Postharvest Losses from Weather and Climate Change: Evidence from a Million Truckloads

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Abstract

We estimate the effect of weather and climate change on postharvest losses using proprietary data on 1.2 million truckloads of processing tomatoes in California. Our reduced-form estimation strategy compares processing tomatoes that originate from the same field in the same growing season but experience different weather and traffic conditions during transit. Hot temperatures during transportation damage product quality and lead to lower producer revenue, particularly if hot temperatures coincide with heavy traffic. We predict climate change will increase postharvest losses by century's end absent additional adaptation. We add to prior work focused on the effects of extreme weather and climate change on farm production with little attention paid to what happens when products leave the farm. Hot temperatures during transportation cause about three times more damage than equivalent exposure during the growing season.

Keywords: quality, postharvest losses, climate change

JEL codes: Q12, Q54, C23

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For every dollar spent on food, about 14.9 cents goes to farms while the remaining 85.1 cents goes to the rest of the food supply chain (USDA ERS, 2022). Yet most work on climate change and adaptation in agriculture focuses on farm production, often the effect of growing-season temperature on staple-crop yields. Though postharvest activities add most of a product's value, we know little about the effect of climate change on agricultural products after they leave the farm.

We bring together novel data and methods to measure the effect of weather and climate change on postharvest losses. We focus on California's $1 billion processing-tomato industry, which produces a quarter of the world's tomatoes destined for processing (henceforth processing tomatoes) (CDFA, 2022; WPTC, 2024). We use granular, high-frequency data on 1.2 million truckloads of processing tomatoes transported from fields to processing facilities in trucks without refrigeration or covers. Truckloads originate from thousands of fields owned by hundreds of independent farmers in California between 2011 and 2020. For each truckload, we observe the date and time the load was inspected, the tonnage of tomatoes that meet a minimum quality threshold, individual quality attributes and how they affect price, and identifiers that link each truckload to its field and grower. We identify each truckload's likely driving route between field and processing-facility coordinates using OpenRouteService (2023). We match each truckload to hourly observations of temperature (UCLA NCAR, 2023) and traffic conditions (Caltrans Performance Management System, 2023) along its route in the hour before delivery.

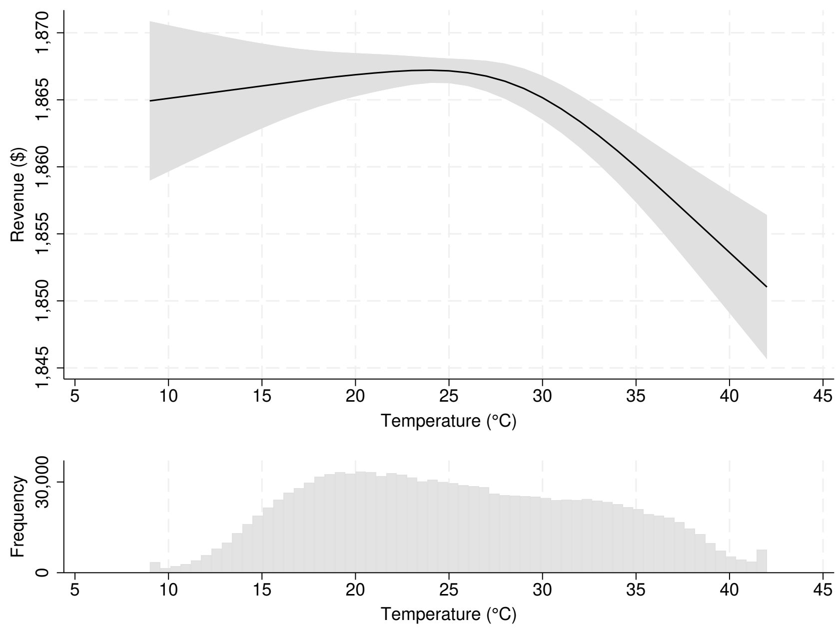
Our research design leverages the fact that a field of processing tomatoes is harvested continuously over a median of three days, yielding around 150 truckloads of tomatoes. Identification comes from comparing truckloads transported at different times over several days during a single pass in the same field. Variation in harvest time causes tomatoes grown in the same field to experience large differences in weather and traffic treatments after harvest. Intuitively, we compare a truckload of tomatoes harvested at 5 a.m. at 10°C traveling quickly and a truckload of tomatoes harvested at 5 p.m. at 35°C stuck in rush-hour traffic. Formally, we include field-year fixed effects to isolate the effect of temperature and time spent in transit on postharvest losses while holding constant characteristics of the field, grower, and year. Following best practices from the literature on the econometrics of climate change (Ortiz-Bobea, 2021), we use a semiparametric restricted cubic-spline specification to flexibly estimate temperature's effect on postharvest losses.

This novel research design improves on earlier work studying the impact of weather and climate change on economic outcomes. Researchers typically observe outcomes at a lower frequency than explanatory variables—for example, data on crop yields are available annually, whereas temperature and precipitation data are available daily. The mixed frequency of outcome and explanatory variables leads to an aggregation problem (Cui et al., 2024) in most studies of the economic effects of climate change including health (for example, Deschênes et al., 2009; Barreca et al., 2015), migration (for example, Cai et al., 2016), productivity (for example, Zhang et al., 2018), and agriculture (for example, Schlenker & Roberts, 2009; Tack et al., 2015; Ortiz-Bobea et al., 2018; Kawasaki, 2023). We sidestep this mixed-frequency issue through our use of within-field *and* within-growing-season variation, thanks to our high-frequency truckload-level outcomes.

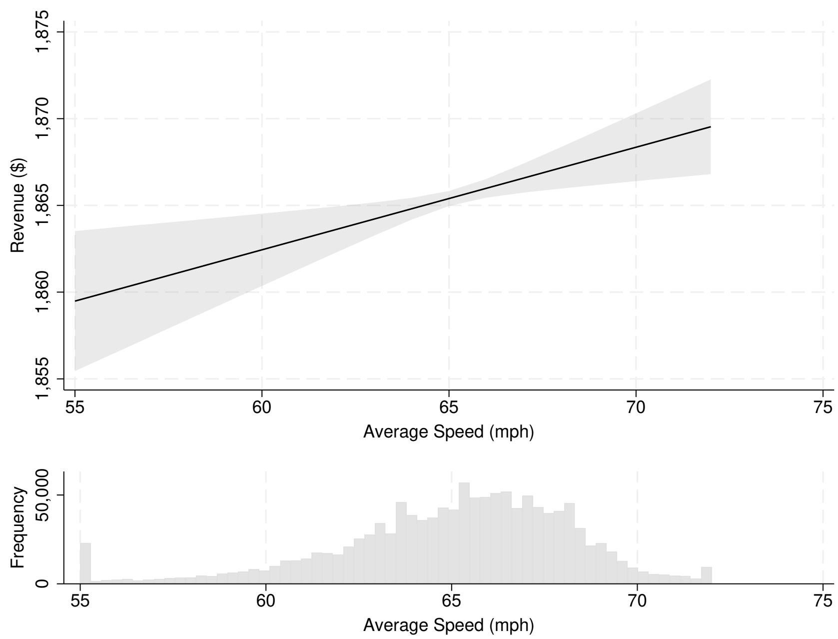
Our empirical work yields three key results. First, we find that hot temperatures during transportation decrease revenue through quality losses. We find that grower revenue is maximized with low- to midrange temperatures around 25°C or less during transportation. Hot temperatures (40°C) during transportation cause revenue to decline by 0.7% relative to the average, reflecting an increase in poor-quality tonnage. While effect sizes are small in absolute terms, 40°C temperatures during transportation are about three times more damaging than equivalent exposure while the tomatoes are still growing.

Second, we find that the time it takes to get from field to processing facility mediates weather's effect on postharvest losses. Conditional on field-year fixed effects that control for average trip duration, traffic conditions introduce plausibly exogenous variation in driving duration. Thousands of sensors buried beneath California's major highways measure the speed and flow of traffic, and Caltrans Performance Management System (2023) publishes these measures at the hourly level for each traffic sensor. When interacting temperature with the average speed along each truckload's route, we find that hot temperatures are particularly damaging to truckloads that experience heavy traffic.

Third, we estimate the effect of climate change on postharvest losses using climate projections that come from the Coupled Model Intercomparison Project Phase 6 (CMIP6) and are dynamically downscaled by UCLA NCAR (2023). We predict that climate change will cause an increase in postharvest losses during the relatively short trip from field to processing facility. This prediction relies on model parameters that capture technologies and techniques used today. Realized climate change impacts will depend on how the industry adapts.



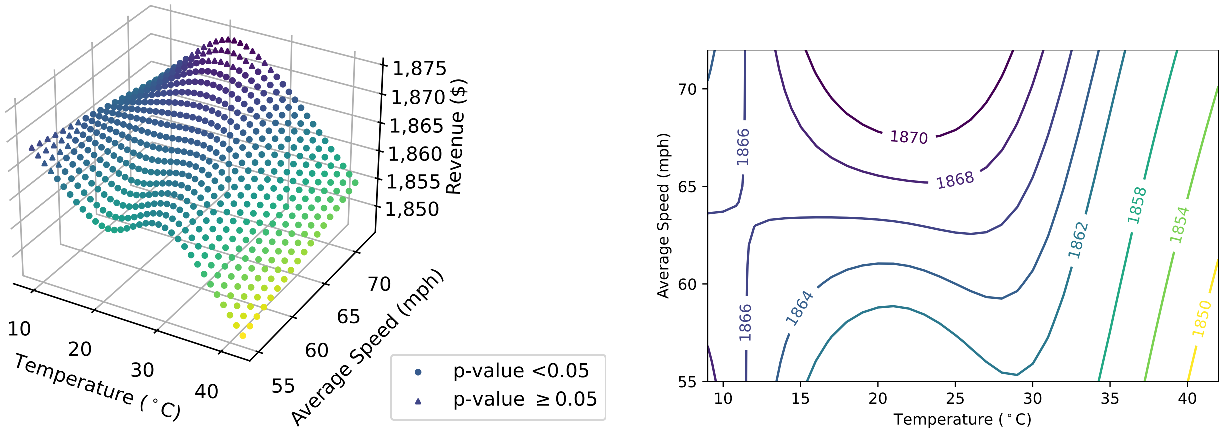
(a) Estimated effect of temperature using a restricted-cubic-spline model



(b) Estimated effect of average speed

Figure 1: Revenue results

Notes: For each panel, the graph at the top shows the effect of the explanatory variable during the hour before delivery on revenue. The 95% confidence intervals in gray account for the possibility of heteroskedasticity, spatial correlation, and temporal correlation in the errors. The histogram at the bottom shows the number of observations of each variable across all truckloads in all years.



(a) Revenue

(b) Revenue isolines

Figure 2: Estimated effect of the interaction between temperature and speed on revenue

Notes: The graph on the left shows the effect of the full continuous interaction between temperature and speed on revenue. Estimates that are significantly different from revenue's maximum value are indicated with a circle (p-values < 0.05), whereas those statistically indistinguishable from the maximum value are indicated with a triangle (p-value ≥ 0.05). The graph on the right is a two-dimensional representation of the same results. It shows isolines connecting points of the outcome variable that are equal in value as a function of temperature and speed. Purple and blue indicate large values of revenue, while green and yellow indicate small values of revenue.

We add to existing research on postharvest losses caused by inappropriate postharvest practices and inadequate storage technologies in developing countries (Sheahan & Barrett, 2017; Bauchet et al., 2021; Ricker-Gilbert et al., 2022). While postharvest mismanagement is known to exacerbate vulnerability to weather shocks (Kaminski & Christiaensen, 2014; Davis et al., 2021), prior work does not quantify the effect of weather and climate change on postharvest losses in either developing or industrialized countries. We causally identify weather and climate change effects on postharvest losses incurred by efficient agribusinesses operating in one of the world's most productive agricultural economies—a context in which postharvest losses are understudied more broadly.

We fill an important gap in the growing literature that documents the effects of weather and climate change on food supply chains. Prior work shows that increasing temperatures can hamper trade (Jones & Olken, 2010; Dallmann, 2019) and yet trade and market openness are important adaptation responses to climate change (Costinot et al., 2016; Gouel & Laborde, 2021; Dall'Erba et al., 2021). Energy required by cold storage will increase with temperatures—for example, the number of days that food products require cold storage is predicted to increase with climate change (Winkler et al., 2018; Lesinger et al., 2020). Finally, rising ambient temperatures may increase the risk of food poisoning or other food safety issues (Mirón et al., 2023). To our knowledge, this paper is the first to quantify postharvest losses caused by weather and climate change.

As highlighted in a recent chapter in the *Handbook of Agricultural Economics* (Ortiz-Bobea, 2021), "there is less research on how weather can affect food quality and postharvesting processing and associated crop losses." Earlier work has been constrained by data availability and methodology. We are able to fill this gap in the literature because our data are available at a fine temporal (hourly) and spatial resolution, our data include precise measurement of quality, and we can track individual truckloads as they move through the supply chain. While we lose some external validity by focusing on a single firm and a single commodity, we benefit from the level of detail necessary to answer a novel research question.

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