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Can Micro-Climate Engineering Save California Pistachios?

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Pistachio orchards in the San Joaquin Valley are threatened by warming winters. Researchers found a way to lower tree temperatures during the winter, a solution concept we term "Micro-Climate Engineering." We assess the economic gains from this innovation at $1-4 billion yearly in 2030. We believe this type of solution will play a major role in climate change adaptation.

Climate Change and Climate Bottlenecks

The focus of empirical research in climate change economics has recently shifted from exploring the effects of mean temperatures on various outcomes to the analysis of more subtle traits, such as the effects of extreme weather events. Abnormally warm days are the classic example, as the negative, non-linear effects of hot days on staple crop yields are by now a well-known result, replicated in various studies around the globe. This kind of extreme weather phenomena, harming yields over a short period of time, are bottlenecks that can bring a demise of a crop, even if the average climatic conditions are suitable for it. There is a reason to believe that much of the climate change damage to agriculture, at least by changes in temperatures, would be brought by an increase in the frequency of such extreme weather events, i.e., tightening of the climate bottlenecks.

If bottlenecks are a problem, the solution needs not be one that alters climate year round. What if we could just alter the temperatures in fields and orchards for a few hours every year, and just enough to prevent most of the damage? As opposed to Geo-Engineering, a set of proposals to intervene in global climate and revert climate change, this is a very local and temporary intervention. We term this adaptation technique "Micro-Climate Engineering" (MCE), and think it could be very useful for some of California's most profitable crops. Specifically, we look into the potential gains from this approach in pistachios, which are sensitive to changes from current climate. Rising daytime temperatures in winter are forming a bottleneck, which is predicted to hurt pistachio yields quite soon.

Before we proceed to our study, let us point out that MCE practices are already in use, and arguably have been used for millennia. Growers have always faced climate bottlenecks. It is the use of MCE as a climate change-adaptation technique that is new. For an existing MCE example, take an infamous temperature bottleneck on the cold side: frost. A frost lasts a few hours but causes great damages. Driving through Northern California's vineyards, one can witness an MCE solution already in use: big fans, sometimes augmented with propane tanks, circulate air around the precious plants on frost nights.

MCE often implements existing technologies to overcome a challenge, in ways many growers would find natural or familiar. While other researchers figure out more MCE solutions for growers, we are left with the task of assessing their potential gains.

California Pistachios and Climate Change

Introduced to California more than 80 years ago, and grown commercially since the mid-1970s, pistachios (*Pistachia vera*) were the state's ninth leading agricultural product in gross value in 2014, generating a total revenue of $1.65 billion. California produces virtually all the pistachio crop in the U.S., and competes internationally with Iran and Turkey (two-thirds of revenues are from export). In 2014, five California

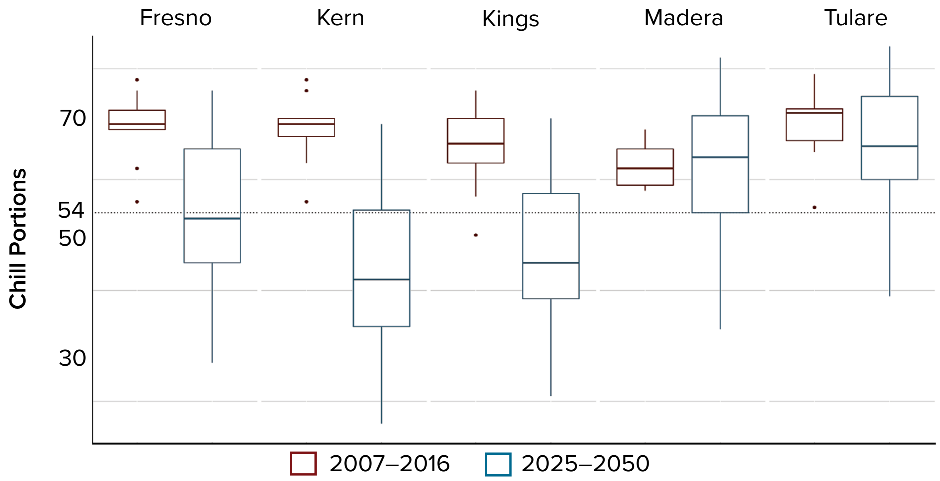

Figure 1. Winter Chill Portion Distributions

Note: 2016–2017 distributions are processed from CIMIS data. The 2025–2050 distributions are processed from our calibrated climate model climate predictions by CEDA. Boxes encompass 25th–75th percentiles of observations. Middle line in each box plot indicates the median.

counties had 96% of the state's pistachio acreage: Kern (24%), Fresno (23%), Tulare (22%), Madera (17%), and Kings (8%).

Pistachios have seen a spectacular acreage growth. Since 2000, total harvested acres in these counties have been increasing by roughly 10% yearly. Since 2010, average yearly growth has been 13.5%. Each increase represents a six to seven-year-old investment decision, as trees need to mature before commercial harvest.

Like many other fruit and nut trees, pistachios require minimal input of winter chill, a temperature metric measured in portions. Many fruit and nut trees "hibernate" during winter and "wake up" in spring. Agronomists stipulate that for optimal bud break scheduling, tree buds "count" chill portions and measure day lengths until reaching both threshold levels. Only then will the buds break and the tree will start blooming. Failure to attain a threshold chill count, varying between crops and varieties, leads to low and non-uniform breaking of buds, and low yields at harvest. Thus, chill accumulation is critical for growers, especially in warmer areas where the chill constraint might be binding.

Agronomists estimate the minimum requirement for the common pistachio cultivars in California at 54–58 portions. Compared to other popular fruit and nut crops in the state, this is a high threshold, putting pistachios on the verge of not attaining its chill requirements in some California counties. In fact, there is evidence of low chill already hurting yields. Thus, winter chill can be seen as a bottleneck: a slight decrease in chill portions could mean a great drop in yields.

Chill in Southern California is predicted to decline in the next decades. Climate literature suggests chill will be declining in the whole San Joaquin Valley. We ran our own calculations, not because we don't trust climatologists, but to get a separate estimate for each of our pistachio-growing counties. Using climate predictions in a "business as usual" Representative Concentration Pathways (RCP) 8.5 scenario (one with high carbon emissions from human sources) from the Centre for Environmental Data Analysis, and calibrating with observed data from the California Irrigation Management Information System (CIMIS), we get a distribution of present and (predicted) future chill-portion distribution in Figure 1. By 2025–2050, three out of our five counties (Fresno, Kern, and Kings) are predicted to get less than sufficient chill in most years.

Scientists at the University of California Cooperative Extension have been experimenting with potential solutions for the threat of low chill. One solution tested successfully in small-scale experiments involves spraying a non-toxic chemical mix, based on kaolin clay, on the dormant pistachio trees. Acting as a de-facto shading device, this creates a special micro-climate for the chill-counting tree buds. Shaded from winter sunlight, they now experience lower effective daytime temperatures, which raises their count of chill portions.

In experiments, the chill-portion count on treated trees was higher than on untreated trees; and the treated trees produced more pistachio clusters. Kaolin itself is already used for other purposes in agriculture, and research continues on the potential of other commonly used reflecting substances for shading. With relatively cheap application costs, this technique can help raise the chill counts in orchards, and at times save harvests. But what would be the gains from this technology?

Modeling Pistachios Market with MCE

To assess the potential gains from the MCE technique in pistachios, we model the market in the year 2030. Starting with an individual, decision-making grower, for whom we maximize profits by setting the level of MCE and traditional inputs, we aggregate on the county level, for which we have past production data as well as the climate predictions. Supply is modeled as the aggregate supply of our five counties, each one with a different (but correlated) climate realization and acreage. Each county serves as the representative of its growers, setting an optimal MCE level given the weather realization and the other counties' choices. Closing the model with a demand function, the solution is a market price and five MCE levels (implying five county supplies).

The benchmark used to assess the gains from MCE is an identical simulation run where the MCE levels are forced to zero. Thus, a "good" year with sufficient chill in all counties has zero gains from MCE. When the chill realization is low, in some or all counties, the benchmark price and quantities in the no-MCE run are different than in the MCE run. This allows us to calculate the gains in grower profits, consumer benefits, and total welfare—their sum.

We calibrate our model with 2014 price and county outputs to get some realistic values. We do not consider additional storage as a no-MCE benchmark, for two main reasons. First, storage is already in extensive use to deal with the alternate-bearing patterns of pistachios. The loss predictions in low-chill years are quite high, meaning that most of the output would have to be stored in any given year, which we find unlikely. Second, pistachio storage time is limited, usually up to a year. Thus, a multi-year storage strategy to deal with insufficient chill is unrealistic.

Besides the climate distribution, we define ranges and distributions for other parameters such as the price sensitivity of demand (elastic—more sensitive to price) and supply (inelastic—less sensitive to price), market power both on the grower side (about half of California pistachios are marketed by one firm) and downstream side (large processing plants or exporters), and estimated cost of kaolin application per acre (courtesy of UCANR's Agricultural Issues Center). Drawing randomly from these distributions, we run our market model many times to obtain gain distributions reported below.

One more decision, external to the model, needs to be made: the growth in acreage and its distribution in 2030. Taking past acreage growth, we create a ***High Scenario*** (acreage grows 5.11 times from current) and ***Low Scenario*** (2.74 times). Demand is modeled to grow at the same rate as the total

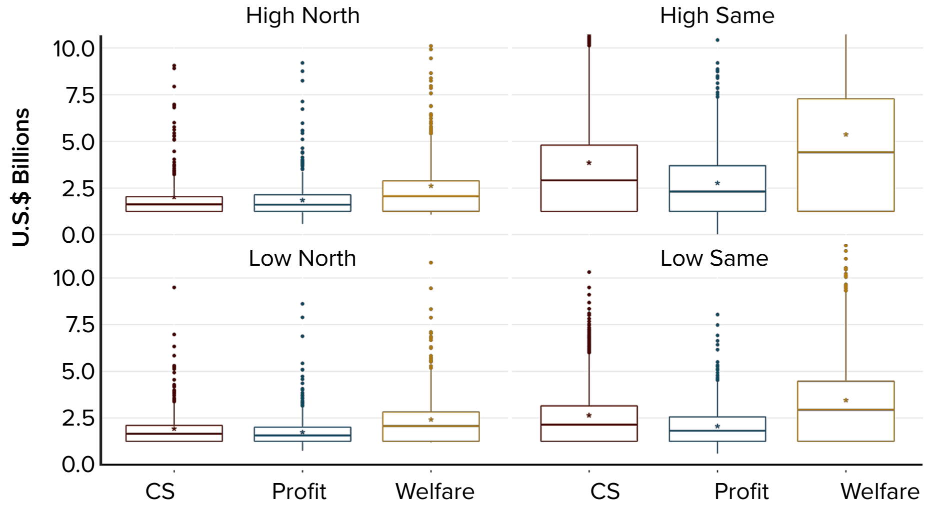

Figure 2. Total Gains Distribution by Scenario

Note: Boxes encompass 25th–75th percentiles of observations. Middle line in each box plot indicates the median, the asterisk is the average.

acreage growth. As growers might take future chill predictions into consideration, we also have a ***North Scenario***, in which all new growth happens in Madera and Tulare counties, where chill is not predicted to decline below critical levels (Tulare isn't really to the north, but it is colder); and a ***Same Scenario***, where the county acreage shares remain the same as present ones.

Together, we have four scenarios: ***High North, High Same, Low North,*** and ***Low Same***. As expected, we later see that gains from MCE are greater when acreage growth is high rather than low, and the distribution is same rather than north. This scenario range excludes the possibility of shifting existing orchards to the north, as this is very expensive and potentially unnecessary with MCE. On the other hand, this also assumes conservatively that the growth rate does not increase in the more damage-prone counties, at the expense of the cooler ones, as a result of MCE technology being available to growers.

Note that the ***North Scenario***, where new acreage is very unlikely to be hit by insufficient chill due to its geographic location, is analogous to planting heat-tolerant pistachio varieties in new acreage in general. This means we also exclude switching varieties in currently harvested acres. It seems reasonable, given the high start-up costs (net costs of $16,137 per acre in the first six years, according to the latest UC Cooperative Extension's cost estimates that do not include uprooting the old orchard), foregone income in the years of establishing orchards with new varieties, and uncertainty on the success of new varieties in California conditions.

Simulation Results

The model is run 1,000 times, solving numerically for price and county MCE levels. We do not include parameters resulting in a grower/consumer price ratio above six, generated by some combinations of market powers and elasticities, leaving us with 942 results for each scenario. These simulations include "good" year realizations where chill is sufficient around the state. Thus, we interpret average simulated gains as expected gains. The mean effect of MCE is a 32–88% quantity increase (scenario depending).

Given California's big market share in production, this increase translates to a 13–31% drop in market price. For the gains in terms of profits, consumer benefits, and total welfare, see simulated distributions in Figure 2. They are virtually all positive. This could be expected with consumer gains, because of their higher price sensitivity. However, for profit gains, as there is some measure of market power in each

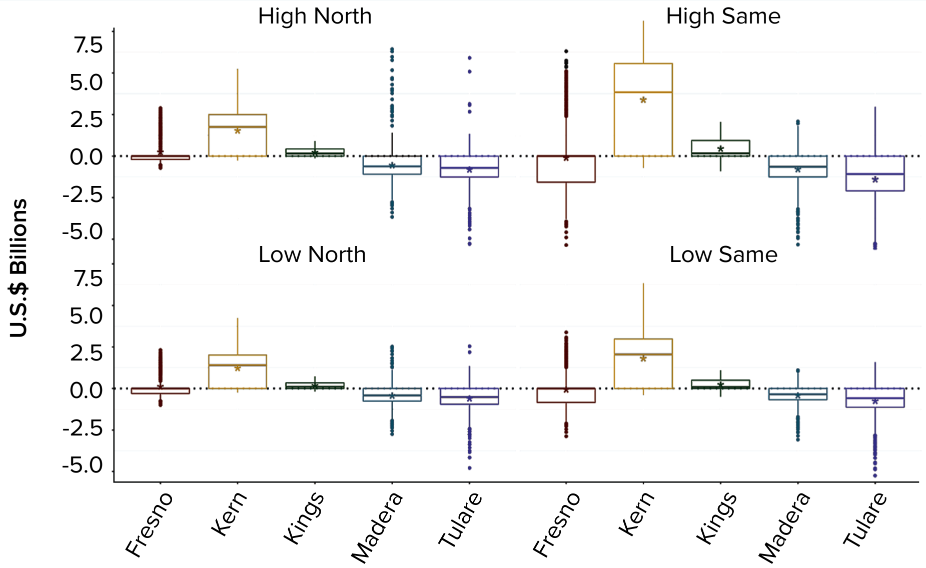

Figure 3. Profit Gains from MCE by County

Note: Boxes encompass 25th–75th percentiles of observations. Middle line in each box plot indicates the median, the asterisk is the average.

simulation, this was not an obvious result.

In total, the average profit gain is \$0.49–\$1.52 billion; the average consumer surplus gain is \$0.68–\$2.60 billion; and the average total welfare gain is \$1.17–\$4.12 billion. The scope of these ranges is mostly the product of our different scenarios: the lower values correspond to the ***Low North Scenario***, while the higher values are from the ***High Same Scenario***. In reality, some combination of these scenarios, and resulting average gains, is possible.

One interesting finding, driven by our county-specific modeling, is the difference in profit gains between counties. In the benchmark setting, i.e., no-MCE, the cooler counties are the obvious winners from climate change, at the expense of the warmer counties. Thus the gains from MCE, while positive in total, vary greatly among counties.

Figure 3 shows the profit-gain distribution by county. Kern County, the largest pistachio producer at present, and also the most threatened by climate change in terms of chill portions, is the big winner from MCE. On the other hand, Tulare and Madera see mostly losses from the new technology.

This insight is relevant to adaptation techniques in general. Besides the baseline climate heterogeneity, not all areas affected by climate change have the research resources available in California, nor are the capital investments required for MCE implementation available around the world.

Another insight from simulation results is that gains are positively correlated with market power. This correlation points in two potential directions for future research. First, the relatively unexplored intersection of market power, agriculture, and climate change. As gains in our model are basically the recovery from a bottleneck, this reflects a positive correlation between climate-change damages and market power.

The second point is about public investment in R&D for MCE solutions. In some cases, market power serves as an extra incentive for investment in R&D, where simple profits are deemed insufficient. This is sometimes said about investment in the pharma industry. Here, consumer gains from MCE increase with market power. A large share of these gains is enjoyed by domestic consumers. Therefore, public investment in research for MCE solutions might be beneficial for taxpayers as well.

Conclusions

Many climate change effects on agriculture could be the result of tightening climate bottlenecks, rather than a drastic change in mean climatic conditions. Where feasible, both physically and economically, MCE technologies could help growers adapt to climate change, delaying eventual crop transitions for decades. We document a new technology to help California pistachio growers overcome low-chill years, and model the market to assess its potential gains in the year 2030. They are in the low-billion dollars for a crop of secondary importance in California agriculture, indicating a great potential for MCE as an adaptation concept in general. We believe we will witness more such MCE solutions in future years.

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Authors' Bios

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For additional information, the authors recommend:

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