other FAFH venues as French fries (USDA, 2024a). The processed potato industry is vertically integrated using production contracts between growers and processors (Patterson and Bolotova, 2011). A concern is that contracts lock growers into selling specific products to specific buyers and thereby result in less resiliency in response to substantial shifts in the types of demands facing buyers (MacDonald et al. 2004).

Thus, the pandemic magnified pre-existing issues and exposed critical constraints in the food supply chain (Chenarides et al., 2021). Pre-pandemic, the nature of supply chains was already quite fragile by design. The widespread use of just-in-time supply models resulted in supply chains being more vulnerable to potential supply chain disruptions. In the United States, pre-existing contracts and an emphasis on cost saving led most businesses to rely on only one or a small number of suppliers to satisfy quotas.

Further, the combination of demand and supply chain disruptions affected food affordability. While the general consumer price index (CPI) fell from March to April 2020, the grocery store CPI increased 2.7 percent in just one month, from March to April 2020, and was 4.1 percent higher

[1] https://www.ers.usda.gov/data-products/food-expenditure-series, "Food Expenditures by Final Purchaser" table.

in April 2020 than in April 2019 (BLS, 2020). Moreover, the April FAFH CPI was 2.8 percent higher than in April 2019. The year-to-year price increases were the highest since the 1970s. The unprecedented price changes were attributed to both demand-side factors and supply chain disruptions, e.g., meat packing plant shutdowns that added to production costs.

At the same time, U.S. households received significant government funds through federal aid programs. The influx of cash likely contributed to the inflation in the food sector. Bina, Tonsor, and Briggeman (2023) evaluate the association between the increased government financial assistance and household spending on both FAH and FAFH. They find that all their studied federal payments are associated with a greater probability of spending on FAFH, but not with how much consumers spent. Only some of the programs have a statistically significant association with expenditures on FAH.

Several studies document general disruptions to fruit and vegetable supply chains during the pandemic (Richards and Rickard, 2020; Weersink et al., 2021) or examine the impact of pandemic restrictions on food prices generally (Dietrich et al., 2022). Along with individual animal product commodities, Weersink et al. (2021) examine the potato market, graphically comparing a year of pre-pandemic shipments to post-pandemic shipments. Chenarides, Richards, and Rickard (2021) graphically compare a year of pandemic potato shipments to post-pandemic shipments. Ridley and Devadoss (2021) estimate the economic impact of COVID-19 on 27 individual fruit and vegetable crops totaling between $12 and $48 million of production losses. Rutledge and Mérel (2022) estimate that a 10% reduction in farm labor supply would result in a 4% reduction in production in the top 10 fruit and vegetable producing counties in California.

In their systematic review of the literature examining the impacts of COVID-19 on supply chains, Chowdhury, et al. (2021) find "a lack of empirically designed and theoretically grounded studies." An exception is Çakır, Li, and Yang (2021) who examine the impacts on COVID-19 on fruit and vegetable prices in the United States and China in a difference-in-difference framework. They find no measurable effect of COVID-19 on an aggregated U.S. price index of apples, oranges, bananas, lettuces, tomatoes, and potatoes when monthly fixed effects are included in the model. Our study differs from their work by individually examining four U.S. fruit and vegetable markets (potatoes, tomatoes, strawberries and apples). We find notable differences based on the predominant end use of each commodity.

The article proceeds as follows: The next section presents the empirical models used to conduct the analyses. Next, the data is presented, follow by a presentation and discussion of the results. The final section provides conclusions.

Empirical Model

ARX Modeling Approach: Specification and Estimation

The ARX (autoregressive disturbance process with exogenous explanatory variables) modeling approach as implemented in STATA is used to analyze the relationship of fruit and vegetable prices with effects of the pandemic. The results are derived from estimating market clearing weekly average price-dependent models for the four fruits and vegetables. The ARX approach fits a regression model of a dependent variable on exogenous (X) variables with a disturbance process that can follow an autoregressive (AR) specification. The general functional form of the ARX models is:

$$\left.\begin{aligned} y_t &= \alpha + \sum_{i=1}^{k} \beta_i X_{it} + u_t \\ u_t &= \sum_{j=1}^{L} \rho_{t-j} u_{t-j} + \varepsilon_t \end{aligned}\right\} \; for \; t = 1, \cdots, n \tag{1}$$

where $\varepsilon_t \sim N\ (0, \sigma^2)$, X_{it} denotes the i^{th} explanatory variable within a set of k independent variables at time *t*, and $L \in \{0, 1, 2, \ldots\}$ is the order of the AR process[2].

In the specific implementation of (1) a Box-Cox analysis is implemented to explore possible non-linear transformations of prices for use as the dependent variable in support of examining robustness of the results. Formally, the functional equation specifications of (1) that are examined can be characterized as:

$$(2) \qquad g(P_t) = \beta_0 + \beta_q Q_\tau + \beta_\upsilon \upsilon(NewCovidDeaths_t) + \beta_f f(Tweets_t) + \beta_h h(NYTarticles_t) + \beta_c CovidUnemployed_t + \beta_\mu UnEmployRate_t + \delta t + \mu_t$$

where $g(P_t) = \dfrac{P_t^\lambda - 1}{\lambda}$ is a *Box-Cox* transformation of prices, $\upsilon(.), f(.), h(.)$ are the smoothing functions defined in section 3.1, and $\tau \in t,\ t-1,\ t-2,$ ... denotes a potentially lagged quantity (Q_τ) relationship with prices.

The quantity lag length exhibiting the highest z-score, and thus lowest probability value of insignificance, is chosen. For strawberries, apples and tomatoes, the first lag is selected, while for potatoes, the second lag is utilized. The order of the AR process is chosen by examining the number of statistically significant (at the 95% level of confidence) sequential lags exhibited by the partial autocorrelation function (PACF) plots, which is then corroborated by the statistical significance of the lag terms in the estimated ARX model. The PACF plots are presented in Appendix Figures A1a-A1d. The final AR process specifications for apples, potatoes, tomatoes, and strawberries were $AR(1),\ AR(3),\ AR(4),$ and $AR(2)$, respectively.

To provide evidence that the estimated ARX models are not adversely impacted by the effects of nonstationary stochastic processes, checks for the stationarity of prices are performed using the Augmented Dickey-Fuller (ADF) test. The ADF test is based on the following standard equation specification:

$$(3) \qquad \Delta y_t = \alpha + \delta y_{t-1} + \sum_{j=1}^{p} \phi \Delta y_{t-j} + v_t$$

where y in (3) refers to the fruit and vegetable price whose stationarity is being assessed, and $v \sim N(\mathbf{0}, \Sigma)$. The ADF tests the null hypothesis $H_o : \delta = 1$ versus the alternative hypothesis $H_a : \delta = 0$. If $\delta = 1$, the series has a unit root and is nonstationary. Rejecting the null hypothesis is consistent with the series being stationary. For all four fruits and vegetables, the null hypothesis can be rejected (Appendix Table A1).

In implementing the Box-Cox analysis of the dependent fruit and vegetable price variables in (2), we examine the log-likelihood (LL) values associated with λ in the interval [0, 2], which spans log, linear, and low-order power functions up to a quadratic form (Appendix Figure A.2). For both potatoes and tomatoes, the LL graphs are nearly flat, with potatoes peaking at $\lambda = 1$ (linear), and tomatoes peaking at $\lambda = ½$ (square root) albeit the latter is nearly imperceptibly distinguishable from $\lambda = 1$. For apples, the LL is highest at $\lambda = 0$ (log), while for strawberries the LL is highest at $\lambda = 1/2$ (square root). We report the linear price model results for both potatoes and tomatoes.

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[2] Note that $\sum_{j=1}^{L} \rho_{t-j} u_{t-j} \equiv \varnothing \ when \ \ L = 0$.

Estimation results and conclusions relating to tomatoes for both the linear and square root forms are similar, except for the quantity effect being marginally statistically insignificant in the square root form. We also compared results for both the linear and log forms of prices for apples, and for both linear and square root forms for prices for strawberries. In both comparative evaluations the impacts of the COVID-19 variables were essentially identical. In the results section, to facilitate interpretability, comparability, and consistency across models, we focus on only the results of the linear models.

Checks of the eigenvalue stability conditions for stationarity of the estimated autoregressive disturbance processes suggested that all processes were stationary (Appendix Figure A.3). If the inverse roots of an AR polynomial all lie inside the (complex) unit circle, the process is stationary, invertible, and has an alternative infinite-order moving-average (MA) representation. The estimated AR processes are dynamically convergent in all models based on the standard eigenvalue stability conditions, i.e., all eigenvalues lie within the (complex) unit circle.

An examination of estimation efficiency and model structural stability issues was conducted relative to data observations that occurred for various data periods. A principal question is whether the estimation of the ARX models is improved or diminished by including observations during the "endemic" period (22 observations) of week 9 through week 30 of 2021, when the effects of the pandemic were thought to begin dissipating. The endemic period was marked by the CDC announcement that fully vaccinated individuals could gather indoors without masks, children in school could reduce their level of distancing, and fully vaccinated individuals could travel safely domestically in the U.S. without a COVID-19 test. In addition, federal websites announced that a threshold of 100 million U.S. individuals were fully vaccinated. An additional question is whether adding observations beyond the endemic period can be interpreted as belonging to the same basic behavioral structure as that which existed in prior observations.

The issue of adding data observations during the endemic period is assessed using the Adjusted Akaike Information Criterion (AAIC), which is appropriate for model selection questions based on models with heterogeneous sample sizes. In this application, data observations in the endemic period are sequentially and cumulatively added to the analysis, from week 9 through week 30 of 2021, and the behavior of the AAIC is observed (Appendix Figure A.4). As in the case of the traditional AIC criterion, models with the lowest AAIC values are preferred in terms of contributing to the estimation of a more efficient model. The effects of adding observations for the purpose of supporting the estimation of the best model differed, depending on the commodity being analyzed:

(i) For potatoes, the last half dozen endemic observations are considered not to be supportive of estimating the best model.

(ii) For tomatoes, none of the endemic observations are considered supportive of estimating the best model.

(iii) In the case of strawberries, the first six observations on AAIC values are similar, where they exhibit a slight and gradual marginal decline. That behavior is followed by a brief two observation spike of higher AAIC values, after which the AAIC continued to exhibit a gradual decline until a minimum AAIC value is attained at the last observation on the data. Despite two observations being dissimilar in AAIC behavior when individually sequentially added to endemic period observations in model estimation, utilizing the total series of endemic observations is associated with the lowest AAIC, suggesting that the entire series treated as a group is supportive of estimating the best model.

(iv) For apples, effectively all the endemic observations are deemed supportive of estimating the best model.

Chow tests for the stability of model parameters in the post endemic period are conducted (Appendix Table A2). Specifically, additional weeks of data spanning week 31 of 2021 to week 30 of 2022 are included for conducting this test. The results of the Chow tests suggest that the potato and apple data series are subject to structural changes vis-à-vis the estimated behavioral parameters in the post pandemic period. For the strawberry and tomato data, no such structural changes are suggested at conventional levels of statistical significance. However, in the case of strawberries, the structural break test is on the cusp of significance at the 10% level, with a probability value of 0.11. The reasons for possible structural stability in the tomato market in the post pandemic period are not readily apparent but might have been due to relative supply chain stability. The large majority of U.S. tomato production is sold under contracts for processing and is mechanically harvested, much more so than for any of the other fruits and vegetables analyzed, with most of the tomato production being utilized in the processed product market channel.

Regarding the addition of post-endemic observations when estimating the models, given that the results of the Chow tests suggest that structural breaks occurred in the post-endemic period in the case of apples, potatoes, and to a notable extent strawberries, no post-endemic observations are utilized. When combined with the AAIC results, the final number of observations used in estimation are N = 239 for both apples and strawberries (i.e., use all of the endemic period observations), and N = 233 for potatoes (i.e., the last six observations of the endemic period are not utilized), where the data set begins with the first weekly observation in 2017. In the case of tomatoes, there is no indication of a structural break via the Chow test, but the AAIC results indicate that adding observations into the endemic period detract from the objective of estimating the best behavioral model, and so we include no observations from the endemic period (N = 211) or beyond.

Data

The analysis is based on time series models of the evolution of commodity prices from the first week of 2017 to the 30th week of 2022, spanning a period prior to, during, and after the COVID-19 pandemic. We use weekly shipment quantities and prices for four representative fruit and vegetable commodities: potatoes, tomatoes, strawberries and apples. This selection of fruits and vegetables was motivated by heterogeneity in end-use characteristics. Four variables relate to information specifically associated with COVID-19 that could potentially impact fruit and vegetable markets, including tweets related to COVID-19, *New York Times* articles related to COVID-19, COVID-19 deaths, and unemployment specifically attributable to COVID-19. We also control for the general unemployment level.

Background on Commodities

The four fruits and vegetables that we selected for this study—apples, potatoes, tomatoes, and strawberries—are differentiated by the share of end-use in FAH versus FAFH settings, by their perishability, the share of production that goes into processing, and by the amount that is imported or exported. A majority of potatoes and tomatoes are consumed in both FAFH and FAH settings. In contrast, the large majority of both apples and strawberries are consumed in FAH settings. Second, fresh potatoes and apples can be stored for months, while tomatoes and strawberries are perishable within days or weeks. Third, a large percentage of potatoes and tomatoes go into processing, while relatively fewer apples and strawberries go to the processed market. Finally, the crops differ in terms of international trade characteristics. The most exported crop in terms of percentage of domestic supply is apples, followed in order by potatoes, tomatoes, and strawberries. In terms of import percentages, strawberries are the most imported, followed in order by potatoes, tomatoes, and apples. This heterogeneity in market characteristics provides the opportunity to contrast marketing channels and storage considerations vis-à-vis the effect of the pandemic on fruits and vegetables.

The vast majority (65%) of the U.S. potato crop are sold to processors for French fries, chips, and dehydrated potatoes; about 23% is sold fresh, and the remaining crop is used for animal feed, seed for the next planting season, grower's home use, and shrinkage/loss (U.S. Department of

Agriculture, National Agricultural Statistics Service, 2024a). Idaho and Washington State produce more than half of the annual potato crop in the United States (U.S. Department of Agriculture, National Agricultural Statistics Service, 2024a). In Washington and Idaho, growers sell roughly 60% of their potatoes to processors (U.S. Department of Agriculture, National Agricultural Statistics Service, 2024a). Guthrie and Lin (2014) calculate that 28% of FAH potatoes are eaten as potato chips, 19% are baked or boiled, 18% are eaten in "other" forms, 15% are mashed, and 10% are fried. In terms of potatoes consumed as FAFH, 59% are fried, 13% are mashed, 12% are baked or boiled, 6% are eaten as potato chips, and 6% are eaten in "other" forms. Thus, there is a mixture of FAH and FAFH.

Tomatoes are the second most consumed vegetable in the United States (Economic Research Service, 2020). The tomato processing industry mainly produces tomato pastes, sauces, ketchup, and canned tomato products and is separate from the fresh market. Most fresh tomatoes are picked and sold on the open market, while essentially all processed tomatoes are mechanically harvested and sold under contract (Geisseler and Horwath, 2016). Tomatoes sold to the fresh market are valued at about 25% of the total crop, and processed tomatoes are 75% of the crop (U.S. Department of Agriculture, National Agricultural Statistics Service, 2024b). In terms of FAFH vs. FAH consumption behavior, Guthrie and Lin (2014) calculate that 22% of FAH tomatoes are consumed fresh (the second largest category), while 17% of FAFH tomatoes are consumed fresh (the third largest category). The largest category for FAH tomatoes is spaghetti sauce with 24%. The largest category for FAFH tomatoes is for pizza at 32% and the second-largest is "other". Thus, tomatoes are consumed both at home and away from home, and a mixture of processed and fresh.

Strawberries are mainly produced in California and Florida, with California producing over 91 percent of the total crop (U.S. Department of Agriculture, National Agricultural Statistics Service, 2021). Beginning in the early 2000's the U.S. strawberry industry experienced an upward trend in per-capita consumption. Some factors contributing to this trend include consumers being more health conscious and seeking healthier diets, yield improvements that created an expanded domestic supply, and imports that allowed for year-round availability. Most strawberries are consumed fresh, representing about 80% of production (U.S. Department of Agriculture, Economic Research Service, 2021). Several decades ago, more than 40% of strawberries produced in the United States were sold in processed form, but that figure has since declined to approximately 20% (Agricultural Marketing Resource Center, 2023). Strawberries are mostly purchased in the FAH outlets, where the FAFH market outlet is a minor component of the demand for strawberries. Fresh strawberries are highly perishable. 11% of domestic supply is imported, and about 15% of domestic utilized production is exported (Samtani et al., 2019).

Apples are the most valuable fruit in the United States (Agricultural Marketing Resource Center, 2023). The quantity of U.S. apples produced and sold was approximately 9.6 billion pounds in 2021.The fresh market accounted for 79% of apples sold, with the processed market accounting for the remaining 21% (U.S. Department of Agriculture, Economic Research Service, 2021). Processed production includes applesauce, juice, cider, pre-sliced apples, as well as other processed apple products. Nearly one third of apple production is exported, and less than 5% of U.S. apples consumption is imported. The FAFH market outlet is a minor component of the demand for apples in all of its forms (U.S Apple Association, 2021).

Table 1: Data Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Apple Prices (Per 42 lb. carton)	292	26.73	3.17	20.17	40.74
Apple Quantities(1000 lb. units)	292	12190.06	2367.15	2386	20909
Potato Prices (Per 50 lb. cartons)	292	14.21	2.85	9.36	27.10
Potato Quantities (1000 lb. units)	292	16073.56	3052.05	8064.94	27114.20
Tomato Prices (Per 25 lb. carton)	292	13.55	2.97	8.17	24.24
Tomato Quantities (1000 lb. units)	292	18264.39	3128.48	11773.32	31873.94
Strawberry Prices (Per 8 1lb. containers with lids)	292	14.64	4.98	5.5	29.335
Strawberry Quantities (1000 lb. units)	292	7506.68	3299.46	1552.72	14870.72
Tweets	138	26835.19	28986.67	19	186015
NYT Article Count	138	323.65	197.47	2	897
New COVID-19 Deaths	138	7546.84	5569.88	0	23752
Unemployed Due to COVID	113	46368.61	46945.32	6310	191974
Unemployment Rate (%)	292	4.92	2.18	3.5	14.8

Note: All data is presented at the week level. Apple prices are per 42-pound carton trays, potato prices are per 50 lb. carton, tomato prices are per 25lb carton, and strawberries are presented per 8 one-lb. containers with lids.

Data Sources

The variables utilized in this analysis were collected from multiple sources and are presented and summarized in Table 1. Data on daily COVID-19 deaths, the number of articles on COVID-19 from the *New York Times (NYT)*, and posts (formerly called "tweets" during the analysis period) related to COVID-19 on X (formerly Twitter) are used to proxy the types, amounts, and evolution of information that were available to consumers relating to the prevalence and impacts of the pandemic. Data relating to overall unemployment and the number of persons unable to work at some point "in the last four weeks because their employer closed or lost business due to the coronavirus pandemic" were obtained from the U.S. Bureau of Labor Statistics (BLS) and provide labor market perspectives on visible economic impacts of the pandemic.

Price and quantity data from the USDA Agricultural Marketing Service (AMS) on potatoes, tomatoes, strawberries, and apples were collected beginning the first week of 2017 through the 31st week of 2022. The series are standardized to normalize prices and quantities by subtracting the respective series average and dividing by the respective series standard deviation. In Figures 1-4, the vertical red line indicates the week when the Centers for Disease Control and Prevention (CDC) confirmed the first COVID-19 case in the United States.

From the shipments and price data figures, one can observe that higher levels of shipments are generally associated with lower prices, as one would expect. However, visualizing the behavior of the data pre- and post- pandemic onset does not suggest a clear and demonstrable impact or change in behavior between the two periods. There is sufficient volatility in the weekly shipment and price data over time that visually identifying the impacts of the COVID-19 pandemic is challenging. This motivates our use of statistical analyses to identify addition details relating to the relationship between the pandemic and apple, potato, tomato, and strawberry markets.

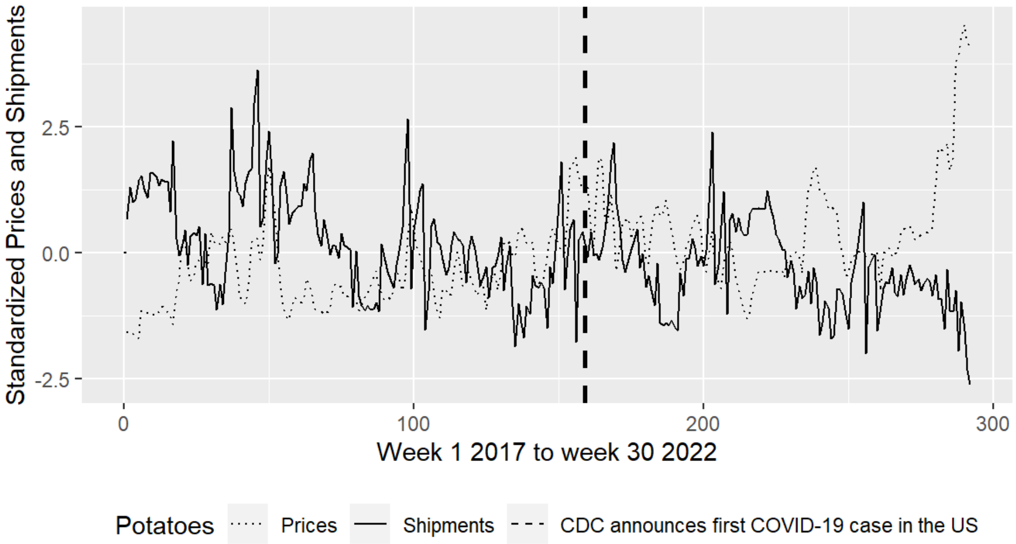

Figure 1: Potato Shipments and Prices.

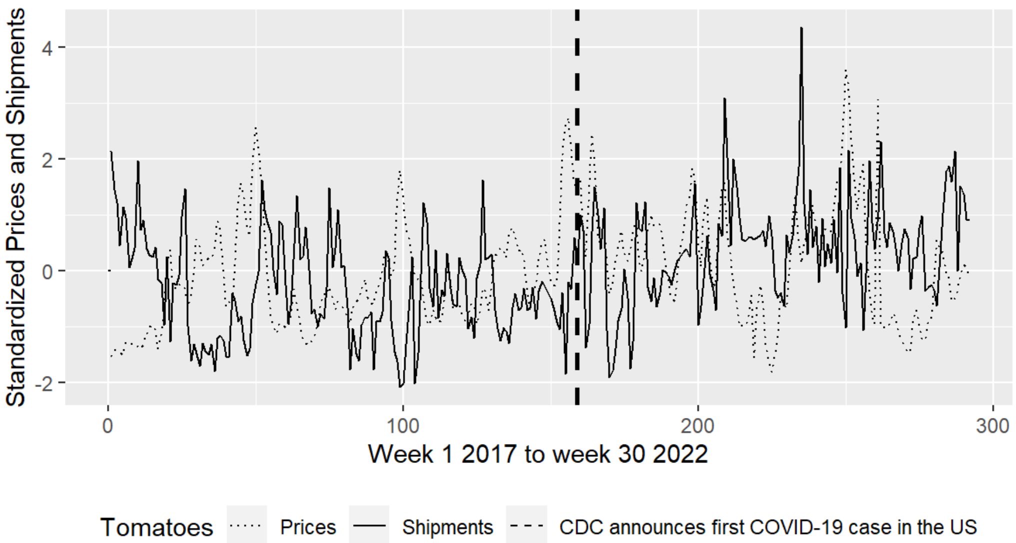

Figure 2: Tomato Shipments and Prices.

To analyze the relationship between the dissemination of information related to COVID-19 and fruit and vegetable markets, we collect data on COVID-19-related social media posts (tweets) from X (formerly Twitter) and the number of weekly articles published by *The New York Times*. To avoid double counting, we identified original tweets (not retweets) containing any of the strings "COVID", "coronavirus", and "corona virus", sent from anywhere in the United States between January 1, 2020, and August 24, 2022. As a proxy for traditional media coverage on the pandemic, we identify articles from the *New York Times (NYT)* website containing the word "coronavirus". Figure 5 presents weekly tweet and *NYT* article counts.

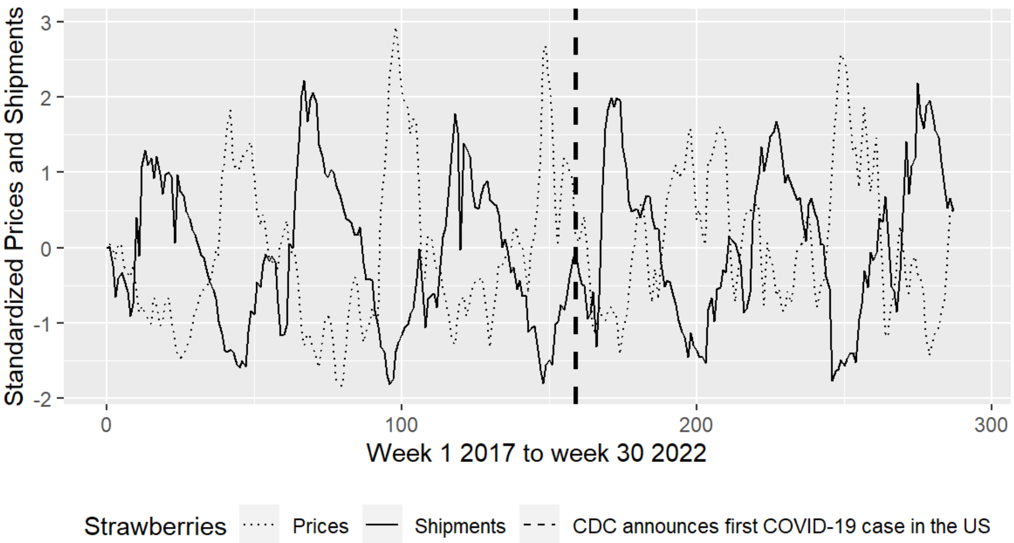

Figure 3: Strawberry Shipments and Prices

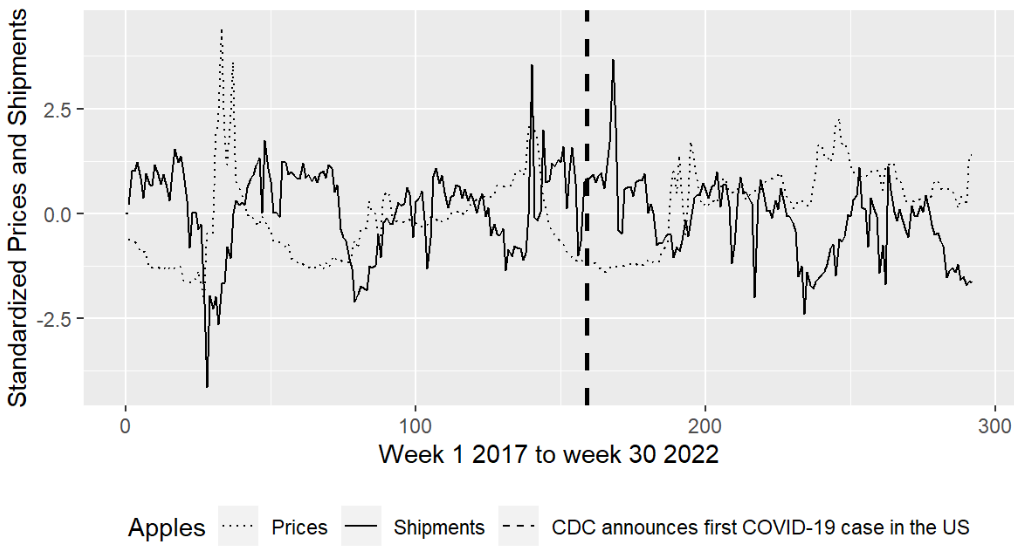

Figure 4: Apple Shipments and Prices

We collected data on total confirmed deaths due to COVID-19 from John Hopkins University's Center for System Science and Engineering (Dong *et al.*, 2020). The data ranges from January 2020 to August 2022. Given the official total cumulative deaths reported on each day, we calculate daily new deaths (our variable of interest) via differencing, i.e., we take the total cumulative deaths at time t and subtract total cumulative deaths at time $t-1$, defining total new deaths for time t. The variable is used to proxy the trajectory of critical health impacts associated with the pandemic. Figure 6 presents the series for weekly new deaths.

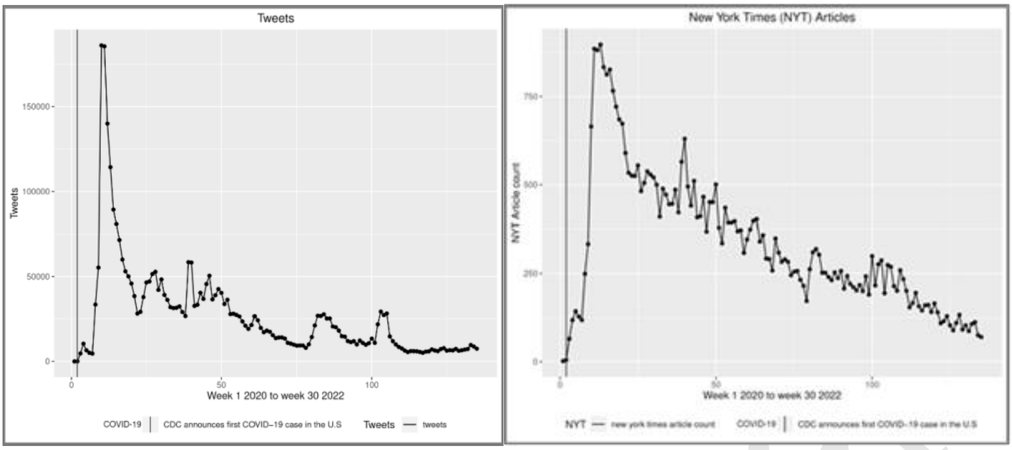

Figure 5: Tweets and NYT Article Counts by Week

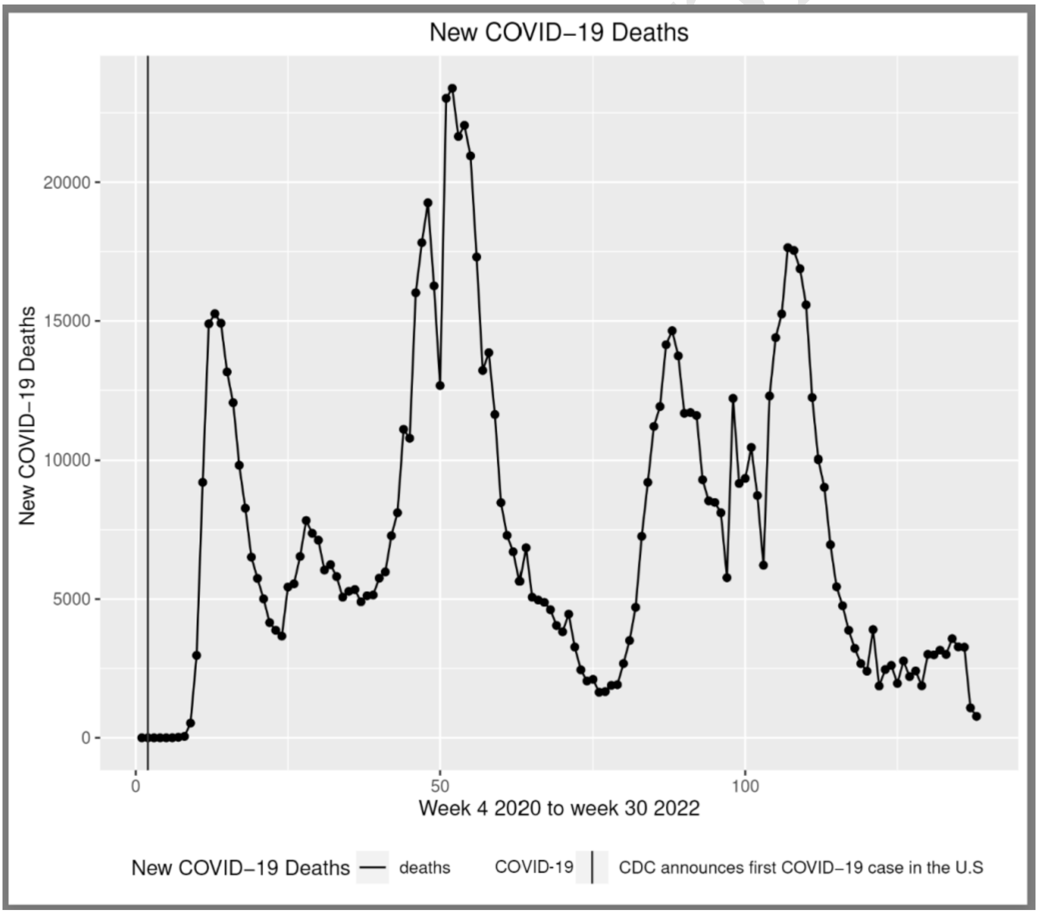

Figure 6: New COVID-19 Deaths.

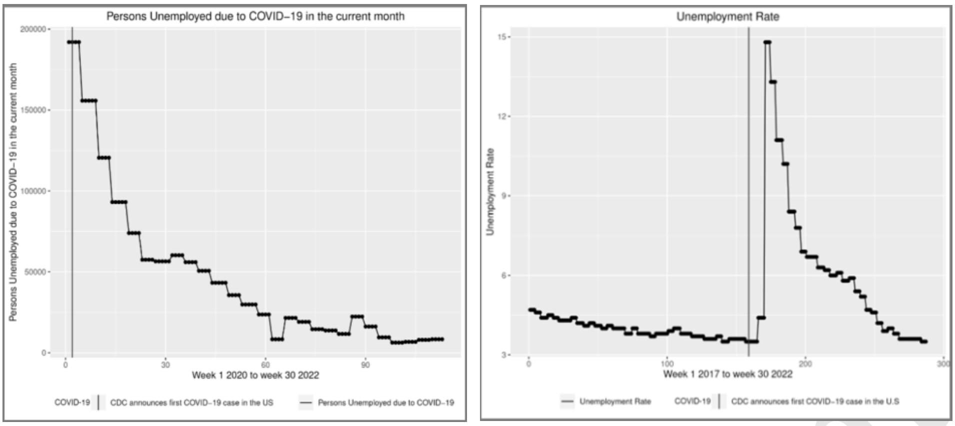

Figure 7: Unemployed Due to COVID-19 and Overall Unemployment Rate

Two variables from the U.S. Bureau of Labor Statistics (BLS) are related to the effect of employment status on consumer demand: the general unemployment rate and the number of people unemployed explicitly due to COVID-19. To obtain the latter statistic, the BLS added questions to the U.S. Census Current Population Survey (CPS) to gauge the direct effects of the pandemic on the labor market with the language "persons unable to work at some point in the last four weeks because their employer closed or lost business due to the coronavirus pandemic." While all other data in this analysis is weekly, the BLS data are reported monthly. All weeks in a given month are assigned the same BLS employment statistic. Figure 7 displays both BLS unemployment measures.

Data Transformations

The following functional forms for COVID-19 related variables (tweets, articles, and deaths) are considered in our analyses: untransformed, as well as power, logarithmic, and exponential functional forms. In addition, smoothing functions are applied to some variables to mitigate data noise in the weekly observations utilized, to facilitate identifying trends, and to support model fit and estimation accuracy. The smoothing functions are weighted moving-average representations with geometrically declining weights that are defined as part of the estimation process, via the estimation of smoothing parameters.

The smoothing weights are solutions to minimum mean square error prediction criteria applied to the data and, in all cases, heavily weight the one-period lag and down-weight information prior to the one period lag. As a result, all of the smoothing functions approximate (but are not identical to) a one-period lag to varying degrees. The final choices of variable functional forms to which the smoothing functions are applied were driven by the quality of statistical fit and interpretability of model results. Smoothing was applied to the weekly counts of *New York Times* articles related to COVID-19, tweets related to COVID-19, and new COVID-19 deaths. The best-fit smoothing function for the weekly count of *New York Times* articles is based on an exponential function, suggesting an exponentially increasing relationship with market outcomes. The smoothing of weekly tweet counts is best-fit by a log function, suggesting a log-attenuated increasing impact on markets. Finally, the smoothing of the new COVID-19 deaths variable is best-fit in terms of its untransformed original units of measure.

The models were initially estimated based on the following three variations of the quantity regressor variable: total domestic quantity, total domestic quantity plus imports, and including total domestic quantity and total imports as separate regressors. Total domestic quantity includes all shipments from a U.S shipping point. Total imports include all shipments into the United States

Table 2: Regression Results: Weekly Potato Prices

Variable	Coefficient	St. Err	z	P>|z|
Quantity(t-2)	-0.0000287	0.000209	-1.37	0.170
Time Trend	0.047994***	0.173913	2.76	0.006
New York Times Articles	-0.0023454**	0.0011105	-2.11	0.035
Tweets	-.1974851**	0.0808852	-2.44	0.015
New COVID-19 Deaths	-0.0001593**	0.0000669	-2.38	0.017
COVID-19 Unemployed	-0.0000102*	5.23e-06	-1.95	0.052
Unemployment Rate	0.2915029***	0.0803518	3.63	0.000
Constant	7.605761***	2.559328	2.97	0.003
L1	1.365718***	0.0679805	20.09	0.000
L2	-0.957232***	0.0948699	-10.09	0.000
L3	0.479138***	0.0699389	6.85	0.000
Sigma	0.7329567***	0.0439956	16.66	0.000

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Sigma is the standard deviation of the residuals. N=233

through a port of entry or a border crossing. Accounting for imports separately does not improve the estimation results in any of the quantity configurations, and in fact detracts from model fit and interpretability, as did ignoring imports in the model. The analysis ultimately proceeds based on quantity defined as total domestic quantity plus imports.

Lags of the effect of quantities shipped on market prices are used to account for timing issues involved between quantities supplied at shipping points and the ultimate effects of quantities shipped on market prices. In the final model specification for apples, tomatoes, and strawberries, the quantity variable is lagged once, while for potatoes, a second-period lag is used. The choice of lag is driven by both statistical significance and the theoretical interpretability of the quantity variable.

Estimation Results

Final ARX model specifications are driven by considerations of statistical significance, Akaike's and Schwarz's Bayesian information criteria, and defensible interpretations of coefficients (e.g., quantity negatively affecting price). The variables labeled $L1$, $L2$, $L3$, $L4$ in the tables refer to coefficients on the lagged residuals comprising the autocorrelation process associated with the estimated price models.

Potatoes are the most substantially associated with the pandemic-related variables of the four fruits and vegetables studied, as is evidenced by the results in Table 2. All the COVID-19-related variables are negatively associated with potato prices and are statistically significant at conventional levels, with NYT articles, Tweets, and new COVID-19 deaths all significant at the 5% level, and the COVID-unemployed variable in close proximity to the 5% level. The positive and statistically significant effect of the more general unemployment rate variable is a countervailing effect that may represent an upward shift in demand due to a substitution effect towards less expensive foods, such as potatoes, during the pandemic. Of the four fruits and vegetables analyzed, potatoes are by far the most heavily utilized in the FAFH sector, with slightly over half of potato production generally directed to supplying FAFH outlets. Over two thirds of potato production is utilized to produce processed consumer potato products, and one fourth is destined for fresh consumption. Relative to percentages of domestic production, it is both the second-most exported and imported of the fruit and vegetable commodities analyzed. Overall, the results suggest that the decline in potato shipments through the FAFH market channel coupled with the concomitant increase in shipments through the FAH market channel, as well as changes in the balance of imports and exports, had an overall net negative effect on potato prices.

Table 3: Regression Results: Weekly Tomato Prices

Variable	**Coefficient**	**Std. Err**	**z**	**P>|*z*|**
Quantity(t-1)	-0.000044**	0.000211	-2.08	0.037
Time Trend	0.0580928***	0.0124224	4.68	0.000
New York Times Articles	-0.320748	0.2016701	-1.59	0.112
Tweets	-0.0439164	0.0769046	-0.57	0.568
New COVID-19 Deaths	-0.00018913***	0.0000578	-3.27	0.001
COVID-19 Unemployed	-9.13e-06*	5.29e-06	-1.73	0.084
Unemployment Rate	0.0873548	0.08585858	1.02	0.309
Constant	7.38486***	1.651521	4.47	0.000
L1	1.625163***	0.0751364	21.63	0.000
L2	-1.439829***	0.1310266	-10.99	0.000
L3	0.9722051***	0.1347078	7.22	0.000
L4	-0.352777***	0.0809827	-4.36	0.000
Sigma	0.8499448***	0.047541	17.88	0.000

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Sigma is the standard deviation of the residuals. N=211

Tomatoes are the second-most associated with the pandemic-related variables of the four fruits and vegetables analyzed. However, the estimated negative associations of the COVID-19-related variables with prices are not as consistent nor as pronounced for tomatoes as they are for potatoes, as is evident in Table 3. New COVID-19 deaths are negatively associated with prices, and the effect is statistically significant at any conventional significance level. The negative association with the COVID unemployed variable, which is directly attributed to COVID-19 policy shutdowns, is also statistically significant at the 10% level. The estimated negative relationship with NYT articles is insignificant at conventional levels but is at the cusp of significance at the .10 level, with a probability value of 0.11. The associations with COVID tweets and the general unemployment rate are statistically insignificant. We note that the signs and statistical significance of the associations with the COVID-19-related variables are consistent across the array of Box-Cox transformations on prices that were examined.

Tomatoes have a mixed utilization in FAH and FAFH settings, like potatoes, but substantially less production is channeled towards supplying the FAFH outlet. Moreover, a much greater percentage of US production is used for processing than for fresh consumption. Most fresh tomatoes are handpicked and sold on the open market, suggesting vulnerability to labor shortages, while essentially all processed tomatoes are mechanically harvested and sold under contract. Relative to domestic available supply, roughly equal amounts of tomato products are exported and imported but in somewhat lower percentage amounts than for potatoes. These differences likely contribute to the less pronounced effects of COVID-19-related variables on tomato prices compared to potatoes.

Based on the estimated ARX results in Table 4, the COVID-19-related variables have no notable association with strawberry prices. The estimated parameters on all of these variables are profoundly statistically insignificant. Regarding any associations with the pandemic, one might have initially expected them to be somewhat different for processed versus fresh strawberries. The onset of the COVID-19 lockdowns was characterized by hoarding behavior by consumers, and this behavior might at least partially explain the initial spike in the purchases of frozen strawberries at the outset of the pandemic, whereas the perishability of fresh strawberries would make hoarding notably less feasible.

Fresh strawberry availability does not appear to have been affected, perhaps due to its highly perishable nature and the urgency with which the product needs to be marketed. While strawberries are a labor-intensive crop (Calvin and Martin, 2012), and thereby might be affected

Table 4: Regression Results: Weekly Strawberry Prices

Variables	Coefficient	Std. Error	z-stat	p>|z|
Quantity (t-1)	-0.00052***	0.0000894	-5.93	0.000
Time Trend	0.0210612	0.0157443	1.34	0.181
New York Times Articles	-0.0021361	0.0027349	-0.78	0.435
Tweets	-0.1288726	0.1842961	-0.70	0.484
New COVID-19 Deaths	-9.18e-06	0.0001211	-0.08	0.940
COVID-19 Unemployed	3.62e-06	0.0000214	0.17	0.866
Unemployment Rate	0.1473597	0.356761	0.41	0.680
Intercept	15.58117***	2.403741	6.48	0.000
L1	1.200762***	0.063306	18.97	0.000
L2	-0.3538411***	0.067608	-5.23	0.000
Sigma	1.545557***	0.0600739	25.73	0.000

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Sigma is the standard deviation of the residuals. N=239

Table 5: Regression Results: Weekly Apple Prices

Variables	Coefficient	St. Err	z	P>|z|
Quantity(t-1)	- 0.0001587**	0.0000756	-2.10	0.036
Time Trend	0.0185651	0.0202139	0.92	0.358
New York Times articles	0.0005881	0.0079659	0.07	0.941
Tweets	-0.0447293	0.3345772	-0.13	0.894
New COVID-19 Deaths	0.000046	0.0002042	0.23	0.822
COVID-19 Unemployed	-9.43e-07	0.0000242	-0.04	0.969
Unemployment Rate	-0.1818342	0.4117681	-0.44	0.659
Constant	26.94927***	2.663446	10.12	0.000
L1	0.8554658***	0.0415959	20.57	0.000
L2	0.0109582	0.0500344	0.22	0.827
Sigma	1.36915***	0.0373558	36.65	0.000

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Sigma is the standard deviation of the residuals. N=239

by labor challenges such as social distancing, workers falling ill, and challenges to farms for obtaining H-2A visas for workers due to COVID-19, the USDA data does not show any sustained or appreciable reduction in the amount of strawberries shipped (Chenarides et al., 2021). Moreover, given that the large majority of strawberry purchases occur in FAH settings as opposed to FAFH outlets, lockdowns per se in the latter market would be expected to not have a substantial effect on the demand for strawberries in any product form. Finally, relative to the other fruits and vegetables analyzed, strawberries are the least exported and the most imported relative to the level of domestic production. Overall, these market characteristics result in strawberry prices being largely resilient and insulated from pandemic influences.

Similar to the case of strawberries, the ARX results in Table 5 suggest that the variables related to the COVID-19 pandemic have little-to-no demonstrable association with apple prices Like strawberries, the estimated parameters on all of these variables are profoundly statistically insignificant. At the pandemic's peak, outbreaks of COVID-19 were emerging on U.S. fruit and vegetable farms, as well as at packing and shipping plants. For example, by late May 2020 there were already 600 cases of COVID-19 among agricultural workers in Yakima County in Washington State. Of those, 62% were workers in the apple industry, which included those involved in packing operations and warehouses (Stephenson, 2020). However, unlike fresh strawberries, apples are readily storable for relatively long periods of time, and supply can quickly and flexibly adjust to changes in upstream demand. Moreover, like strawberries, apples have only minor use in FAFH settings, and so lockdowns affecting demand in FAFH settings would be expected to have little appreciable effect on the demand for apples. There are also ready opportunities to divert apples into a variety of other processed apple products, further supporting the long-term storability of apple products. Of all the fruits and vegetables analyzed, apples are the most exported and the least imported. And, like strawberries, although likely for somewhat different reasons, market characteristics for apple products are such that apple prices are largely resilient and insulated from pandemic influences.

Conclusions

At the beginning of the COVID-19 pandemic the United States economy faced a wide array of shocks that rippled through markets caused by both the disease itself, as well as policies enacted in response to the pandemic. Markets for perishable commodities such as fruits and vegetables experienced pandemic disruptions and effects that differed depending on product characteristics. Through the spring of 2020, the total number of agricultural workers infected by COVID-19 decreased partly due to sanitation and social distancing measures imposed at most packaging and shipping facilities. As more workers reentered the workforce, producers had the ability to redirect the focus of their supply chains more readily. Consequently, the effects of the COVID-19 pandemic on shipping point prices and quantities, by extension, were thought to be short-lived, lasting an average of only nine weeks (Weersink et al. 2021)

We identify a stark contrast in market impacts of the pandemic between food consumed away from home (FAFH) and food consumed at home (FAH). In particular, COVID-19 variables have little to no association with prices of crops whose end use is concentrated in FAH settings (strawberries and apples) compared to crops (potatoes and tomatoes) that have substantial usages in FAFH settings. Potatoes, which are consumed more in FAFH settings than any of the other fruits and vegetables studied, were most affected. Both social and traditional media messaging relating to the pandemic had negative and statistically significant associations with potato prices, which is consistent with previous research showing that media coverage can affect consumers' risk perceptions. There were also demonstrative negative associations with COVID-19 deaths and unemployment directly attributable to the pandemic. Tomatoes, which are used to a significant but notably lesser extent in FAFH outlets than potatoes, exhibited negative associations with COVID-19 deaths and unemployment directly attributable to the pandemic, but the negative relationship with media messaging was not as consistent nor pronounced. Overall, for both potatoes and tomatoes, observations on the direct detrimental effects of COVID-19 (deaths, pandemic-induced unemployment) were negatively associated with markets for both commodities. Media messaging related to COVID-19, its effect on heightened consumer awareness to the pandemic, and its impact on reduced consumers' willingness to participate in FAFH settings, had a demonstrable negative association with the potato market, and a negative but less compelling association with the tomato market.

In the endemic period and beyond, food prices have remained high. Labor shortages and other factors (including avian influenza) continue to challenge the food supply chain to some degree, and wages at the lower end of the spectrum have increased greater than the rate of inflation. Many people changed their habits, including not commuting to an office each workday. Restaurants, especially near central business districts, continue to struggle. The results of our analysis underscore that individual fruit and vegetable markets, as well as potentially other markets by extension, can face differential challenges during national economic shocks, in large part due to the idiosyncrasies of their supply chains and end-uses.

The COVID-19 pandemic highlighted the vulnerability of crop supply chains to sudden shocks, with impacts that varied widely across crops. Similar shocks in the future could result in comparable disruptions, exacerbating existing supply chain weaknesses and market disruptions. For apples and potatoes, strategies to mitigate these disruptions could include enhanced storage and transportation infrastructure. For strawberries and tomatoes, investment in labor-augmenting technologies and diversified market channels could reduce the risks of labor shortages exacerbated by perishability. Finally, awareness of the differential effects on markets resulting from policies enacted to address shocks can serve to inform policymakers about the relative needs of addressing varying degrees of financial hardships created by market disrupting actions.

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Appendix

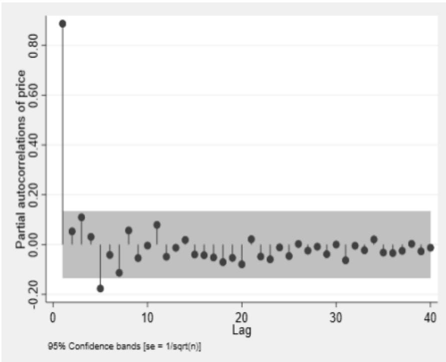

Figure A1a: Apple Partial

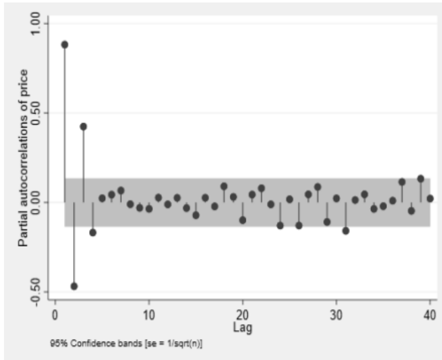

Figure A1b: Potato Partial Autocorrelation

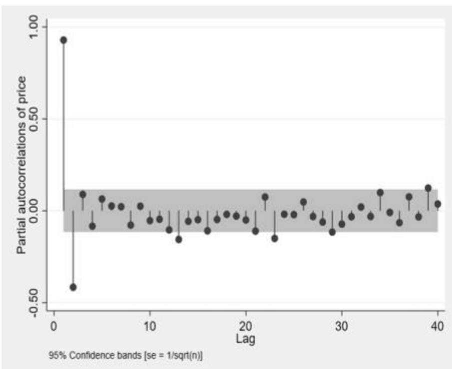

Figure A1c: Tomato Partial Autocorrelation

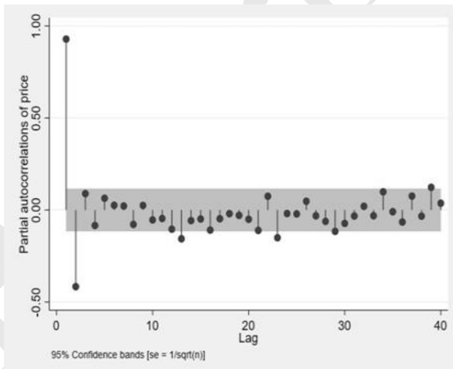

Figure A1d: Strawberry Partial Autocorrelation

Figure A1: PACF Plots

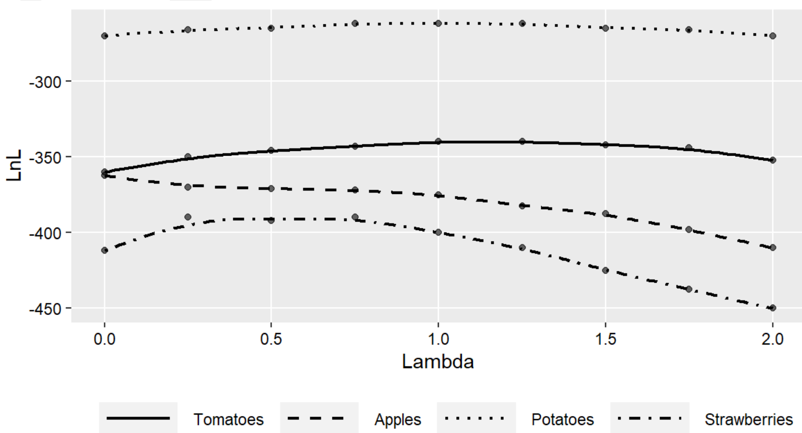

Figure A.2: Box Cox λ Values and Associated Ln(*L*) for Functional Forms

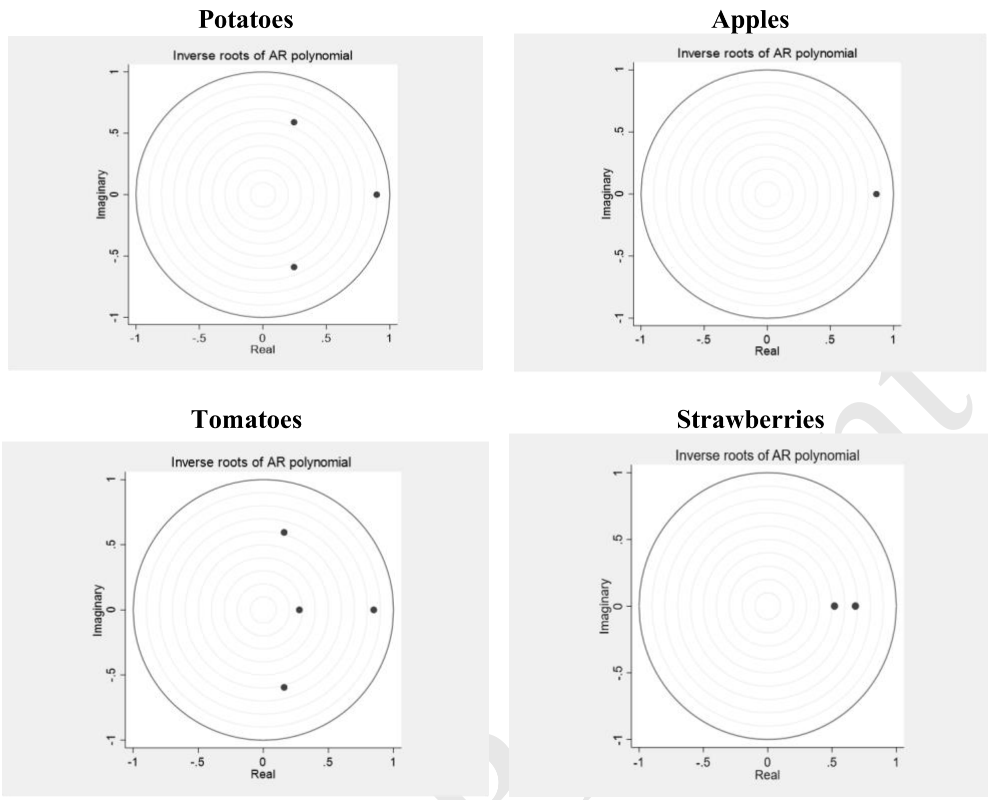

Figure A.3: Unit Circle Plots for Eigenvalues of AR Polynomials

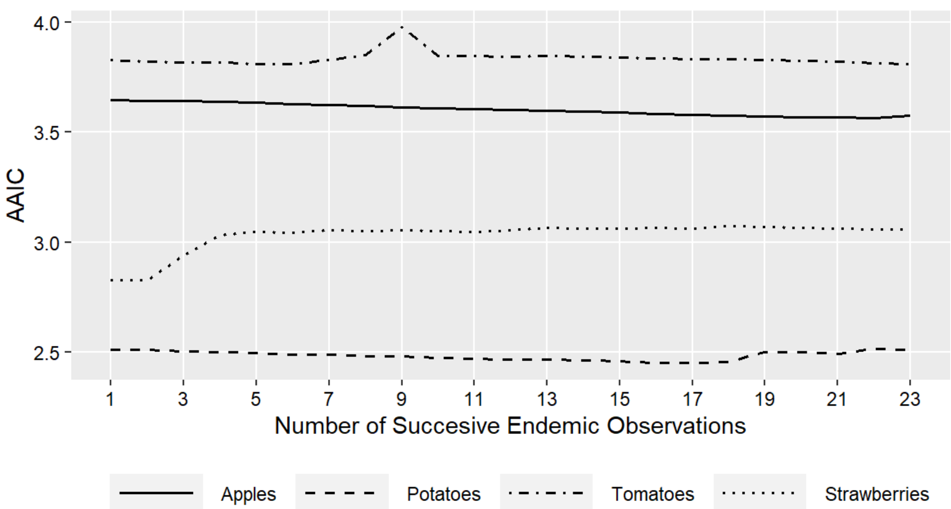

Figure A4: AAICs for Endemic Period Observations

Table A1: ADF Test Results: Prices

Series	ADF Statistic	P value	Stationary
Apples	-3.89**	0.0027	Yes
Potatoes	-3.03**	0.0322	Yes
Tomatoes	-6.94***	$1.04e^{-09}$	Yes
Strawberries	-4.26***	0.0005	Yes

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table A2: Chow Tests of Parameter Stability in the Post-Endemic Period

Series	Chow Statistic	P value
Apples	18.28^{***}	3.44e-08
Potatoes	28.34^{***}	6.09e-12
Tomatoes	0.83	0.44
Strawberries	2.22	0.11

Note: Chow tests assess the stability of coefficients in the post-endemic period, which defines the data breakpoint in the Chow test. Significant levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.