Weather Shocks and Diminishing Organic Premiums: An Analysis of the California Cherry Market[*]

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November 3rd, 2023

As the production of fruits and vegetables becomes more geographically concentrated, understanding the influence of increasingly frequent extreme weather events on the modern produce market remains a focus of researchers and policy makers. However, to the extent that conventional and organic markets are influenced differently by weather shocks remains an open empirical question. In this study, we focus on the California fresh cherry market and apply a quasi-experimental framework to investigate the impacts of extreme weather events on equilibrium prices at the downstream retail level as transmitted through the supply chain from upstream producers. Using store scanner data and USDA Agricultural Marketing Service data to identify production shocks due to weather, we find that local weather shocks lead to a 25% increase in overall cherry prices but reduce pre-shock organic premiums by 27% at the retailer level. Moreover, our results reveal that weather shocks of greater magnitude are associated with a more significant decrease in organic premiums, which implies that larger and more frequent climate shocks could lead to a further convergence of organic and conventional food prices. Our findings further show that a natural hedge of prices against yield shocks due to supply side disruptions may not fully apply in the case of organic produce production, which contributes to ongoing discussion on specialty crop insurance and support for organic production.

Key words: Weather shocks, modern supply chain, retailer prices, organic premiums, cherry

JEL Classification: Q11, Q13, Q18, Q54

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[*] The author thanks H. Allen Klaiber for his indispensable feedback and advice. The author also thanks Xiao Dong and Greg Astill from USDA ERS for their support with funding and data access under the USDA project of *Local and Organic Farming Systems in the United States*.

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1. Introduction

As food production is increasingly geographically concentrated, particularly for fresh fruits and vegetables (FV), disruptions such as extreme weather events, disease outbreaks, water scarcity and labor shortages in the primary production areas have substantial impacts on the agri-food systems (Splading et al 2023; Lim et al 2023; Rutledge and Mérel 2023; Arellano-Gonzalez and Moore 2020; Griffin et al 2015). It remains a pressing topic for researchers and policymakers to understand the impacts of these shocks to agri-food systems and the resulting disruptions in the food supply chain. (Kaminski et al 2013; Hadachek et al 2023). Perennial crops such as fruit and nut trees are long-term investments and incur high upfront establishment costs taking multiple years to reach marketable yields. As a result of these high costs, acreages of perennial crops are relatively stable due to less cropping flexibility (Witzel and Finger 2015; Price and Wetzstein 1999; Feinerman and Tsur 2014). Perennial crops are also inherently more exposed to adverse weather shocks because abandoning or fallowing land is very costly (Arellano-Gonzalez and Moore 2020).

An extensive body of literature studies the impacts of adverse weather events on food prices of commodity crops, but there is little attention given to seasonal fresh produce (Wimmer et al 2023; Lesk et al 2016; Xiao and Astill 2021). In addition, downstream costs in the context of modern supply chains are understudied relative to the impacts to upstream producers largely due to data limitations (Venkat and Masters 2022; Spalding et al 2023). In particular, the extent to which extreme weather events impact labor-intensive and perishable perennial crops with long-life cycles is missing from the literature. Weather shocks not only affect food prices by reducing crop yield and agricultural productivity but also through changes in product quality (Dalhaus et al 2020). One aspect that has seen little attention in the literature is whether produce price adjustments due to weather shocks depend on product differentiation. A recent study by Salazar et al (2023) provides some initial evidence in this regard by examining the impacts of droughts on two classes of tomatoes and potatoes in Chile finding that prices of high-quality products and less perishable products respond more intensively to droughts.

The organic food market has grown at a double-digit rate over the past two decades, both across the U.S. and globally, introducing significant new product differentiation in many agricultural product categories. In 2022, certified organic sales accounted for 6% of total food sales in the U.S. according to the Organic Trade Association (OTA)[1]. U.S. sales of organic food products reached $52 billion in 2021 with organic fruits and vegetables making up 40% of sales estimated at $19.2 billion (USDA ERS 2023). Organic markets present an emerging market opportunity for both farmers and retailers to seek higher profit margins given an average 20% price premium over conventional produce as well as market differentiation (Lin et al 2008). Organic acreage takes only 1 percent of farmland while organic farm sales account for about 3% of total farm receipts in 2019, suggesting the prevalence of high-value fruit and vegetables (11%) in the organic sector and substantial price premiums (ERS USDA 2023; Carlson et al 2023). Growing consumer interest in organic food brings opportunities as well as challenges to markets and supply chains, particularly for the nimble and dynamic local food system (Thilmany et al 2021).

Organic farmers face a number of challenges including high production costs, inability to access organic markets and uncertainty around future organic price premiums, among other issues (Strochlic and Sierra 2007). Organic premiums are the most cited challenge as organic farmers rely on these premiums to offset higher production costs to maintain profitability in spite of lower yields, higher risks of crop loss, and higher labor costs associated with pest management relative to conventional production (McBride et al 2015; Cakir et al 2022; McFadden and Huffman 2017; Klonsky 2012; Kuminoff and Wossink 2010). A price premium for organic commodities over the conventional counterparts is needed to incentivize producers' stable production of organic crops and attract new growers into the organic sector (Carlon et al 2023; Brady et al 2023).

Understanding organic premiums has significant welfare and policy implication for both producers and policymakers. Despite the rapid growth of organic markets, organic production still remains a tiny portion of overall food production. The volatility of organic prices is one of the most mentioned reasons underlying slow growth in organic production. For example, 42 percent of organic farms in California identify price issues as one of three major production challenges according to the 2021 Certified Organic Survey.[2] McFadden and Huffman (2017) argue that the higher production costs hinder growth in organic food production leading to higher imports whereas the current market structure continues to hinge on consumers willing to pay higher retail price for organic foods. From the consumer side, price is identified as the major perceived barrier

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[1] More details of Organic Trade Association can be found at https://ota.com/news/press-releases/22820#:~:text=The%20sector's%20four%2Dpercent%20growth,sales%20in%20the%20United%20States.

[2] Regulatory problems and production problems are another two major production challenges for organic farms according to the survey.

to purchase organic food (Aschemann-Witzel and Zielke 2017). Demand for organic food compared to supply and domestic sales of organic food have also significantly outpaced organic acreage (Organic Trade Association 2019), leading to increasing imports of organic foods (USDA ERS 2023; Kenner 2023).

There is a large body of literature studying organic premiums and consumer demand for foods such as tomatoes, carrots, milk, wine (Jaenicke and Carlson 2015; Carlson and Jaenicke 2016; Waldrop and McCluskey 2017; Huang and Lin 2007; Smith and Huang 2009). However, studies focusing on the supply of organic foods have received much less attention. The existing literature on supply of organic typically focuses on shifts in production costs but has not examined the role of weather shocks on organic premiums (Staudigel and Trubnikov 2022; Baker and Russell 2017; Jaenicke and Carlson 2015; Su and Cook 2015; Badruddoza et al 2022). For instance, Jaenicke and Carlson (2015) apply a two-stage hedonic model on retailer food prices and find that increases in cost factors of marketing and electricity increase conventional prices more than the organic price, leading to a drop in organic premium. Baker and Russell (2017) show that the price premium diminished for small grain crops which were difficult to manage. They argue that organic costs of production need to stabilize in order for organic crops to remain attractive for farmers, whereas the risks inherent in producing without the use of most chemical fertilizers and pesticides need to be mitigated. Su and Cook (2015) conduct a case study of Organic Valley and show that organic premiums reflect both the market conditions and production costs. Badruddoza et al (2022) document a decrease in organic egg premium in 2014-2015 due to an outbreak of avian influenza which affected both organic and conventional egg production but did not explicitly analyze the relationship.

Surprisingly, the literature has not explored the extent to which organic produce prices are affected by extreme weather events, a factor known to be particularly important for high-value and perishable fruits and vegetables. Organic produce may be particularly vulnerable to weather conditions as a consequence as domestic organic fruit and vegetable production is getting concentrated in specific regions such as California and Washington (Ro and Frechette 2001). Given that organic producers are bearing more input costs, investigating the heterogeneous impacts on organic producers is of importance for organic production (Lim et al 2023). However, the effects on organic produce market relative to conventional market in response to adverse weather events are not well understood. Catastrophic shocks caused by external events are beyond what farmers or markets can cope with and for which the insurance market often does not provide appropriate instruments or at very high premiums (Jensen and Barrett 2017).

In this study, we examine a highly perishable perennial crop, sweet fresh cherries,[3] which account for 5% of fresh produce sales on average during their 16-week domestic U.S. season (Nelson 2019). As a highly perishable produce, fresh cherries are marketed quickly after harvest with a very short shelf life and there is virtually no import of cherries during this time period due to geographic seasonality differences. The concentrated nature of domestic fresh cherry production in California and the Pacific Northwest makes them an ideal crop to study as linkages between weather shocks and retail outcomes can be precisely linked with little import competition.

We apply a quasi-experimental setup using two exceptional weather shocks to California cherry production to estimate the influence of shocks on retail prices and further explore the heterogeneous impacts differentiating between conventional and organic markets. Using store scanner data and USDA Agricultural Marketing Service data to identify production shocks owing to weather, we develop a series of difference-in-difference (DD) and difference-in-difference-in-difference (DDD) treatment effects models using weekly data on prices at retail stores in California to discern the impacts of adverse weather shocks on market prices as transmitted through the modern supply chain. We find that local weather shocks lead to a 25% increase in overall cherry prices but reduce pre-shock organic premiums by 27% at the retailer level. Moreover, our results reveal that weather shocks of greater magnitude are associated with a more significant decrease in organic premiums, which implies that larger and more frequent climate shocks could lead to a further convergence of organic and conventional food prices.

Our study contributes to literature and ongoing policy discussions in three important ways. First, our study is one of the first empirical papers using real market transaction data to study cherry market and analyze organic premium, which receives little attention in the literature. Second, we provide new empirical evidence on the impacts of temporary weather shocks on the long-run market equilibrium for fresh produce in the context of modern supply chain. Third, we highlight the disproportionate weather influence on organic prices relative to conventional prices, a topic which is particularly important for small and organic produce farms and a key policy focus in creating sustainable and local food systems.

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[3] In this study, we focus on sweet cherries, which makes up the vast majority of U.S. fresh-market cherries. The other category of fresh cherries are tart or "sour" cherries, which are mainly processed and used in cakes, pies, and tarts or dried for additional uses, primarily grown in Michigan.

2. California Cherry Market and Weather Shocks

Fresh sweet cherries are a highly perishable and seasonal fruit, which can only be stored for 2 to 4 weeks under controlled atmosphere and temperature. The taste of fresh cherries is closely related to freshness, and it is better to consume refrigerated cherries within a week after purchasing. Sweet fresh cherries are dominated by domestic production while imported cherries only make up 7% of domestic fresh cherry disappearance from 2011 to 2021 (Economic Research Service, U.S. Department of Agriculture 2022). The United States experienced steady growth in cherry production up to 2010, after which it has remained relatively stable albeit with annual fluctuations (Figure A1). The three leading states contribute 90% of the total domestic cherry acreage with Washington accounting for 40%, followed by California with 35% and Oregon with 14%, according to 2017 Census of Agriculture.[4] Figure 1 illustrates the primary production areas of fresh sweet cherries at the county level. Cherry production in California is highly concentrated in San Joaquin County which makes up about 50% of total production acreage. In contrast, cherry production in the PNW, encompassing Washington and Oregon, is spread widely across counties including Yakima (21% of total cherry acreage in PNW), Wasco (18%), Grant (14%), Clelan (10%) and Benton (11%). [5]

As a perennial crop, cherry takes over 4 years to bear an economic crop and 9 years to reach maturity, which require considerable higher costs associated with investment, management costs. Cherries are a most labor-intensive fruit as all cherries are harvested by hand. For a representative cherry farm in California, harvest costs including hand harvest and packaging ($11,781 per acre) contribute to 64% of total costs ($18,405) according to UC Davis cost studies[6]. Cherries from the field that meets market quality standards will be packed out and sold in the fresh market. In general, gross field yields are sorted, resulting in 75% fresh cherries pack out pending on weather, diseases, insects and crop yields. The remaining cherries will be diverted to various channels such as brining, peddler sales and discarded as culls.

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[4] According to 2017 Census of Agriculture, there are 105,978 acres of sweet cherries from 7,771 farms in the U.S Most cherry farms are small farms while large farms dominate production. 71% of US cherry farms are small farms with fewer than 5 acres yet 3% of large farms with more than 100 acres contribute to 50% of total cherry acreage.

[5] According to 2017 Census of Agriculture, there are 36,853 acres, 42,010 acres and 14,884 acres of sweet cherries in California, Washington, and Oregon respectively.

[6] More details about sample costs for sweet cherries in California can be found at https://coststudies.ucdavis.edu/en/current/commodity/cherries/

Cherries are among the most contaminated produce with pesticides according to Environmental Working Group[7]. Having organic cherries differentiates both retailers and farmers for sustainable and healthy commitment as well as price premiums over conventional options (Stagl 2002). Sweet cherries are among the top organically produced and sold fruits in the U.S. following grapes, apples, oranges, peaches and pears but receives very limited attention in the literature. According to the Organic Survey, the total gross value of organic cherry sales reach \$26.6 million in 2021, Organic cherries are generally 36% higher than regular cherries, equivalent to \$1.66 per pound (Weber et al 2023). In contrast to the rapid growth in other fruits, organic cherries have reached a plateau during the past decade. As reported in Table A1 based on the USDA Organic Survey, organic production acreage of sweet cherries only increases by 1% from 2011 to 2021, with 9% decline in organic farms and almost no growth in sales. Organic cherries only represent a small portion of total cherry production. Washington leads organic cherry production, making up 72 percent of harvested acres for domestic organic cherries according to the 2008 Organic Production Survey. As reported in Table A2, organic cherry farms make up 3.4% of total cherry farms, which slightly decreases from 4.9% in 2007 according to Census of Agriculture and Organic Survey.

The harvest season for cherries in California differs notably from that in PNW due to variation in climate and geographical features. California's cherry production is primarily centered in the San Joaquin Valley whereas the PNW sees its cherry production spread across both the Yakima and Wenatchee Valleys and situated at diverse elevations. Every year, California grown cherries first hit the market at the end of April or early May depending on weather. Early-season cherries from California typically command a higher price up to \$7.99 per pound given limited supply. California grown cherries dominate the market until mid-June after which cherries from the PNW take over. PNW cherries remain available until September, marking the close of the domestic cherry season. During the off-season when domestic cherries are unavailable, the California market is supplied with fresh cherries imported from the southern hemisphere. As shown in Table A3, 95% of imported cherries to California come from Chile while Argentina, New Zealand and Australia share the remaining 5% of imports. In this context, consumers in California typically encounter one of three choices at any given time: locally grown California cherries,

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[7] According to the 2023 Shopper's Guide by Environmental Work Group (EWG), cherries rank the 10th most contaminated produce out of 46 based on the testing data from the Department of Agricultural and Food and Drug Administration. More details can be found at https://www.ewg.org/foodnews/summary.php.

domestic but non-local cherries from the PNW, or imported cherries from the southern hemisphere, each signifying distinct cherry seasons.

Cherry production is facing severe climate change such as lower chill hours, unusual precipitation patterns. California cherries as particularly vulnerable to warming winters, with yields expected to decrease 20 percent by the year 2050 according to California Climate and Agriculture Network[8]. California cherries undergo distinct weather-driven production shocks in some years that are far beyond normal yield variation due to severely unfavorable weather conditions. As a result of insufficient chill hours, the total production of California cherries in 2014 decreased to 33,200 tons which is over 50% lower than average production of 66,650 tons. In 2018, due to the freezing weather during bloom, the total production of California cherries is 44,800 tons, a decrease of 33% relative to the average. Figure 2 shows the daily shipment of fresh cherries in California over the period of 2011 to 2018. The daily shipment volume in 2014 and 2018 is significantly lower than normal volume. Temporary weather shocks to California in a particular year would lead to supply shortages of California cherries in the shocked years while other factors of demand remain unchanged.

Additionally, we also use the average shipping point prices in each separate season to verify the presence of production shocks. Shipping Point prices are free on-board prices that represent open market sales by first handlers at point of production which represent the most uniform level of trading before any promotions or other incentives from retailers (Agricultural Marketing Service USDA 2023). We calculate the average value in each season following the same time frames as discussed above, i.e. California season (early May to Mid-June), PNW season (mid-June to early September) and off-season (November to February next year). As reported in Table A4, we observe an exceptionally high price in 2014 at $59 during the CA season while other prices largely remain stable during both PNW and off-season. In addition, there is no record in the 2018 CA season partly due to minimal supply from California.

We leverage exogeneous weather shocks as a quasi-experimental setup to explain the impacts of supply-driven shift on cherry prices. To empirically implement the quasi-experiment using regional weather shocks to cherry production, we first need to identify the treatment effects as seasonality in cherry production. Given harvesting seasons of three primary cherry production

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[8] See more discussions on warm winters, draughts and impacts on California fruit growers at https://calclimateag.org/fruit-growers-adapt-to-warmer-winters-drought/

areas typically do not overlap, we rely on seasonality to define cherry origins and treatment effects of regional adverse weather conditions. Specifically, we use different cherry seasons across primary production areas to indicate treatment effects as regional weather shocks only affect cherries produced in that region.

3. Data

There are several sources of data required to analyze the impact of production shocks on organic premiums. The primary dataset in our analysis is IRI InfoScan retail data on weekly sales of fresh cherries in California grocery stores. [9] To construct the data set on weekly prices of fresh cherries in each store, we first identify all sales of fresh cherries using the perishable product data based on the department "produce," category "fruit" and product name "cherries." It is noted that produce is not perfectly designed by Unique Product Codes (UPCs) as most produce including fresh cherries usually use price lookup codes (PLUs) with stickers, bands or ties. Thus, we define fresh cherries using perishable products description as "cherries" in the fresh produce department and obtain the list of IRI-generated "UPC". [10] IRI only provides limited information on perishable products compared to regular UPC-labelled products. For example, country or state of origins are often shown in PLU stickers attached to the produce itself or packages or placards in retail stores which are unobservable to researchers though as these are generally missing from the scanner data for produce. In addition, information about cherry size, shelf life, color and packaging are not available. We further limit our data to random-weight sales to reduce potential impacts of fixed-weight packaging in various formats. We next combine the filtered data for fresh cherries with store-level random-weight sales data by these generated "UPC" to identify all store-level weekly sales of fresh cherries. We then join with the store information data to obtain store information by unique store ids. We finally filter by California grocery stores and drop all other non-grocery stores.

Following discussion in the previous section, we rely on the seasonality of cherry production to identify the production origins. We obtain the weekly movement data from USDA Agricultural Marketing Service for movement. Specifically, our approach considers the following

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[9] The IRI data contains two separate data series including UPC-labelled packaged products and perishable products such as fresh produce, meat, deli and bakery. Fresh produce such as fresh cherries are covered in the random weight perishable data section.

[10] Fresh produce and other perishable products are different from other UPC-labelled products. Sales of perishable produce are reported at an aggregate level just above the individual item with similar products grouped together into one IRI-generated "UPC". And these generated UPCs are not unique across stores but can be applied to join multiple databases. It is noted that fresh produce like fresh cherries, cannot be distinguished by these UPCs.

three facts. First, the domestic cherry season spans from May to September, while the off-season imports from the southern hemisphere run from November to March of the following year. Due to their contrasting production cycles, there is limited overlap between the two. As such, cherry imports do not directly compete with domestic production, and therefore, are unlikely to affect the prices of domestically grown cherries. Second, in terms of two domestic seasons, we can use data on the weekly shipment volumes of fresh cherries to differentiate although we do not have detailed information on weekly production. As outlined in Table A4, we note that California and the PNW each have distinct and consistent harvest periods, with only slight overlaps annually. For instance, during the week of June 12th, 2012, California shipped 8,390 thousand pounds of fresh cherries, whereas PNW dispatched only 260 thousand pounds. However, in the following week of June 19th, shipments from the PNW surged to 9,720 thousand pounds, while California's volume dipped significantly to 1,170 thousand pounds. This shift helps pinpoint the transition from the California cherry season to the PNW season. Each year exhibits a similar pattern allowing us to distinguish between the seasons consistently. Lastly, it is very unlikely that fresh cherries from other regions with minimum production such as Michigan and New York sharing similar harvesting periods transport across the country and supply the California market.

Our final data set consists of 138,477 observations at the store-by-week level spreading across 1,001 individual stores with 13 distinct store names from 7 parent companies over 417 weeks from 2011 to 2018. Each observation describes sales information for fresh cherries including sales revenue and quantity, observed attributes of fresh cherries including varieties (golden rainier or regular red/black), organic claim (conventional or organic) [11], store characteristics such as unique store IDs, retailer names, parent company, channels, and geographical locations. Unit price is not directly available from the data set, and thus we divide the store weekly sales revenue by sales amount to obtain the unit price of fresh cherries (dollars per pound). Our primary explanatory variables of interest are the organic claim, which is observed from the data set denoted by a dummy variable.

Table 2 provides descriptions and summary statistics for cherry prices by key categories used in the analysis. The average price for conventional dark red cherries in California grocery stores is $4.81 per pound in the California cherry season and decreases to $3.58 per pound during

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[11] As with other produce commodities, fresh cherries characteristics are not well documented such as origin, package. To remain consist, we restrict to the random weight fresh cherries.

PNW season. During the off-season, the price increases to \$5.60 per pound, 33% higher than domestic in-season cherries. The lowest price is observed at \$1.97/pound in July 2018 while the highest at \$8.85/pound in December 2015. The organic attribute also plays a substantial role in product differentiation with up to a 62% price premium over conventional cherries as reported in Table 3. In addition, we observed noticeable seasonal price variations for fresh cherries. In general, cherry prices during the California season are 6.2% higher than off-season prices whereas during the PNW season, prices are 1.5% lower than those. Organic premiums are generally higher in the domestic season compared to off-season. In-season organic fresh cherries command the largest price premium in each year with the peak often happening during PNW peak time in July.

To analyze the weather effects on cherry prices by organic status, we summarize the average prices of conventional and organic cherries across different seasons in Table 3, which provides us some motivation. We further group normal years excluding two shocked years, i.e. 2014 and 2018, and draw the average premiums. California cherries also tend to have a substantial decrease in organic premium when California cherries production is significantly affected in 2014 and 2018 compared to controls years without adverse weather shocks. It is noted that in each year, shock only happens regionally and therefore treatment effects are defined by seasons.

4. Theory and Empirical Estimation

Adverse weather conditions are anticipated to have a negative effect on both conventional and organic cherry supply, but the overall impacts on organic premiums depend on whether the weather shock has a distinct impact on organic cherries in comparison to conventional ones. We apply Figure 3 to discuss the influence of exogenous weather shocks on the market equilibrium. Given organic and conventional farms have distinct cost functions and consumer demand for organic fruits differs from conventional options, we discuss the weather influence by differentiating the conventional and organic market considering both the supply side and demand side.

On the supply side, given distinct cost functions, it is anticipated that organic and conventional copping systems respond differently to exogeneous changes such as weather, pest and disease outbreaks due to increased production risks without using pesticides and fertilizer following production methods (Lien et al 2007; Lim et al 2023). Pest and disease management practices in organic production are more expensive and labor-intensive than conventional methods as organic farmers have to use more labor than conventional growers for weed suppression as they cannot use herbicides and fumigants (Calvin and Martin 2010; Galinato, Gallardo and Hong 2014; Burfield 2022). For example, Klonsky (2012) calculates the sample costs for the representative California farms and shows that the total cost of fertility, weed, pest, and disease control is higher for the organic systems than the conventional systems except for strawberries and lettuce.

Suppose in the conventional market, supply curve shifts from S_{CON} to S_{CON}^{*} [12] due to weather shocks, leading to a new market equilibrium at B. The equilibrium price increases from P_A to the new price at P_B. In the organic market, the organic supply curve is expected to shift substantially compared to conventional supply due to higher costs to achieve the same amount of quantity. That is, the change in supply curve consists of a shift from S_{ORG} to S'_{ORG} as well as a rotate from S'_{ORG} to S_{ORG}^{*}. And the new market equilibrium arrives at point D, with new equilibrium price of P_D.

On the demand side, consumer demand for organic fruits is highly elastic relative to conventional produce and consumers are substituting organic fruits for conventional fruits depending on relative prices[13] (Lin et al 2009; Lim et al 2023). In addition, consumers with a strong preference for organic fruits, tend to substitute to other organic fruits outside the same fruit type as they are committed to the 'organic lifestyle' (Zhang et al 2011). There are evidence from previous studies on the substitution relationship of local and organic food attributes (Thilmany et al 2008; Onozaka and McFadden 2011; Connolly and Klaiber 2014; Meas et al 2015). California consumers are likely to substitute locally produced cherries with the organic cherries as all fresh cherries are produced within the state during the season, resulting in an highly elastic demand compared to conventional cherry market.

Contingent on the distinct price elasticities of conventional and organic produce as well as different magnitude of the weather-driven supply shifts following organic and conventional production, weather shocks are anticipated to affect organic premiums in positive, negative or zero impacts. The price difference between organic P_C and conventional cherries P_A in the original market equilibrium (either in absolute value or in percentage), conditional on variety, store and seasonality, represents the organic premiums, i.e. $\Delta = P_C - P_A$, which is supposed to be positive.

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[12] There are no existing studies estimating the elasticities of supply for organic fruits and vegetables (McFadden et al 2021), and therefore we do not explicitly discuss the magnitude of supply response to weather shocks from the quantitative perspective but in a qualitative perspective.

[13] Estimates of price elasticity of organic cherries do not exist in the literature, and we reply on some recent studies on price elasticities of fruits and vegetables to assume an elastic organic demand relative to conventional counterparts (McFadden et al 2021; Lin et al 2009; Lim et al 2023)

During the period when production of cherries are reduced due to adverse weather conditions in the region, both organic and conventional cherry prices are impacted, leading to the change in premiums at $\Delta^* = P_D^* - P_B^*$. The price premiums of organic cherries during affected periods and during normal time form the basis for our primary DDD specification. If Δ is statistically different from Δ^*, the weather shocks are anticipated to influence organic versus conventional cherry market disproportionately.

Difference in Differences

The challenge of quasi-experimental setup is to identify a counterfactual group because all fresh cherries in the California market (domestic market as well) during the period come from California, which are affected by the weather shocks. We refer to recent studies dealing with similar difficulties to frame our quasi-experimental setting in time-time space (Cakir et al 2021; Gupta et al 2023; Aggarwal and Narayanan 2023). In particular, we choose normal years without adverse weather conditions as counterfactuals, that is, years of 2011-2013 and 2015-2017 serve as the comparison years while 2014 and 2018 as treatment unit. Further, we use the California season, generally from May to mid-June pending on each year, to partition post-treatment time periods while the rest of the time in the year as pretreatment time periods. In the modern produce market, market prices follow a long-run equilibrium prices as we observed in Figure 4, and cherry production in each year is separate from each other without cherry producer exit or entry in a short run as a perennial crop, which validates our setting of the quasi-experiment. We will revisit the common trends between control years and shocked years in the results section.

We apply a reduced form price function to examine whether cherry prices at the retailer level are affected by weather-driven production shocks. We first start with a baseline DD model by regressing observed cherry prices on a number of characteristics using a log-linear form and a fixed-effects approach as follows in Equation (1). We follow the literature to apply the most commonly used log-linear functional form to account for the possible non-linear curvature of the price function (Aldy and Viscusi 2008). A log-linear specification also simplifies the interpretation and comparison of results across models (Ray et al 2022).

$$lnP_{jst} = \alpha_0 + \alpha_1 ShockYear_t + \alpha_2 CAseason_t + \alpha_3 (ShockYear \times CAseason)_t + \alpha_4 Organic_j + \beta Rainier_j + \delta_{st} + \varepsilon_{jst} \quad (1)$$

Where lnP_{ist} is the natural log of the price of fresh cherries j (dollar per pound, \$/lb) sold in store s at week t. $ShockYear_t$ is a dummy variable that takes value one if the prices are observed in shocked years of 2014 and 2018, and zero otherwise. $CAseason_t$ are dummy variables indicating the California cherry season which vary by weeks in each year, which control for the trends over seasons and capture the influence is not contaminated by an underlying seasonality trends in shocked and control years. We have additional control variables for organic claim and variety. $Organic_j$ equals 1 if the cherry is organically labelled and zero indicates conventional cherries. The dummy variable $Rainier_j$ equals one if the cherry is golden rainier and zero if black red varieties. In addition, we add month and year fixed effects to take care of time variation of prices as well as store level fixed effects across stores to account for any store or store brand level variation such as store's overhead and labor costs, transportation, local consumers characteristics etc. Year and month fixed effect absorb additional price variation over time such as price inflation. We also control for store brand (ie. retail banners) by month effects to account for potential storewide promotions in a particular month. ε is a stochastic error term.

Specifically, coefficient estimate of α_1 measures the average price during shocked years relative to other normal years. α_2 measures the price difference on average across seasons in each year, controlling for seasonality in a year. The coefficient α_3 associated with interaction terms, capture the average impacts of the regional weather shocks on cherry prices relative to the average value of cherry prices in the same season in control years, after accounting for all other factors that influence the price.

Our most interesting explanatory variable is $Organic$. We follow the literature to define the organic premium as the relative premium of organic cherry prices relative to conventional cherry prices in percentage, i.e. $[(P_{organic} - P_{conventional})/P_{conventional}] \times 100$ (Carlson and Jaenicke 2016). Given all our explanatory variables are dummy variables, the resulting coefficients no longer represent the percentage change in price corresponding to a dummy category (McConnell and Stran 2000; Chang, Lusk and Norwood 2010 Palmquist AER cite here.). The percentage effect of organic claim on cherry prices is measured by $(e^{\alpha_2} - 1) \times 100$[14], which

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[14] In the semi-log linear price function, we obtain the implicit price of a specific attribute by taking the derivative of price with respect to the attribute $\frac{\partial P(z)}{\partial z}$ in the case of a continuous variable z. If z is a dummy variable, the implicit price is obtained by $lnP(z_1) - lnP(z_0) = \alpha z_1$ where z_1 and z_0 here indicates whether the product has the attribute or not. After a simple algebra, the resulting $(\exp(\alpha) - 1) \times 100\%$ measures the percentage price change in the presence of the dummy attribute z.

implies the relative premiums of organic cherry prices compared with conventional cherries in percentage.

Difference in Differences in Difference

We are most interested in exploring how do the impacts vary differently on organic cherries versus conventional cherries. Considering distinct cost functions in organic farming, asymmetric cost transmission through the supply chains as well as demand elasticity compared to the conventional market, we further apply a set of DDD specifications to capture the heterogeneous impacts in Equation (2).

$$\begin{aligned} lnP_{jst} = {} & \alpha_0 + \alpha_1 ShockYear_t + \alpha_2 CAseason_t + \alpha_3 (ShockYear_t \times CAseason_t) \\ & + \alpha_4 Organic_j + \alpha_5 \left(Organic_j \times ShockYear_t\right) + \alpha_6 \left(Organic_j \times CAseason_t\right) \\ & + \alpha_7 \left(Organic_j \times ShockYear_t \times CAseason_t\right) + \beta Rainier_j + \delta_{st} + \varepsilon_{jst} \quad (2) \end{aligned}$$

α_9 is the coefficient on triple difference terms which measures the difference in price affected by the adverse weather shocks during the California season between conventional and organic cherries. Similarly, α_{10} captures the DDD estimate of weather shocks during $PNWseason$ on organic premiums, which measures the change in organic premiums in response to production shocks while other attributes are held constant. Our hypothesis is that weather shocks have heterogeneous impacts on organic and conventional cherries given different production costs and consumer demand. Therefore, we anticipate that the coefficient α_7 is statistically different from zero with a negative sign.

5. Results

Difference in Differences

Before we discuss results, we first examine the fundamental assumption of parallel trends as with other DD identifications. We need to validate whether the conventional and organic cherry prices conditional on controls and absent of weather shocks, share common trends in two ways. Figure 4 plots the weekly cherry prices in shocked years and control years. Outside California season when the treatment effect happens, prices trends are very similar, and both lines display strong seasonality with systematic and predictable variation in both price and quantity throughout each calendar year. When fresh sweet cherries from California first hit the market in late April or early

May, their prices tend to be exceptionally high due to limited supply and novelty effects. However, as the California cherry season progresses, prices begin to decline. By early July, when PNW cherries are at their peak, cherry prices typically reach their lowest. As the domestic cherry season nears its conclusion, prices start to rise again.

Turning to our primary results, results of the baseline DD estimates are reported in Table 4 with varying fixed effects at store or brand levels in the first five columns. Overall, the model fits the data well with R^2 ranging from 0.474 without any store level fixed effects. Once we include the store brand by month fixed effects to account for potential brand-level promotions in each month, R^2 increase to 0.633. Results are in line with price trends with consistent estimates across specifications. We rely on the preferred specifications in Column (4) for discussion.

We are most interested in the interaction terms $ShockYear \times CAseason$. We find a consistently positive impact. When California cherry market is affected during weather shocked periods, cherry prices increase by 25% $((\exp(0.222) - 1) * 100)$ compared to control years. Organic claim is statistically significant in all specifications. Our results show that organic cherries command a price premium of 45% (i.e. $[exp\ (0.373) - 1] * 100\%$) over regular cherries, which aligns with previous studies on price premiums of organic fruits using Nielsen data (Lin et al 2008; Carlson and Jaenicke 2016). Lin et al (2008) reports a wide range between 20% for grapes to 42% for strawberries, and fresh produce with greater seasonality commands a higher organic premium. The golden rainier variety commands a larger price premium at 49% (0.401 coefficient) over regular dark red varieties as expected.

Difference in Differences in Difference

Before we discuss the DDD estimation results, we again begin with examining the common trends in treatment and control years of conventional cherry prices and organic prices. That is, the price movements of conventional cherry prices in control years and shocked years follow a similar trend outside California season, and organic cherry prices do the same. In Figure 5, we extend the results from Figure 4 to include the price trends of organic cherries. We therefore have four groups following the DDD model. We can see that both conventional and organic prices follow similar trends during the time before California season, which is affected by adverse weather events. Conventional prices return to long-run equilibrium after California season whereas organic prices remain notably high throughout the following PNW season. It is also noted that the organic premiums in shocked years, marked as the difference between two solid lines, is substantially smaller than the gap between two dashed line for control years. We also plot residuals of regressing logged prices on the same set of explanatory variables in Equation (2) (except for those pertaining to treatment, i.e. $ShockYear$ and $Organic$) in Figure A2. We also observed similar price trends of conventional and organic cherry during domestic season through organic prices are more volatile in shocked years.

Table 5 presents the empirical estimates of our DDD model following Equation (2). To further examine whether the magnitude of production shocks would influence organic premiums differently, Organic premiums shrink substantially following the production shocks. The first column reports the full sample, and the second column drops off-season observations to focus on domestic cherries. The coefficient estimates of the interaction terms of $ShockYear \times CAseason$ remains consistent with DD estimation in Table 4, which suggests retailer price increase by 26% compared to normal years. The estimated treatment effects of triple interaction term of $ShockYear \times CAseason \times Organic$ from the DDD model in both identifications are almost the same with negative signs at 1% significance level. The results reveal that organic premiums of fresh cherries decrease by 27% (coefficient -0.308) in response to the weather shocks. Our findings are in line with studies suggesting that higher-quality products such as organic experience higher price fluctuations at the face of droughts than in conventional food markets (Salazar et al 2023).

Considering the different magnitude of weather shocks in 2014 and 2018, we further distinguish between the two sperate shocks and examine their impacts respectively. The coefficients on interaction terms $Shock2014 \times CAseason$ and $Shock2018 \times CAseason$ measure DD estimates and coefficients of $Shock2014_t \times Organic_j \times CAseason_t$ and $Shock2018_t \times Organic_j \times CAseason_t$ represent our DDD estimates of two separate shocks on organic premiums. Cherry prices appear to respond to the magnitude of weather shocks in a positive way. More interesting, we find a similarly negative impact on organic premiums, though the extent of effects differs with a larger premium reduction in 2014 by 32% (coefficient -0.386) compared to 18% (coefficient -0.199) in 2018. Our results suggest that as cherry production faces more severe weather shocks, retail prices escalate more steeply, accompanied by a more pronounced reduction in the price premiums for organic cherries. Our analysis reveals that weather shocks of greater magnitude are associated with a more significant decrease in organic premiums, which highlights the potential impact of climate variability on market dynamics, particularly in sectors characterized by product differentiation, such as organic and conventional produce. Our findings align with previous studies showing that climate shocks may trigger food price convergence in non-homogeneous agricultural markets, which has been less studied in the literature (Bittmann et al 2020a, 2020b; Salzar et al 2023).

To test for the joint significance of interaction terms in DD and DDD models, we use the Wald test with robust standard errors to account for potential presence of heteroscedastic or clustered errors.[15] Results are reported in Table A6. Specifically, we first test the joint significance of weather shocks on cherry prices, that is whether coefficients of $ShockYear$ and $ShockYear \times CAseason$ (i.e. $\alpha_1 + \alpha_3$) from Equation (1) are jointly zero. The resulting F-statistic is statistically different from zero at 1% level, indicating that weather shocks impact the cherry market. In terms of heterogeneous impacts on organic cherries, we conduct another two sets of tests to explore the joint significance following Equation (2). In particularly, we test the joint significance of $\alpha_5 + \alpha_7$ (i.e. $Organic \times ShockYear$ and $Organic \times ShockYear \times CAseason$), as well as $\alpha_1 + \alpha_3 + \alpha_5 + \alpha_7$ (i.e. $ShockYear + (ShockYear \times CAseason) + (Organic \times ShockYear) + (Organic \times ShockYear \times CAseason)$) separately. Both sets of results are statistically significant, which confirms the heterogeneous impacts on organic cherry prices.

Robustness

In our main analysis, we do not explicitly incorporate retailer's markup but rather use store or retailer banner fixed effect as well as interaction of month by banner. When retailers do not compete in a single product category, Xiao (2008) argues that we can assume retailers set prices with the fixed markup rule and retail prices are determined non-strategically. Hauman and Leonard (2002) and Slade (1995) also provide evidence that retailers are competing through product quality or overall pricing policies, but not pricing individual commodities strategically. The marketing literature also explores price dynamics assuming fixed markup within a retail chain (Lan et al 2022; Nijs et al 2009). Following the line of literature, it is safe to assume that observed retailer prices are set as a fixed markup over the wholesale price. We conduct another two sets of robustness checks by focusing on a single retailer banner and one parent company. As present in Table 6, the results are very consistent with our main results except for slight change in magnitude.

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[15] There are other alternative tools such as likelihood-ratio test, F-test, Chow test. But all these tests assume independent and identically distributed normal errors.

6. Discussion and Conclusions

With increasing frequency and intensity of extreme weather events, the agri-food system is exposed to growing challenges from producers to retailers throughout the supply chain as weather-induced costs pass through to retail prices. We apply a quasi-experimental setup using two exceptional weather shocks to California cherry production to estimate the impact of shocks on retail prices and further explore the heterogeneous impacts on organic market prices. Our results show that retailer prices increase by 25% following the weather shocks. However, we also find that organic premiums decrease by 27%, reducing the gap between conventional and organic prices. These impacts are also shown to increase in magnitude with the size of the weather shock, suggesting increasing impacts over time as weather shocks become more frequent and of greater magnitude due to climate change.

Our study highlights the disproportionate risks confronted by organic producers, particularly for the highly valuable fruit and vegetable market, because a natural hedge to supply side disruptions may not fully apply in the case of organic produce production given their distinct production costs and potential greater negative impacts on quality. Organic farmers are exposed to elevated risks as they bear a larger burden of quality risk in addition to yield risk. Because organic farmers face higher production costs associated with organic farming but lower organic premiums in the case of weather shocks, a natural hedge driven by price increases may not fully offset their costs, leading to potentially significant profit losses.

In light of ongoing efforts of USDA to enhance crop insurance options for specialty crops and organic producers, our study provides empirical evidence of the price risks induced by extreme weather events. Importantly, we highlight the disproportionate impacts of weather shocks on organic producers. Currently, the Risk Management Agency (RMA) runs a cherry insurance program to protect growers against losses from low yields, low prices, low quality, or any combination of these events (USDA 2022). The RMA issues annual prices for each crop year to determine revenue to count for certain appraised or unsold marketable production.[16] However, quality differentiation between organic food versus conventional food is not incorporated in the policy, which results in fewer organic farmers entering the organic sectors as they may face higher

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[16] For sweet fresh cherries in 2022, the annual price for California cherries is $2.30 per pound, and cherries from all other states are at $1.63 per pound. Crop price for other sweet cherries for processing can be also found at https://www.rma.usda.gov/en/Policy-and-Procedure/Bulletins-and-Memos/2023/PM-23-017

potential risks. This is consistent with the fact that the number of organic cherry farms decreased during the past two decades in California and across the U.S. as reported in Table A1.

Our study also sheds light on the price transmission of perishable fruit and vegetables in the modern produce market in response to weather shocks, which remains overlooked in the literature except for a few studies examining the events of disease outbreaks (Durborow et al 2016; Splading et al 2023; Lim et al 2023) Moreover, climate change increasingly compels defensive investments (e.g., pesticide, labor) by small farmers to protect crops, generating costly tradeoffs with productivity-enhancing inputs such as inorganic fertilizer, which has been recognized as one of the upcoming challenges to agri-food systems (Barrett 2021). As organic farmers are confronted with competition from imported off-season produce as well as volatility in price premiums due to external shocks, our study emphasizes the importance of considering the unique price risks organic farmers face in light of accelerating climate change.

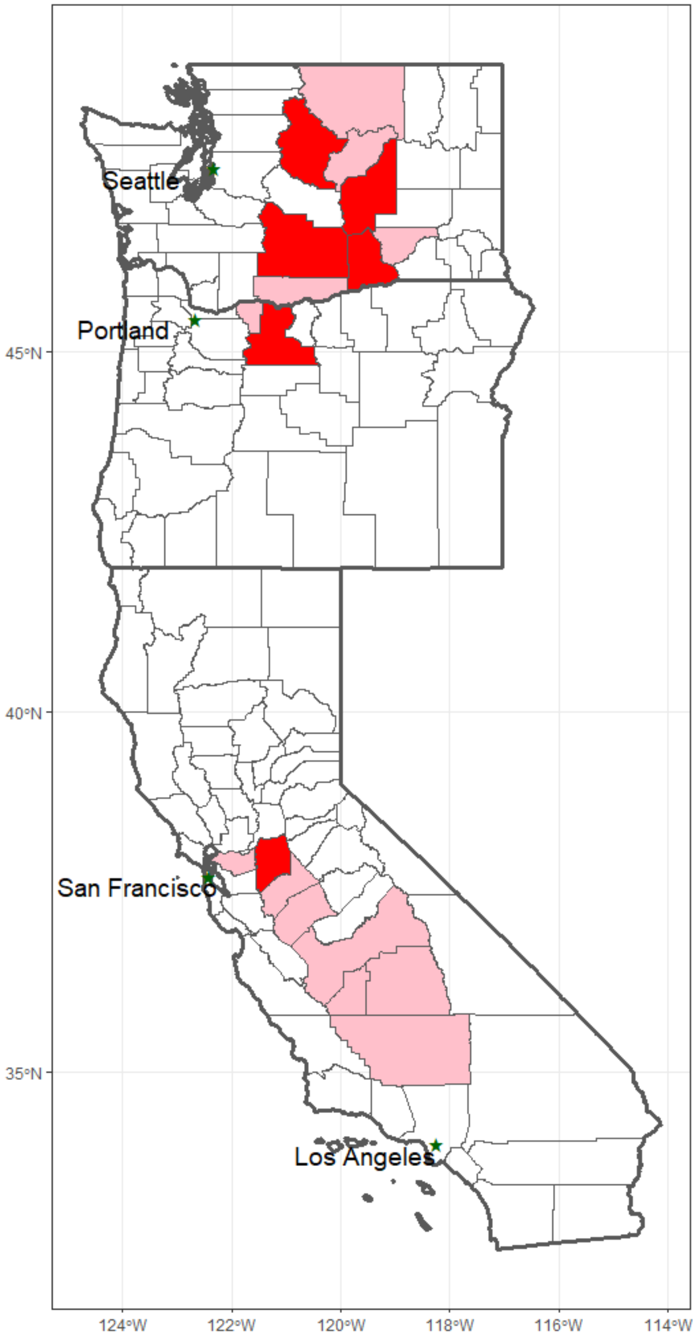

Figure 1 Primary Sweet Cherry Producing Areas in the United States

Note. This map depicts the primary sweet cherry producing counties according to 2017 Census of Agriculture. Light shaded area indicates counties with larger than 1,000 acres of sweet cherries while dark shaded area are counties having more than 5,000 acres of cherries. Note that the San Joaquin County as dark shaded area in California, has the largest acreage of sweet cherries at 17,698 acres in the U.S., taking up almost half of California cherry acreage. Cherry production in Washington and Oregon is widely distributed in several areas as marked in dark shade.

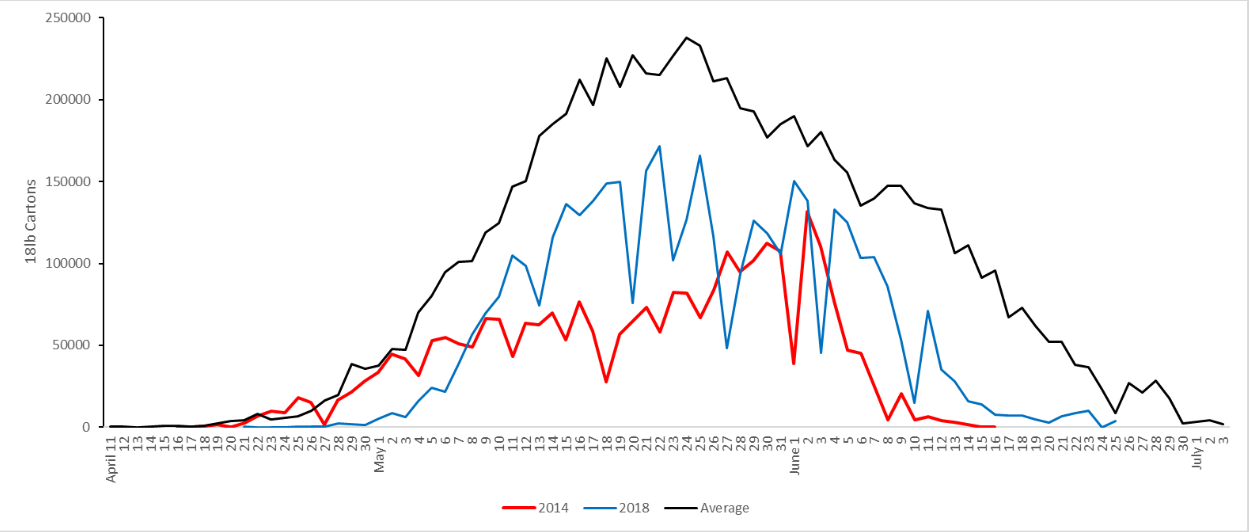

Figure 2. Daily Shipment of Sweet Cherries in California, 2011-2018

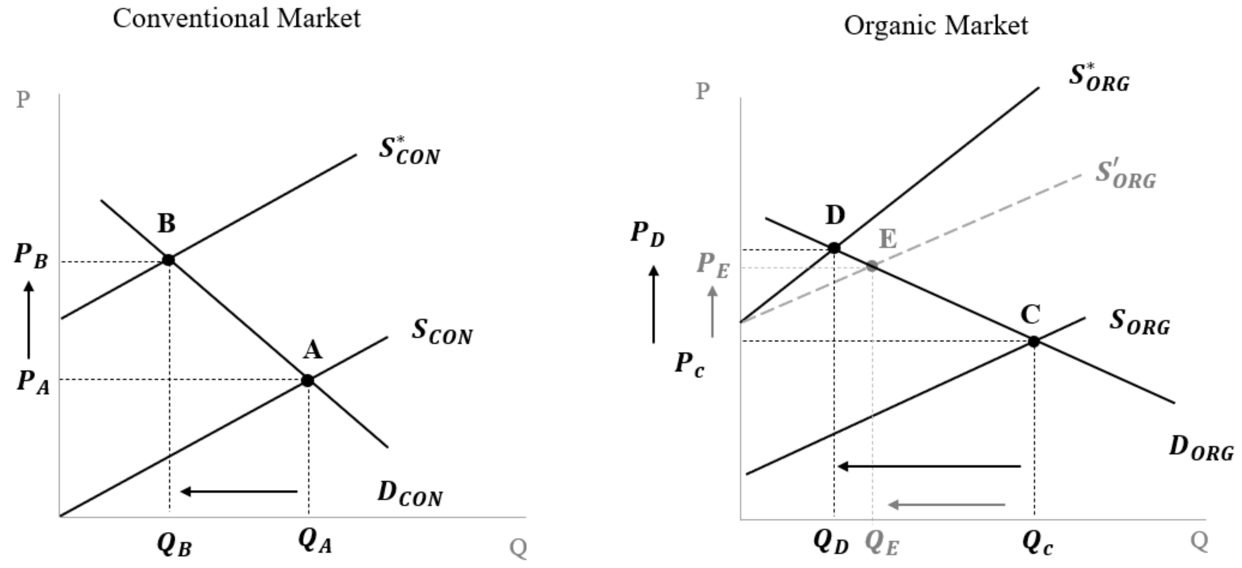

Figure 3. Framework of Conventional and Organic Market with Supply-Side Shift

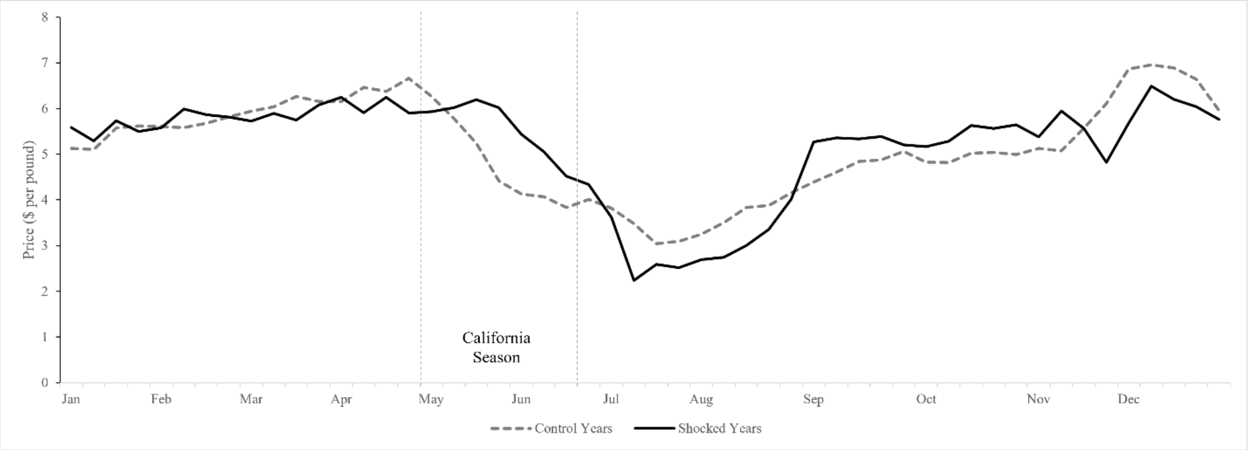

Figure 4. DD Trends for Weekly Prices of Fresh Cherries in California

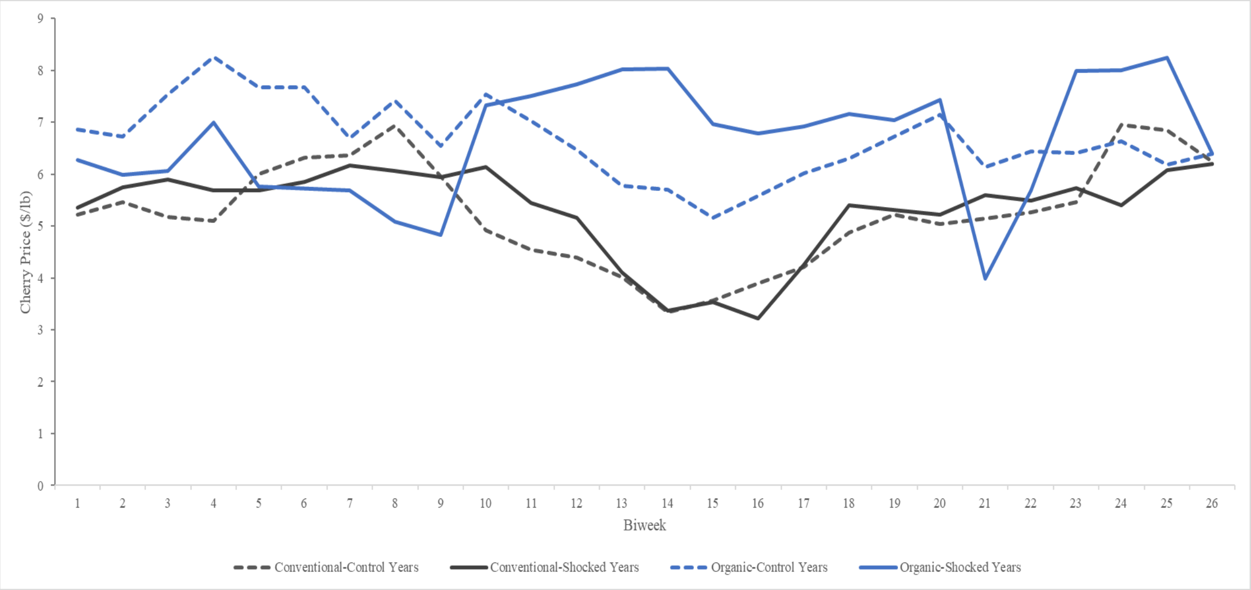

Figure 5 DDD Trends of Average Prices Relative to Weather Shocks and Organic Status

Table 1. Cherry Production in California

	Bearing (Acres)	Production (Tons)	Yield (Tons per acre)	Fresh Market (Tons)	Total Shipments (Tons)
2011	30,000	68,000	2.27	57,000	54,289
2012	31,000	92,300	2.98	78,000	75,533
2013	33,000	82,000	2.48	70,000	70,000
2014	33,000	33,200	1.01	25,000	24,141
2015	33,000	60,100	1.82	53,300	53,039
2016	33,000	55,000	1.67	47,400	46,032
2017	33,000	97,800	2.96	86,600	86,001
2018	32,000	44,800	1.4	35,660	35,653
2019	33,000	56,400	1.71	48,500	50,395
2020	33,000	66,700	2.02	59,360	59,247

Note. Production data are based on California Agricultural Statistics Review 2021-2022. Total Shipments are obtained from California Cherries Daily Shipment Report.

Table 2. Summary Statistics of Fresh Cherries Prices in California Market, 2011-2018

	Variety	Season	N	Mean ($ /lb)	Standard Deviation	Organic Premium ($ /lb)	Organic Premium (%)
Conventional	Red Varieties	California	25,958	4.65	1.33		
		Pacific Northwest	52,422	3.52	1.24		
		Off-season	34,828	5.60	1.40		
	Rainier	California	4,344	6.74	1.07		
		Pacific Northwest	12,333	5.71	1.34		
		Off-season	2,305	6.91	1.18		
Organic	Red Varieties	California	564	5.94	1.06	1.29	27.7%
		Pacific Northwest	5,107	5.83	1.15	2.31	65.6%
		Off-season	251	6.62	1.14	1.02	18.2%
	Rainier	California	18	8.79	0.66	2.05	30.4%
		Pacific Northwest	310	8.53	1.05	2.82	49.4%
		Off-season	37	7.45	1.41	0.54	7.8%

Note. Each observation (N) is store-by-week sales. There is a total of 138,477 store weekly sales of fresh cherries in California grocery stores, including 1,001 individual stores with 13 distinct store brand names from 7 retail companies over 417 weeks. Season is defined based on weekly shipment according to USDA Agricultural Marketing Service. Premium ($) measures the price difference between organic cherries and conventional cherries, whereas premium measured by percentage (shown in parenthesis in the last column) is calculated by (organic price - conventional price)/conventional price *100.

Table 3. Organic Premiums of Dark Red Cherries

	Conventional ($/lb)	Organic ($/lb)	Premium ($/lb)	Premium (%)
Control Years				
CA Season	4.46	5.87	2.11	43.24
PNW Season	3.60	5.71	1.76	44.56
Off-season	5.57	6.62	1.20	21.31
Shocked Years				
CA Season	5.47	6.92	0.94	16.40
PNW Season	3.25	7.07	3.35	85.24
Off-season	5.71	6.55	0.89	15.48

Note. Control years include six years of 2011-2013 and 2015- 2017

Table 4. Impacts of Weather Shocks on California Cherry Prices, 2011-2018

	Dependent variable ln(p)				
	Full Sample				Drop off-season
	(1)	(2)	(3)	(4)	(5)
ShockYear	-0.288***	-0.203***	-0.028***	-0.019***	-0.118***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)
CAseason	0.054***	0.068***	0.073***	0.069***	0.052***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
ShockYear*CAseason	0.291***	0.270***	0.242***	0.222***	0.259***
	(0.006)	(0.005)	(0.004)	(0.004)	(0.005)
Organic	0.346***	0.510***	0.372***	0.373***	0.410***
	(0.005)	(0.004)	(0.004)	(0.003)	(0.004)
Rainier	0.384***	0.498***	0.394***	0.401***	0.453***
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Constant	1.471***	1.657***	1.677***	1.619***	1.751***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.014)
Year FE	YES	YES	YES	YES	YES
Month	NO	YES	YES	NO	NO
Store Brand	NO	NO	YES	NO	NO
Chain*Month FE	NO	NO	NO	YES	YES
N	138,477	138,477	138,477	138,477	101,056
R2	0.193	0.474	0.587	0.633	0.619
DD estimate	33.8%	31.0%	27.4%	24.9%	29.6%

Note. *p<0.1**p<0.05***p<0.01. There is a total of 138,477 observations at the store-by-week level spreading across 1,001 individual stores with 13 distinct store names from 7 parent companies over 417 weeks over eight years from 2011 to 2018. Last column drops off-season observations to only focus on domestic cherry prices.

Table 5. DDD Estimates of Heterogeneous Impacts in the California Cherry Market, 2011-2018

	Dependent variable ln(p)	
	Full Sample (1)	**Drop off-season (2)**
ShockYear	-0.024***	-0.126***
	(0.003)	(0.004)
CAseason	0.074***	0.057***
	(0.003)	(0.004)
ShockYear*CAseason	0.228***	0.268***
	(0.004)	(0.005)
Organic	0.363***	0.399***
	(0.004)	(0.004)
Organic*ShockYear	0.148***	0.169***
	(0.009)	(0.009)
Organic*CAseason	-0.127***	-0.148***
	(0.011)	(0.012)
Organic*ShockYear*CAseason	-0.308***	-0.332***
	(0.041)	(0.043)
Rainier	0.401***	0.454***
	(0.002)	(0.002)
Constant	1.620***	1.747***
	(0.004)	(0.014)
Year FE	YES	YES
Brand*Month FE	YES	YES
N	138,477	101,056
R2	0.634	0.622
DD estimate	25.6%	30.7%
DDD estimate	-26.5%	-28.3%

Note. *p<0.1**p<0.05***p<0.01. Last column drops off-season observations to only focus on domestic cherry prices.

Table 6. Impacts of Varying Weather Shocks on the California Cherry Market, 2011-2018

	Dependent variable ln(p)			
	Full Sample		**Drop off-season**	
	DD	**DDD**	**DD**	**DDD**
Shock2014	0.050***	0.037***	-0.016***	-0.035***
	(0.003)	(0.003)	(0.004)	(0.004)
Shock2018	-0.015***	-0.015***	-0.116***	-0.118***
	(0.003)	(0.003)	(0.004)	(0.004)
CAseason	0.069***	0.075***	0.051***	0.057***
	(0.003)	(0.003)	(0.003)	(0.004)
Shock2014*CAseason	0.242***	0.256***	0.266***	0.284***
	(0.006)	(0.006)	(0.006)	(0.006)
Shock2018*CAseason	0.203***	0.202***	0.252***	0.253***
	(0.006)	(0.006)	(0.006)	(0.006)
Organic	0.373***	0.362***	0.410***	0.399***
	(0.003)	(0.004)	(0.004)	(0.004)
Organic*Shock2014		0.221***		0.230***
		(0.011)		(0.011)
Organic*Shock2018		0.033**		0.075***
		(0.013)		(0.014)
Organic*CAseason		-0.126***		-0.147***
		(0.011)		(0.012)
Organic*Shock2014*CAseason		-0.386***		-0.395***
		(0.051)		(0.053)
Organic*Shock2018*CAseason		-0.199***		-0.241***
		(0.066)		(0.068)
Rainier	0.400***	0.400***	0.453***	0.453***
	(0.002)	(0.002)	(0.002)	(0.002)
Constant	1.620***	1.622***	1.751***	1.745***
	(0.004)	(0.004)	(0.014)	(0.014)
Year FE	YES	YES	YES	YES
Brand*Month FE	YES	YES	YES	YES
N	138,477	138,477	101,056	101,056
R2	0.633	0.635	0.619	0.622
DD estimate – 2014 Shock	27.4%	29.2%	30.5%	32.8%
DD estimate – 2018 Shock	22.5%	22.4%	28.7%	28.8%
DDD estimate – 2014 Shock		-32.0%		-32.6%
DDD estimate – 2018 Shock		-18.0%		-21.4%

Note. *p<0.1**p<0.05***p<0.01. Last two columns drops off-season observations to only focus on domestic cherry prices.

Table 7. Robustness Checks, 2011-2018

	Dependent variable ln(p)	
	Parent Company (1)	**Store Brand (2)**
ShockYear	-0.032***	-0.026***
	(0.005)	(0.006)
CAseason	0.057***	0.060***
	(0.006)	(0.007)
ShockYear*CAseason	0.165***	0.162***
	(0.008)	(0.010)
Organic	0.285***	0.287***
	(0.006)	(0.007)
Organic*ShockYear	0.232***	0.230***
	(0.010)	(0.012)
Organic*CAseason	-0.100***	-0.102***
	(0.013)	(0.016)
Organic*ShockYear*CAseason	-0.263***	-0.260***
	(0.040)	(0.050)
Rainier	0.361***	0.361***
	(0.003)	(0.004)
Constant	1.671***	1.684***
	(0.009)	(0.006)
Year FE	YES	YES
Brand*Month FE	YES	YES
N	36,273	22,338
R2	0.503	0.505
DD estimate	17.9%	17.6%
DDD estimate	-23.1%	-22.9%

Note. *p<0.1**p<0.05***p<0.01. Results in (1) are based on stores under the same parent company while (2) are restricted to the same store brand. Standard errors are robust standard errors clustered at stores.

Appendix

Table A1. Harvested Acreage, Quantity and Sales of Organic Certified Fruits in the United States

	Harvested Acreage (acre)			**Harvested Farms**			**Total gross value of sales (thousand $)**		
	2011	2021	Change (%)	2011	2021	Change (%)	2011	2021	Change (%)
Grapes	31,771	42,283	33	515	774	50	160,625	309,221	93
Apples	13,363	31,002	132	377	756	101	122,213	628,773	414
Strawberries	1,638	5,301	224	356	546	53	66,472	335,964	405
Blueberries, Tame/Cultivated	2,780	12,372	345	279	611	119	39,744	220,529	455
Oranges, All	6,610	4,780	-28	233	288	24	34,155	33,262	-3
Sweet Cherries	1,965	1,988	1	133	121	-9	26,535	26,634	0
Pears	1,990	3,635	83	171	281	64	27,507	26,211	-5
Lemons	1,740	5,092	193	138	319	131	13,471	40,497	201
Peaches	2,735	3,206	17	182	231	27	20,025	51,666	158

Note. Data are based on 2011 and 2021 Organic Survey by USDA.

Table A2 Organic Cherry Farms

	Year	Organic Farms	Total Farms	Share
California	2007	55	1,115	4.9%
	2012	38	975	3.9%
	2017	33	985	3.4%
Washington	2007	121	1,992	4.9%
	2012	80	1,763	3.9%
	2017	79	1,606	3.4%
USA	2007	279	6,687	4.9%
	2012	160	5,677	3.9%
	2017	154	5,696	3.4%

Note. The number of cherry farms are based on Organic Survey while total number of cherry farms are based on Census of Agriculture.

Table A3 Imported Conventional Fresh Cherries to California by Origins (10,000 pounds)

Year	Chile	Argentina	Australia	New Zealand	Total
2010	977	0	0	0	977
2011	772	15	0	0	787
2012	352	0	0	0	352
2013	414	0	0	0	414
2014	355	0	0	1	356
2015	174	0	11	8	193
2016	192	4	26	21	243
2017	366	7	15	34	422
2018	418	39	0	2	459
Period	mid-Nov to mid-Feb next year	early Nov to late Dec	mid-Jan to early Feb	early Jan to mid Feb	

Note. Values are based on weekly movement of fresh cherries imported into California including Los Angles and San Fransico via air or Long beach and Oakland via boat according to Agricultural Marketing Service, U.S. Department of Agriculture retrived on September 1st, 2023 from https://www.ams.usda.gov/market-news/custom-reports

Organic cherry prices at farm gate level, wholesale level, shipping point and terminal market level are unavailable in 2014 and 2018 California cherry seasons from AMS. Retail level prices are reported by regions such as the Southwest region, which is not comparable to our results.

Table A4. Weekly Shipment Volumes and Definition of Cherry Seasons

Date_firstday	Date	IRIweek	CA(10,000lb)	NW(10,000lb)	season
5/1/2011	5/7/2011	1652	186	NA	CA
5/8/2011	5/14/2011	1653	704	NA	CA
5/15/2011	5/21/2011	1654	1669	NA	CA
5/22/2011	5/28/2011	1655	2199	NA	CA
5/29/2011	6/4/2011	1656	1734	NA	CA
6/5/2011	6/11/2011	1657	812	NA	CA
6/12/2011	6/18/2011	1658	839	26	CA
6/19/2011	6/25/2011	1659	117	972	CA
6/26/2011	7/2/2011	1660	11	2537	CA
7/3/2011	7/9/2011	1661	NA	3919	NW
7/10/2011	7/16/2011	1662	NA	4187	NW
7/17/2011	7/23/2011	1663	NA	3894	NW
7/24/2011	7/30/2011	1664	NA	3037	NW
7/31/2011	8/6/2011	1665	NA	2819	NW
8/7/2011	8/13/2011	1666	NA	2516	NW
8/14/2011	8/20/2011	1667	NA	1714	NW
8/21/2011	8/27/2011	1668	NA	568	NW
8/28/2011	9/3/2011	1669	NA	255	NW
9/4/2011	9/10/2011	1670	NA	12	NW
4/29/2012	5/5/2012	1704	13	NA	CA
5/6/2012	5/12/2012	1705	250	NA	CA
5/13/2012	5/19/2012	1706	854	NA	CA
5/20/2012	5/26/2012	1707	923	NA	CA
5/27/2012	6/2/2012	1708	1726	NA	CA
6/3/2012	6/9/2012	1709	2616	49	CA
6/10/2012	6/16/2012	1710	1966	587	CA
6/17/2012	6/23/2012	1711	919	2419	CA
6/24/2012	6/30/2012	1712	49	3726	CA
7/1/2012	7/7/2012	1713	NA	4307	NW
7/8/2012	7/14/2012	1714	NA	4487	NW
7/15/2012	7/21/2012	1715	NA	4047	NW
7/22/2012	7/28/2012	1716	NA	4115	NW
7/29/2012	8/4/2012	1717	NA	3357	NW
8/5/2012	8/11/2012	1718	NA	2812	NW
8/12/2012	8/18/2012	1719	NA	1499	NW
8/19/2012	8/25/2012	1720	NA	656	NW
8/26/2012	9/1/2012	1721	NA	333	NW
9/2/2012	9/8/2012	1722	NA	17	NW
9/9/2012	9/15/2012	1723	NA	12	NW
4/21/2013	4/27/2013	1755	13	NA	CA

4/28/2013	5/4/2013	1756	139	NA	CA
5/5/2013	5/11/2013	1757	975	NA	CA
5/12/2013	5/18/2013	1758	1446	NA	CA
5/19/2013	5/25/2013	1759	2498	NA	CA
5/26/2013	6/1/2013	1760	1824	2	CA
6/2/2013	6/8/2013	1761	1050	175	CA
6/9/2013	6/15/2013	1762	48	1091	CA
6/16/2013	6/22/2013	1763	0	2327	NW
6/23/2013	6/29/2013	1764	NA	3063	NW
6/30/2013	7/6/2013	1765	NA	2791	NW
7/7/2013	7/13/2013	1766	NA	3020	NW
7/14/2013	7/20/2013	1767	NA	3710	NW
7/21/2013	7/27/2013	1768	NA	2979	NW
7/28/2013	8/3/2013	1769	NA	1571	NW
8/4/2013	8/10/2013	1770	NA	762	NW
8/11/2013	8/17/2013	1771	NA	254	NW
8/25/2013	8/31/2013	1773	NA	60	NW
4/20/2014	4/26/2014	1807	47	NA	CA
4/27/2014	5/3/2014	1808	195	NA	CA
5/4/2014	5/10/2014	1809	272	NA	CA
5/11/2014	5/17/2014	1810	432	NA	CA
5/18/2014	5/24/2014	1811	418	NA	CA
5/25/2014	5/31/2014	1812	607	18	CA
6/1/2014	6/7/2014	1813	580	527	CA
6/8/2014	6/14/2014	1814	89	2194	CA
6/15/2014	6/21/2014	1815	NA	4314	NW
6/22/2014	6/28/2014	1816	NA	5559	NW
6/29/2014	7/5/2014	1817	NA	4290	NW
7/6/2014	7/12/2014	1818	NA	6186	NW
7/13/2014	7/19/2014	1819	NA	5348	NW
7/20/2014	7/26/2014	1820	NA	4093	NW
7/27/2014	8/2/2014	1821	NA	1863	NW
8/3/2014	8/9/2014	1822	NA	853	NW
8/10/2014	8/16/2014	1823	NA	261	NW
8/17/2014	8/23/2014	1824	NA	192	NW
8/24/2014	8/30/2014	1825	NA	37	NW
8/31/2014	9/6/2014	1826	NA	11	NW
9/7/2014	9/13/2014	1827	NA	8	NW
4/19/2015	4/25/2015	1859	46	NA	CA
4/26/2015	5/2/2015	1860	422	NA	CA
5/3/2015	5/9/2015	1861	1094	NA	CA
5/10/2015	5/16/2015	1862	1568	NA	CA
5/17/2015	5/23/2015	1863	1962	NA	CA

5/24/2015	5/30/2015	1864	1322	282	CA
5/31/2015	6/6/2015	1865	301	2004	CA
6/7/2015	6/13/2015	1866	19	3443	CA
6/14/2015	6/20/2015	1867	NA	4790	NW
6/21/2015	6/27/2015	1868	NA	5307	NW
6/28/2015	7/4/2015	1869	NA	3702	NW
7/5/2015	7/11/2015	1870	NA	3809	NW
7/12/2015	7/18/2015	1871	NA	2444	NW
7/19/2015	7/25/2015	1872	NA	1419	NW
7/26/2015	8/1/2015	1873	NA	998	NW
8/2/2015	8/8/2015	1874	NA	152	NW
8/9/2015	8/15/2015	1875	NA	57	NW
8/16/2015	8/22/2015	1876	NA	13	NW
8/23/2015	8/29/2015	1877	NA	4	NW
4/10/2016	4/16/2016	1910	3	NA	CA
4/17/2016	4/23/2016	1911	102	NA	CA
4/24/2016	4/30/2016	1912	821	NA	CA
5/1/2016	5/7/2016	1913	1724	NA	CA
5/8/2016	5/14/2016	1914	1775	NA	CA
5/15/2016	5/21/2016	1915	1082	NA	CA
5/22/2016	5/28/2016	1916	745	NA	CA
5/29/2016	6/4/2016	1917	194	1144	CA
6/5/2016	6/11/2016	1918	NA	3343	NW
6/12/2016	6/18/2016	1919	NA	4418	NW
6/19/2016	6/25/2016	1920	NA	4933	NW
6/26/2016	7/2/2016	1921	NA	5214	NW
7/3/2016	7/9/2016	1922	NA	3931	NW
7/10/2016	7/16/2016	1923	NA	3103	NW
7/17/2016	7/23/2016	1924	NA	2077	NW
7/24/2016	7/30/2016	1925	NA	1002	NW
7/31/2016	8/6/2016	1926	NA	448	NW
8/7/2016	8/13/2016	1927	NA	237	NW
8/14/2016	8/20/2016	1928	NA	205	NW
8/21/2016	8/27/2016	1929	NA	9	NW
4/23/2017	4/29/2017	1964	26	NA	CA
4/30/2017	5/6/2017	1965	400	NA	CA
5/7/2017	5/13/2017	1966	1868	NA	CA
5/14/2017	5/20/2017	1967	2264	NA	CA
5/21/2017	5/27/2017	1968	2776	NA	CA
5/28/2017	6/3/2017	1969	2325	NA	CA
6/4/2017	6/10/2017	1970	1254	NA	CA
6/11/2017	6/17/2017	1971	173	1376	CA
6/18/2017	6/24/2017	1972	0	4197	NW

6/25/2017	7/1/2017	1973	NA	4582	NW
7/2/2017	7/8/2017	1974	NA	4396	NW
7/9/2017	7/15/2017	1975	NA	4724	NW
7/16/2017	7/22/2017	1976	NA	3464	NW
7/23/2017	7/29/2017	1977	NA	4591	NW
7/30/2017	8/5/2017	1978	NA	3754	NW
8/6/2017	8/12/2017	1979	NA	1989	NW
8/13/2017	8/19/2017	1980	NA	1256	NW
8/20/2017	8/26/2017	1981	NA	908	NW
8/27/2017	9/2/2017	1982	NA	835	NW
9/3/2017	9/9/2017	1983	NA	85	NW
4/22/2018	4/28/2018	2016	2	NA	CA
4/29/2018	5/5/2018	2017	39	NA	CA
5/6/2018	5/12/2018	2018	609	NA	CA
5/13/2018	5/19/2018	2019	1067	NA	CA
5/20/2018	5/26/2018	2020	1161	NA	CA
5/27/2018	6/2/2018	2021	743	NA	CA
6/3/2018	6/9/2018	2022	715	809	CA
6/10/2018	6/16/2018	2023	209	2845	CA
6/17/2018	6/23/2018	2024	NA	4978	NW
6/24/2018	6/30/2018	2025	NA	5996	NW
7/1/2018	7/7/2018	2026	NA	5069	NW
7/8/2018	7/14/2018	2027	NA	5004	NW
7/15/2018	7/21/2018	2028	NA	4688	NW
7/22/2018	7/28/2018	2029	NA	3540	NW
7/29/2018	8/4/2018	2030	NA	2684	NW
8/5/2018	8/11/2018	2031	NA	1032	NW
8/12/2018	8/18/2018	2032	NA	602	NW
8/19/2018	8/25/2018	2033	NA	521	NW
8/26/2018	9/1/2018	2034	NA	47	NW
9/2/2018	9/8/2018	2035	NA	7	NW
9/9/2018	9/15/2018	2036	NA	3	NW

Source: Agricultural Marketing Service, U.S. Department of Agriculture. Data is retrieved on August 15th, 2023 from https://www.ams.usda.gov/market-news/custom-reports

Table A5 Average Shipping Point Prices of Conventional Fresh Cherries ($)

Year	CA Season	PNW Season	Imported
2011	47.29	35.86	31.46
2012	42.22	26.68	39.41
2013	38.75	40.89	35.08
2014	59.03	33.74	34.84
2015	44.24	40.10	42.54
2016	50.06	44.62	39.79
2017	45.09	33.35	38.09
2018	NA	33.91	39.64

Note. Shipping Point prices are free on board prices that represent open market (spot) sales by first handlers at point of production San Joaquin Valley or port of entry in California on fresh cherries of generally good quality and condition. The shipping point prices represent the most uniform level of trading before any promotions or other incentives from retailers. We calculate the average prices in each season based on the date where California seasons range from early May to Mid-June, followed by Pacific Northwest season until early September and imported season from November to February next year. Observations are unavailable in 2018 California season. More details can be found at https://cat.ams.usda.gov/app/main#/dashboards/

Table A6 Wald Tests of Interaction Terms in DD and DDD models

Hypothesis: $ShockYear + ShockYear \times CAseason = 0$
Model 1: restricted model
Model 2: $lnP_{jst} = \alpha_0 + \alpha_1 ShockYear_t + \alpha_2 CAseason_t + \alpha_3 (ShockYear_t \times CAseason_t) + \alpha_4 Organic_j + \beta Rainier_j + \delta_{st}$

Res.Df	RSS	DF	Sum of Sq	F	Pr(>F)
138317	8556.5				
138316	8351.6	1	204.9	3393.5	<2.2e-16***

*p<0.1**p<0.05***p<0.01.

Hypothesis: $(Organic_j \times ShockYear_t) + (Organic_j \times ShockYear_t \times CAseason_t) = 0$
Model 1: restricted model
Model 2: $lnP_{jst} = \alpha_0 + \alpha_1 ShockYear_t + \alpha_2 CAseason_t + \alpha_3 (ShockYear_t \times CAseason_t) + \alpha_4 Organic_j + \alpha_5 \left(Organic_j \times ShockYear_t\right) + \alpha_6 \left(Organic_j \times CAseason_t\right) + \alpha_7 \left(Organic_j \times ShockYear_t \times CAseason_t\right) + \beta Rainier_j + \delta_{st}$

Res.Df	RSS	DF	Sum of Sq	F	Pr(>F)
138315	8317.7				
138314	8316.8	1	0.84681	14.083	0.0002***

*p<0.1**p<0.05***p<0.01.

Hypothesis: $ShockYear_t + (ShockYear_t \times CAseason_t) + \left(Organic_j \times ShockYear_t\right) + \left(Organic_j \times ShockYear_t \times CAseason_t\right) = 0$
Model 1: restricted model
Model 2: $lnP_{jst} = \alpha_0 + \alpha_1 ShockYear_t + \alpha_2 CAseason_t + \alpha_3 (ShockYear_t \times CAseason_t) + \alpha_4 Organic_j + \alpha_5 \left(Organic_j \times ShockYear_t\right) + \alpha_6 \left(Organic_j \times CAseason_t\right) + \alpha_7 \left(Organic_j \times ShockYear_t \times CAseason_t\right) + \beta Rainier_j + \delta_{st}$

Res.Df	RSS	DF	Sum of Sq	F	Pr(>F)
138315	8317.1				
138314	8316.8	1	0.31967	5.3163	0.021**

*p<0.1**p<0.05***p<0.01.

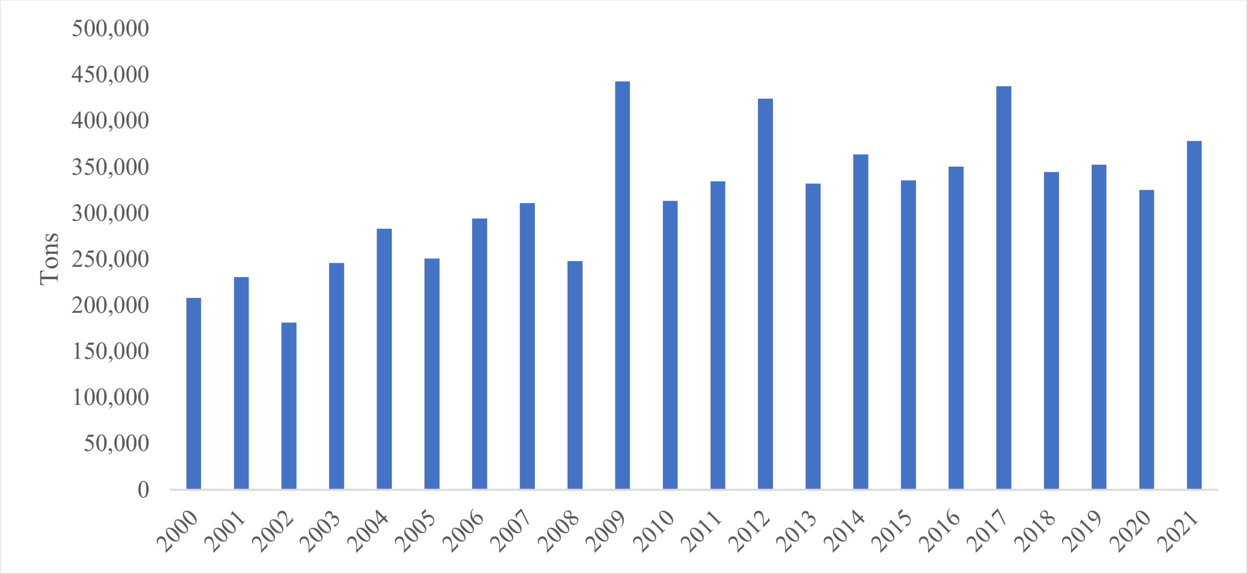

Figure A1. Production of Fresh Sweet Cherries in United States, 2000-2021

Data Source: USDA, National Agricultural Statistics Service, Noncitrus Fruits and Nuts Summary, various issues at https://www.ers.usda.gov/webdocs/DataFiles/54499/FruitYearbookNoncitrusFruit_BTables.xlsx?v=1553.4

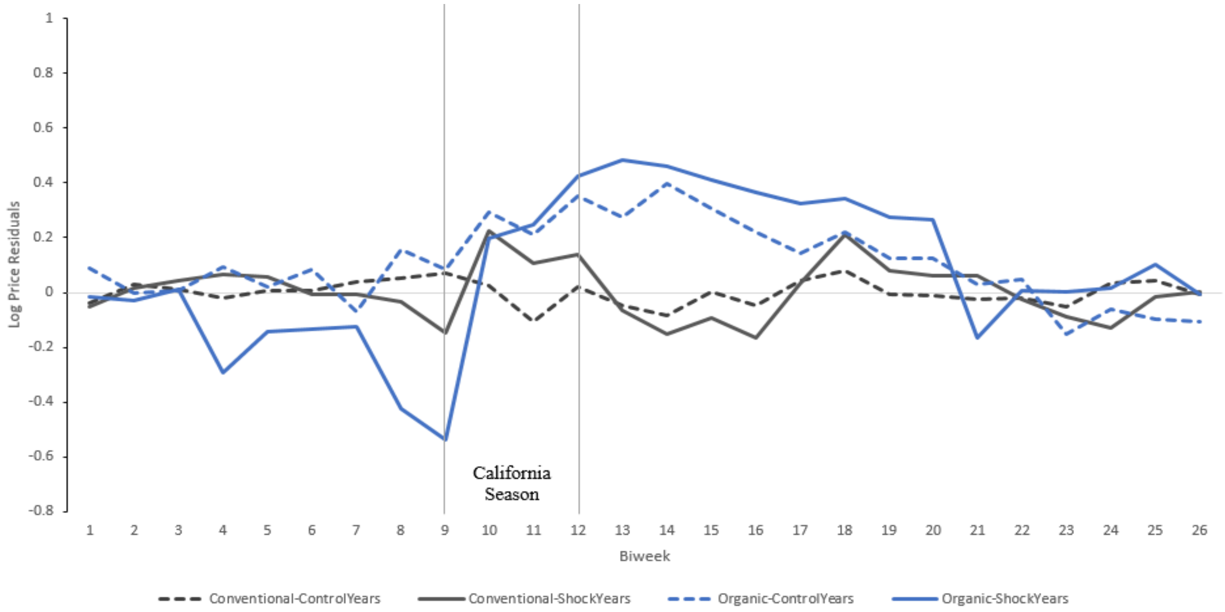

Figure A2 Residual Plot of Cherry Prices Relative to Weather Shocks and Organic Status

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