# Seasonal Farm Labor and Risk of COVID-19 Spread

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**Abstract**

Worker safety during the coronavirus pandemic is of primary concern, particularly in essential industries where working remotely is not possible. Despite employer precautions, there have been numerous worksite outbreaks of COVID-19. This paper examines the relationship between month-to-month changes in expected agricultural employment within counties and new COVID-19 cases. The results show a positive association between agricultural employment and new COVID-19 cases with employment in fruit production having the strongest relationship. I find that employment of 100 additional workers in fruit, vegetable, and horticultural (FVH) production within a county is associated with 21 new COVID-19 cases.

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Worker safety during the coronavirus pandemic is of primary concern, particularly in essential industries where working remotely is not possible. Despite employer precautions, there have been numerous worksite outbreaks of COVID-19 in the past several months. The agricultural industry is under particular scrutiny since the nation depends on agriculture for its food supply, and the seasonal nature of farm work potentially exposes workers to greater risk. COVID-19 outbreaks on farms could be fatal for some workers and their families, and they could be devastating to producers and consumers if they stall harvest of perishable fruits and vegetables. This paper investigates the relationship between seasonal changes in agricultural employment and the number of new COVID-19 cases and deaths within U.S. counties. The findings indicate that agricultural employment, and employment in fruit production in particular, is associated with increased spread of COVID-19. The findings from this paper have important implications for assessing production risk in the food supply chain during the pandemic.

Due to the precise timing of biological processes in agricultural production, a labor shortage at a critical stage of production could ruin an entire crop. In 2006, The *New York Times* reported that several tons of pears were rotting on the ground in Lake County, California because there were insufficient workers to harvest the crop (Presont, 2006). The coronavirus pandemic magnifies the risk and uncertainty involved in producing labor-intensive crops since COVID-19 can quickly spread from one individual to another and there is, as yet, no vaccine and no cure. Yakima County, Washington, one of the primary counties for fruit and vegetable production, had the highest rate of COVID-19 infection on the West Coast in June 2020 (Dorning and Skerritt, 2020). Immokalee, Florida, a rural farm worker community, reported 900 cases of COVID-19 between April and June 2020 (Reiley, 2020). The outbreak in Immokalee is particularly concerning since many of the workers in that region follow the crop as the harvest moves up the Eastern shore. Workers are needed further north as the summer progresses, but if workers are carrying the virus, they may leave a trail of new COVID-19 cases in their wake. Ridley and Devadoss (2020) simulate crop losses in the fruit and vegetable industries of $13-$53 million in 2020 due to COVID-related labor disruptions alone.

The findings in this paper provide insight into which crops are expected to experience the greatest turnover in labor due to the spread of COVID-19 and what regions of the United States are most susceptible to coronavirus-related farm labor shortages. These insights can help policymakers anticipate vulnerabilities in the food supply chain. As stated in a 2020 Congressional report, "If labor shortages become severe, they could lead to wider multi-state, and possible national, food shortages of affected products" (Congressional Research Service, May 8, 2020). Understanding which commodities are most associated with COVID-19 spread can help industry leaders throughout the food supply chain prepare for and mitigate losses. In the longer term, investments in the development and adoption of labor-saving technologies are expected to increase most rapidly among crops that experience greatest risk of farm labor shortages. The findings in this paper help inform which crops have increasing potential gains during the coronavirus pandemic from the use of labor-saving technologies.

Farm labor shortages were of primary concern to agricultural producers prior to the pandemic and could be exacerbated by worker sickness and quarantine until a vaccine is available or herd immunity achieved. While the coronavirus pandemic poses a critical threat to agricultural production in the short-term, it also demonstrates the vulnerability of agricultural production to potential spread of viruses among essential workers in general. Broadly speaking, farm labor shortages have been a primary concern to U.S. agricultural producers for many years. The U.S. farm workforce is aging and fewer new immigrants are coming to work in agriculture. Reports of farm labor shortages are becoming more frequent, and producers are increasingly turning to the H-2A guest worker program to supply new workers (Zahniser et al., 2018).

The coronavirus pandemic could potentially accelerate innovations in labor-saving technologies to reduce the agricultural industry's dependence on farm workers, thus mitigating the risk of a labor shortage. Clemens, Lewis, and Postel (2018) show that reduced labor supply following the termination of the Bracero agricultural guest worker program with Mexico in 1964 led to the development and adoption of new labor-saving agricultural technologies. Similarly, Charlton and Kostandini (2020) find that the dairy industry became more technologically advanced and labor-efficient following the implementation of county-level 287(g) immigration enforcement mandates. Koundouri, Nauges, and Tzouvelekas (2006) show that technology adoption serves as a method of hedging against production risk. Thus, increased risk of incurring labor shortages during the coronavirus pandemic could induce producers to invest in new technologies. Understanding how viruses like COVID-19 spread in relation to economic activities and determining how risks to worker health potentially vary across industries can help farmers, researchers, and policymakers anticipate where labor-saving technologies might be most beneficial in hedging production risk.

This paper measures the relationship between month-to-month changes in expected agricultural employment from March-October and number of new COVID-19 cases and deaths within counties. I regress the number of new COVID-19 cases (deaths) at the county-month level on monthly agricultural employment in 2017 controlling for county fixed effects. COIVID-19 data come from the *New York Times* database, and agricultural employment data are taken from the Quarterly Census of Employment and Wages (QCEW). The advantage of using the QCEW is that it records employment by industry at the county-month level. I use employment data in 2017 because employment decisions in 2017 are exogenous to the COVID-19 shock as employers and employees could not anticipate the pandemic, and national weather conditions in 2017 were similar to 2020.[1] Controls for state-by-month fixed effects account for changes in state mandates and attitudes with respect to social distancing, quarantine, and masks, along with other unobserved state-level temporal changes in COVID-19 growth and susceptibility. I limit the sample to counties that have positive agricultural employment, and as a robustness check, I repeat the analysis using data from California alone. The advantages of analyzing Californian agriculture alone are that 1) California grows a diverse selection of labor-intensive crops that have peak seasonal farm employment at different times from March-October, and 2) California has complete employment data by crop, including H-

[1] At the time of writing this paper, the QCEW has not yet released 2020 employment data. Further research is needed to measure the effects of the pandemic on agricultural employment.

2A agricultural guest workers, regardless of employer size (University of California, Davis, 2020).[2]

The findings in this paper show a strong positive relationship between month-to-month changes in agricultural employment and new COVID-19 cases. The results show that employment of 100 additional farm workers within a county is associated with 6 new COVID-19 cases. The results indicate that 100 additional workers on berry farms are associated with 50 new COVID-19 cases, and 100 additional workers on other non-citrus fruit farms are associated with 87 new COVID-19 cases. The findings of this paper cannot rule out the possibility that COVID-19 spread may occur in off-farm activities correlated with changes in on-farm employment. Of particular concern is the potential for COVID-19 spread in downstream activities, such as work in fruit packing facilities where essential workers must work indoors where there is reduced air flow. Although identification of the mechanisms is beyond the scope of this paper, the findings indicate that community spread of COVID-19 rises during peak agricultural employment when a farm labor shortage would be most costly to producers and consumers.

## Farm Labor Background

Farm workers may be particularly susceptible to COVID-19, not only because their work is essential and cannot be performed remotely, but also because farm workers often share a number of characteristics that are highly correlated with greater risk for COVID-19. Farm workers and their families often live below the poverty line, reside in dense living quarters, and lack access to healthcare and health insurance. According to the National Agricultural Workers Survey (NAWS) 48.92% of farm workers in 2016 reported that they did not have health insurance, 37.04% had not used any type of healthcare services in the United States in the past 2 years, even fewer had used health services in another country, and 19.15% reported that they did not seek medical care because it was too

[2] Many states require only agricultural producers of a minimum size to report workers for unemployment insurance, and many states do not require employers to record H-2A workers, thus leading to an under-count of workers in some states since I use employment counts from the Quarterly Census of Employment and Wages (QCEW), which uses employers' unemployment insurance documents to calculate employment by sector.

expensive.[3] Policy interventions can only partially offset some of these disadvantages. For example, the Families First Coronavirus Response Act (FFCRA) requires employers with fewer than 500 employees to provide paid sick leave for workers affected by COVID-19. However, employers with fewer than 50 employees can request an exemption, and there is no guarantee that workers will select to take time off from work if they or their family members display coronavirus symptoms even if they are offered paid sick leave.

Lack of legal work authorization can contribute to farm workers' vulnerability. An estimated 48% of farm workers, excluding H-2A guest workers, are unauthorized immigrants.[4] Many farm workers may be fearful of seeking public services, including healthcare or legal services, if they believe that their immigration status might be exposed or if they believe that someone might try to deport them or their friends or family. H-2A workers may be less vulnerable to some of these challenges in obtaining services since they have legal documentation to work in the United States.[5] However, their working conditions and access to legal and health services likely vary. Since H-2A workers can only legally work for one employer during their residence in the United States, some H-2A workers may not be aware of the services that are available to them or may fear that certain actions would displease their employer or jeopardize future employment.

Farm worker ethnicity also plays a role in susceptibility to COVID-19. An estimated 81% of farm workers in 2016 were of Hispanic descent, not including H-2A workers.[6] Hispanics appear more likely to get COVID-19 and more likely to have severe symptoms. Even though Hispanics represented only 24% of workers in industries with the highest rates of COVID-19 outbreaks in Utah, Hispanics made up 73% of the COVID-19 cases in those industries (Bui et al., 2020). Much is still unknown about the risk factors associated with COVID-19, but race appears to be an important factor determining risk of contracting COVID-19 and severity of the disease. Cultures and lifestyles that involve

[3] Statistics based on author's analysis of the United States Department of Labor, Employment and Training Administration (2017).

[4] Statistics based on author's analysis of the United States Department of Labor, Employment and Training Administration (2017).

[5] H-2A workers constitute an estimated 10% of the full-time equivalent farm workforce (Costa and Martin, 2020).

[6] Statistics based on author's analysis of the United States Department of Labor, Employment and Training Administration (2017).

more compact living spaces and shared meals and transportation also likely experience more rapid spread of COVID-19.

Many employers are implementing policies to reduce the risk of spreading COVID-19 while working in the fields, but measures also need to be taken to increase social distancing in worker housing and transportation. Some Farm Labor Contractors (FLCs) have rented additional buses to transport workers to worksites or made additional trips with the same bus to increase social distancing on the bus (Beatty et al., 2020). Some of the employers who provide housing for farm workers are housing fewer workers per living unit and designating quarantine housing for workers who show symptoms of COVID-19. These measures could be vital in preventing a COVID-19 outbreak, but they also increase the marginal cost of employing each worker. The increased cost of labor, along with increased risk of labor shortages, is expected to lead producers to consider investing more in labor-saving technologies.

Prior to the coronavirus pandemic, many fruit and vegetable producers were already experimenting with new technological innovations to reduce labor inputs in production and harvest. For example, Taylor Farms of Salinas, California began installing robotic arms that package salads in its processing facility. In the fields, they harvest with automated lettuce harvesters that use patented jet knife technology to cut the Romaine heads near the ground. The harvester then delivers the Romaine heads to workers who inspect and sort them on the harvester's platform. These harvesters arguably improve workers' safety by removing the need for workers to bend over rows of lettuce, wielding machetes, for several hours everyday. Taylor Farms says these innovations reduce their risk of labor shortages and provide opportunities for workers in higher-skilled, better-paying jobs.[7]

Increased risk of farm labor shortages due to the coronavirus pandemic could accelerate the development and adoption of labor-saving technologies as producers seek options to mitigate risk. A positive relationship between farm employment and new COVID-19 cases could be a viable signal that efforts to mechanize will soon follow. As Taylor farms found with the mechanized lettuce harvester, labor-saving innovations can potentially

[7]See Taylor Farms. "The Automated Farm" August 22, 2017. https://www.taylorfarms.com/news/the-automated-farm/. Accessed August 28, 2020.

improve worker safety and generate higher paying jobs. Nevertheless, some farms and workers will benefit from the development of labor-saving technologies while others will not.

## Data

Sector-specific employment data come from the U.S. Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW). The QCEW records employment and wages for establishments that report to U.S. Unemployment Insurance (UI) programs. These establishments employ about 97% of all wage and salary civilian employees. I use monthly employment by industry, aggregated to the county-level in 2017. I examine the association between monthly employment in agriculture, forestry, fishing, and hunting (NAICS 11) and new COVID-19 cases and deaths within counties. Importantly, I drop all counties that do not report any agricultural employment so as to eliminate strictly urban counties. I also drop all observations from Florida and North Carolina since these states employ a large share of H-2A agricultural guest workers but do not record H-2A workers in the UI employment counts.[8]

I make one minor adjustment to the NAICS 11 employment count since some farm workers are the employees of farm labor contractors (FLCs) and may not work in the county of their employer's address. Since FLCs transport workers from farm to farm, the number of FLC employees reported per county may not accurately correspond to the number of workers working and residing in the county. I account for this by estimating the FLC employment in each county every month based on FLC shares in the 2017 Agricultural Census and statewide FLC employment counts each month. I calculate each county's annual share of agricultural contract labor expenditures in the state using the 2017 Agricultural Census. I then multiply each county share by the number of FLC employees in the state each month. I use the resulting product as a proxy for county

[8]Personal phone conversation with North Carolina Division of Employment Security in 2019 revealed that North Carolina does not record H-2A workers in the UI. Florida also does not record H-2A employees in the UI (University of California, Davis, 2020). Regulations for reporting H-2A and workers on small farms vary by state. I address these concerns by limiting the sample to only California as a robustness check.

FLC employment. I thus replace county FLC employment in the QCEW (NAICS 115115) with the FLC proxy.

I select monthly employment data from 2017 because because both 2017 and 2020 were characterized by warm, dry conditions throughout most of the United States and likely followed similar patterns of expected farm labor demand apart from disruptions caused by COVID-19.[9] Importantly to the econometric analysis, employment in 2017 is exogenous to changes in farm labor supply and demand caused by the coronavirus pandemic since no one could have anticipated the pandemic in 2017.

Figure 1 plots national monthly employment by crop in 2017. Employment generally rises in the spring and peaks in the summer. Exceptions are oranges and other citrus fruit, which are harvested in late winter. I leverage temporal variation in labor demand within each county. I keep only months March-October since COVID-19 testing was uncommon prior to March and there were few known cases in the United States.[10]

The QCEW records agricultural employment in most counties throughout the country. Production of labor-intensive fruit, vegetable, and horticultural crops is primarily concentrated along the Pacific and Atlantic coasts and bordering the Great Lakes. Figure 2 illustrates the variation in agricultural production in July, the peak month for national agricultural employment. The counties with no data are those where there is no agricultural employment in any month (or data are suppressed due to few employers) or counties intentionally dropped from Florida and North Carolina because of their strong dependence on H-2A workers who they do not record in the UI. I remove these counties from the sample.

The public QCEW suppresses employment data in some counties. This may be of concern for agricultural employment since suppression rates are higher in agriculture. Data are suppressed when there are few employers in the sector of interest in the county so as to protect confidentiality of individual firms. Suppressed counties are dropped from

[9]Figures from the U.S. National Oceanic and Atmospheric Administration can be found in Appendix A to illustrate similarities in average temperature and precipitation percentiles in 2017 and 2020.

[10]I also repeated the analysis ending in July to eliminate concern that different policies with respect to opening schools will affect results since few schools opened prior to August. Results were qualitatively similar and are available upon request.

my analysis and most of them likely have relatively few agricultural employees since there are few firms in the county. Thus dropping these counties should have little effect on the results.

Next, I examine the association between changes in employment in specific agricultural crop groupings and new COVID-19 cases. I divide agricultural employment into employment on berry (including strawberry) farms, other non-citrus fruit farms (including fruit and nut diversified farms), vegetables and melon farms (excluding potatoes), nursery and floriculture production, greenhouse production, and a proxy for employees of farm labor contractors (FLCs).[11]

COVID-19 case and death data come from the *New York Times*, which compiles cumulative counts of coronavirus cases and deaths at the county level over time from state and local governments and health departments. I assume that missing values in the COVID-19 data are zeroes since most counties did not report COVID-19 cases and deaths prior to detecting COVID-19 in the county, and I difference the data to find new cases and deaths. When I repeat the analysis in California alone, I obtain data directly from the California Department of Health (CDH), which additionally reports daily hospitalizations attributed to COVID-19. Data do not indicate when new patients are admitted to the hospital or when they leave. Since I know only the daily number of patients in the hospital for COVID-19, I take the mean daily number of COVID-related hospitalizations as a third indicator of the spread of COVID-19 in the county.

New case and death data obtained from the CDH differ somewhat from the *New York Times*, possibly because the CDH updates their data as more information about the virus becomes available. This underscores the uncertainty and measurement error in COVID-19 case and death data.[12] Nevertheless, these data should serve as a reasonable proxy for changes in the number of COVID-19 cases and deaths.

[11]These industries include NAICS codes 111331-111334, 111336, 111339, 11141-11142, and 111219. The NAICS for FLC employment is 115115, and I proxy for FLC employment using the methods described above.

[12]Note that the Centers for Disease Control and Prevention (CDC) asserts that COVID-19 counts are provisional and may need to be updated. See, for example, Centers for Disease Control and Prevention (September 1, 2020) "Daily Updates for Totals by Week and State: Provisional Death Counts for Coronavirus Disease 2019 (COVID-19)." https://www.cdc.gov/nchs/nvss/vsrr/covid19/index.htm. Accessed September 1, 2020.

Figures 3 illustrates the correlation between agricultural employment each county-month and new COVID-19 cases. As can be seen, there is a strong positive correlation. The positive correlation suggests that COVID-19 spread in the agricultural industry should be of concern to workers, producers, and consumers, and it should motivate further study, though this does not necessitate a causal relationship.

## Model

I measure the association between month-to-month changes in agricultural employment and COVID-19 growth within counties by estimating the following equation:

$$Y_{i,t} = \beta Ag_{i,t} + \sum_{k} \alpha_k hr_{k,i,t} + \gamma_{s,t} + \rho_i + \epsilon_{i,t}$$

where $Y_{i,t}$ is the outcome of interest in county $i$ in month $t$ in 2020, $Ag_{i,t}$ is employment in agriculture, forestry, fishing, and hunting in county $i$ month $t$ in 2017, $hr_{k,i,t}$ is employment in "higher risk" non-agricultural industry $k$, $\gamma_{s,t}$ is a vector of state-by-month fixed effects, $\rho_i$ is a vector of county fixed effects, and $\epsilon_{i,t}$ is the error term.

Outcomes of interest include new COVID-19 cases reported in the county each month and deaths attributed to COVID-19. I look at level case reports and deaths because workers are not expected to interact with the entire community and thus spread COVID-19 throughout the county population affecting the COVID-19 case rate. Many statistical reports focus on the COVID-19 case rate within rural communities, which is an important indicator for understanding the the probability of COVID-19 contact for individuals interacting at random with other members of the community. This paper is instead focused on the relationship between expected agricultural employment and level COVID-19 growth, which may occur on farms, off-farm in farm worker communities, or in correlated activities up or down the food supply chain. Agricultural activity may have little bearing on Covid-19 rates within the community since farm workers are a relatively small share of the county population.

The controls for "higher risk" non-agricultural employment include employment in industries that were considered essential during the coronavirus pandemic for which workers could not perform many of the essential tasks remotely. These industries, defined by subscript $k$, include construction, retail trade, transportation and warehousing, healthcare and social services, accommodation and food, and other service industry.

Since employment measures come from 2017, three years prior to the COVID-19 pandemic, the pandemic had no effect on hiring decisions in the explanatory variable. State-by-month fixed effects control for statewide growth in COVID-19, including shocks to COVID-19 growth potentially due to changes in state health mandates. County fixed effects control for time-invariant characteristics of the county.

Next, I disaggregate agricultural employment into specific crop group. These crops include berries, other non-citrus fruits, vegetables (excluding potatoes) and melons, greenhouse production, nursery and floriculture production, employees of farm labor contractors (FLCs), and other agricultural activities defined under NAICS 11. I thus estimate the following equation:

$$Y_{i,t} = \sum_j \beta_j ag_{j,i,t} + \sum_k \alpha_k hr_{k,i,t} + \gamma_{s,t} + \rho_i + \epsilon_{i,t}$$

where the subscript $j$ represents specific agricultural crop groups. I also repeat the analysis of crop-specific employment controlling for state-by-month fixed effects.

Of potential concern is that some agricultural employers do not have to report their employment to Unemployment Insurance (UI) in some states, and thus the QCEW undercounts agricultural employment. For example, in North Carolina farm employers with fewer than 20 employees do not report to UI, and employers do not report workers who have an H-2A guest worker visa.[13] To my knowledge there is no single source that indicates which states require agricultural employers to report all employees for UI. I drop North Carolina and Florida from the primary analysis since both states employ a large share H-2A workers and are known not to report them in the UI. Sources indicate

[13] Based on author's conversation with North Carolina Division of Employment Security in 2019.

that employers in California and Washington must report all agricultural employees to UI regardless of employer size and H-2A status (University of California, Davis, 2020). Thus as a robustness check, I repeat the analysis in California alone.

It is important to note the limitations of this analysis. Specifically, agricultural labor activity may be correlated with other activities that are relatively high risk for spreading the COVID-19 virus. I expect that many correlated activities are absorbed in state-by-month fixed effects, but changes in housing density, communal living, or shared transportation, which may be directly associated with changes in farm labor, will not be absorbed in the fixed effects. This investigation does not provide sufficient evidence to suggest that on-farm activities themselves increase the risk of spreading COVID-19, but it does provide insights into which crops likely bear greatest risk of COVID-related disruptions to farm labor supply.

## Results

The main results are presented in table 1. The dependent variable in columns(1)-(3) is new COVID-19 cases, and the dependent variable in columns (4)-(6) is deaths attributed to COVID-19. All specifications include county fixed effects. Columns (1) and (4) include month fixed effects. Columns (2) and (5) additionally include controls for expected employment in “higher risk” non-farm industry employment. Columns (3) and (6) control for state-by-month fixed effects in addition to the non-farm employment controls. Standard errors are clustered at the state.

Panel A shows the results from the most general specifications using all agricultural employment (NAICS 11) as an explanatory variable. Panel B separately estimates the effects of expected fruit, vegetable, and horticultural (FVH) employment and employment in all other agricultural industries. Panel C further divides agricultural employment into more specific crop groupings.

The preferred specifications are in columns (3) and (6) with the most comprehensive set of controls. The results indicate that 100 additional agricultural employees are associated with 6.4 new COVID-19 cases within counties. The results in Panel B indicate that the positive relationship between farm employment and new COVID-19 cases can be attributed primarily to employment in the FVH sectors. The results indicate that 100 additional FVH workers are associated with 21.08 new cases of COVID-19 and 0.42 COVID-related deaths.

Finally, Panel C shows that 100 additional workers on berry farms are associated with 49.93 new COVID-19 cases and 1.81 COVID-related deaths, and 100 additional workers on other non-citrus fruit farms are associated with 86.56 new COVID-19 cases.

I find no evidence that employment in vegetable production has any effect on COVID-19 spread. Possibly this is because many vegetables that were originally destined for restaurants and cafeterias in the spring of 2020 were tilled into the ground or harvested for livestock feed using relatively few labor inputs. Vegetables harvested in spring may have employed workers before COVID-19 had a widespread presence in the rural United States, or workers in vegetable production may be better equipped to social distance on and off farm. Alternatively, fruit production may be associated with more rapid spread of COVID-19 because farm employment might be correlated with other activities that increase the spread of COVID-19. Fruit packaging and processing often requires workers to labor in relatively tight indoor spaces where viruses are expected to spread more quickly. These off-farm activities likely correlate with employment in fruit orchards and fields and may lead to increased spread of COVID-19 within the same counties.

I find relatively large coefficients on expected greenhouse employment, which requires workers to work indoors, but the coefficient is not statistically different from zero when I control for state-by-month fixed effects (column 3). I do not find a statistically significant association between expected nursery and floriculture employment or FLC employment and COVID-19 cases or deaths. FLC employment should be highly correlated with employment in fruit production, so it may be difficult to measure the distinct relationship between FLC employment and COVID-19 spread. Nevertheless, FLC employment may entail greater risk of COVID-19 exposure since employees often board in tight living spaces with one another and commute to multiple farms on communal buses, though I am unable to detect a significant relationship between expected FLC employment and COVID-19 spread in the data.

As a robustness check, I limit the sample to counties in California and measure the association between crop employment and new COVID-19 cases, deaths, and mean hospitalizations attributed to COVID-19 per day. Results are presented in Table 2. All specifications include month fixed effects and county fixed effects. Even columns include controls for expected employment in "higher risk" non-farm industries.

The results are qualitatively similar to those in the national sample. I estimate positive coefficients on employment on berry and other non-citrus fruit farms in all specifications. Only the coefficients on non-citrus fruit employment are statistically significant, indicating that 100 additional workers on non-citrus fruit farms are associated with 107.96 new COVID-19 cases and 2.04 COVID-related hospitalizations. The relatively small sample size in the analysis of California alone may account for the lack of statistically significant coefficients on berry employment. Berries are predominately grown in a few coastal counties in California, but U.S. berry production spans numerous locations, including farms in Oregon, Washington, Michigan, and Florida. California is one of the primary fruit producing states, including hundreds of acres of orchards and vineyards located in counties throughout the state. The large, statistically significant positive association between expected non-citrus fruit employment and COVID-19 cases and hospitalizations support the findings from the national analysis.

## Discussion

The findings in this paper suggest that there is a large, statistically significant positive association between month-to-month changes in FVH employment within counties and new cases of COVID-19. However, the analysis does not illuminate the precise mechanisms that correlate month-to-month changes in FVH employment and COVID-19 case growth. It is notable that employment on fruit farms in particular are associated with new COVID-19 cases since fruit production is often associated with labor-intensive downstream activities in fruit packing sheds where viruses could simultaneously spread. Other off-farm activities, including transportation, housing, and dining activities that correlate with farm employment could also lead to increased COVID-19 growth within local communities.

Numerous factors may correlate with both changes in FVH employment and new COVID-19 cases. For example, the majority of farm workers in the United States are Latinos, and Latinos appear to be more susceptible to COVID-19 than other races. In California, there were 1,750.3 COVID-19 cases for every 100,000 Latino residents in August 2020, compared to just 514.3 cases per 100,000 White residents and 438.9 cases per 100,000 Asian residents (Ibarra, Castillo, and Yee, March 24, 2020).[14] In addition, newspaper reports suggest that misinformation surrounding COVID-19 is more prevalent in Latino communities, likely stemming from greater distrust in government, worse access to medical care, and language barriers (Klepper, Sainz, and Garcia Cano, August 13, 2020). If Latinos are more susceptible to COVID-19 than other races, then the migration of Latino farm workers into communities as agricultural labor demand rises, or increased activity and increased interactions between different social circles of Latino households during peak farm labor seasons could increase COVID-19 cases within the county.

The results do not indicate that COVID-19 is necessarily spreading on farms, and understanding how or why COVID-19 is spreading in farm labor communities is beyond the scope of this paper. Many labor activities on farms could involve relatively high risk of spreading COVID-19 if it is difficult to socially distance. Nevertheless, many farms have taken precautions to reduce social contact on the farm, including assigning workers to the same work crews each day, taking additional trips to transport workers to worksites on buses, taking workers' temperatures each day, spreading workers in the field, and providing additional wash stations in the fields. Nevertheless, if workers share seasonal housing with one another, cook and eat meals together, or share childcare responsibilities among several families, among other shared activities, then COVID-19 could spread in seasonal farm labor communities even if the work environment is safe. Furthermore,

[14] Race/ethnicity is unknown for 231,446 (34.1%) of cases. The only ethnicity that surpasses the Latino COVID-19 rate is Native Hawaiian and Pacific Islander with 1,834.3 cases per 100,000 residents.

increased activity on farms is often associated with increased employment in other related industries, such as fruit packing and shipping.

Although identifying the mechanisms that link FVH employment to new COVID-19 cases is beyond the scope of this paper, the results provide strong suggestive evidence that FVH employers are facing mounting risks of labor shortages in correspondence with increasing county FVH employment due to potential COVID-19 outbreaks. Farms with greater production risk, and farmers with better information about technologies that reduce production risk typically place lower option value on waiting to adopt the technology (Koundouri, Nauges, and Tzouvelekas, 2006). Increased risk of labor shortages combined with increased marginal cost of labor to implement social distancing and safety measures on-farm suggest that the coronavirus pandemic could spur increased efforts to mechanize FVH production.

Investments in developing labor-saving technologies are expected to emerge first for the most vulnerable crops and gradually expand to more crops and more geographical settings, similar to Griliches (1957) findings for the diffusion of hybrid corn. Numerous variables factor into a producer's decision to adopt a new technology, and producers are not homogeneous. Just and Zilberman (1988) find that the joint distribution of risk preferences, farm size, access to credit, and the stochastic structure of alternative production activities is critical in determining who adopts a new technology and who benefits from government policies to encourage adoption. Interest rates dipped down to historical lows during the coronavirus pandemic, potentially reducing the costs of capital investments, and government appropriations to agricultural producers could influence producers' production and investment decisions in the short-term.

## Conclusion

This paper measures the relationship between expected month-to-month changes in agricultural employment within counties and new cases of COVID-19 each month from March-October 2020. The results suggest that the employment of 100 additional agricultural workers within a county is associated with an 6 new cases of COVID-19. More labor-intensive agricultural activities appear to have a larger and more robust effect on COVID-19 spread, and employment of 100 additional workers in fruit, vegetable, and horticultural (FVH) sectors is associated with 21 new cases of COVID-19.

Results are robust to the inclusion of state-by-month fixed effects, but do not preclude the possibility that other social activities correlated with agricultural employment could be responsible for the observed relationship. Nevertheless, the findings have important implications for agricultural producers and consumers. Outbreaks of COVID-19 in agricultural communities as employment rises increase the risk of farm labor shortages at critical stages of production. Potential health risks to workers are a public concern, and new strategies may need to be implemented to help protect farm workers' safety. Labor shortages could also be very costly to individual producers, and in the extreme event, labor shortages could lead to regional or national food shortages for consumers.

Employer policies to increase social distancing in the workplace likely slow the spread of COVID-19. Nevertheless, these precautions come at considerable cost to the employer and do not entirely remove the risk of COVID-19 outbreaks. COVID-19 preventative measures increase the marginal cost of labor, and the results in this paper suggest that agricultural producers also bear considerable profit risk due to potential COVID-19 outbreaks in farm worker communities.

If COVID-19 outbreaks prevent producers from harvesting crops, consumers may experience food shortages, particularly among labor-intensive FVH commodities. There were numerous food shortages on grocery shelves in March and April 2020, but these shortages were due primarily to major disruptions in U.S. food supply systems. The U.S. food supply chain is not equipped to rapidly shift from wholesale supply for restaurants and cafeterias to retail supply for direct-to-consumer purchases. Consequently, when restaurants and cafeterias closed and consumption moved almost exclusively to grocery retailers in March 2020, grocery retail stores experienced food shortages, even though farms often had stockpiles of produce and no place to sell their products. Over time, as the food supply system adjusted to a new equilibrium and restaurants began to open, many of the shortages and gluts previously seen along the food supply chain disappeared.

However, if workers cannot harvest crops due to COVID-19 outbreaks in farm labor communities, then there may be shortages that stem from the farms themselves.

The current rise in farm labor costs and increased risk of labor shortages induced by COVID-19 are expected to accelerate investments in technological innovations that make the U.S. food production more resilient to labor supply shocks. The results in this paper suggest that fruits, including berries and other non-citrus fruits, along with greenhouse products may be particularly susceptible to local COVID-19 outbreaks. Thus, one would expect investments in labor-saving technologies to increase most rapidly in these industries. Ideally mechanization in the FVH sector, including the use of robotics, would improve worker safety and create more skilled, higher-paying jobs while simultaneously reducing the risk of labor shortages on farms and food shortages for consumers.

## Appendix

Weather conditions in 2017 and 2020 were similar. Thus month-to-month changes in agricultural employment in 2017 are a plausible proxy for expected agricultural employment in 2020 absent the coronavirus pandemic. Figure 4 shows average temperature percentiles from January-June 2017 and 2020, and figure 5 shows total precipitation percentiles. As the maps illustrate, most regions of the United States experienced drier and warmer than average conditions in both years.

Unlike the first half of 2020, May 2018-April 2019 was the wettest 12-month period on record for the United States, and the unusually high precipitation delayed planting (Rippey, 2019). Figure 6 shows monthly employment in fruit, vegetable, and horticultural crop production in 2017 compared to 2019. Both years follow similar patterns with employment rising and peaking in summer months, but employment rises more quickly and peaks sooner in 2017.

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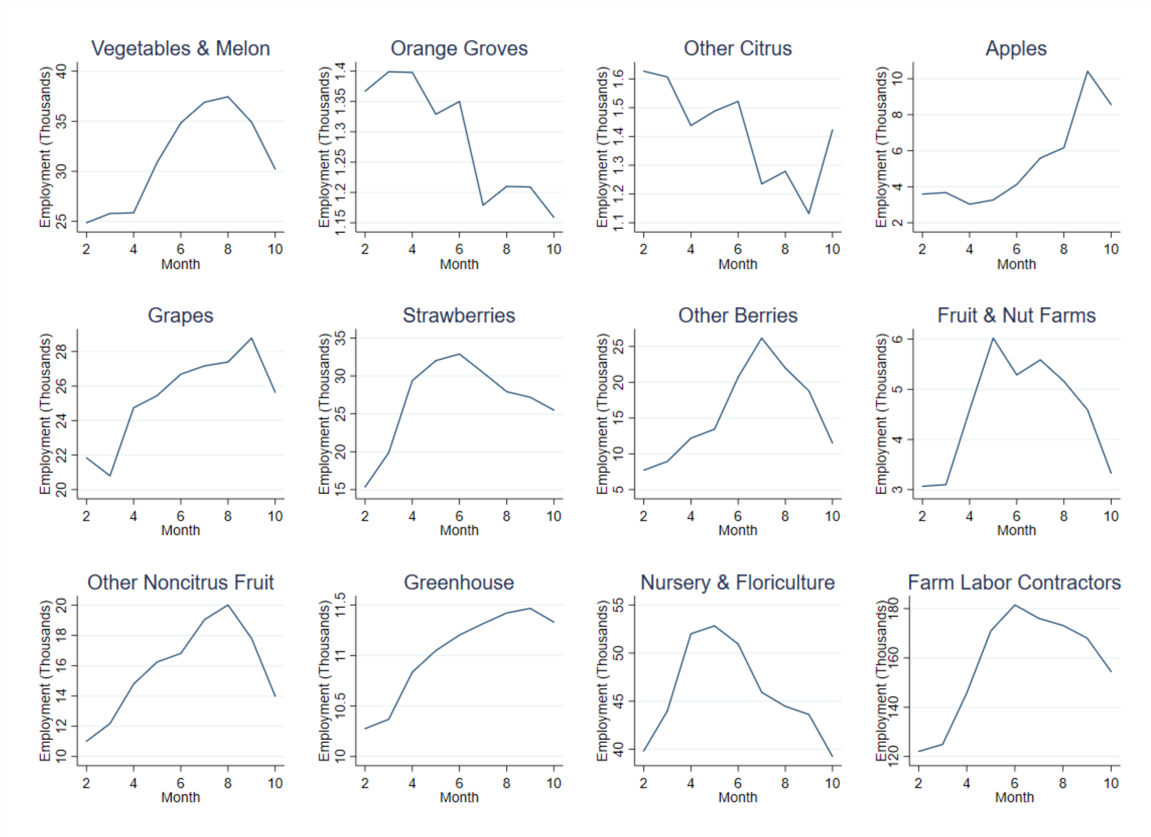


Figure 1: Monthly Employment by Crop (2017)

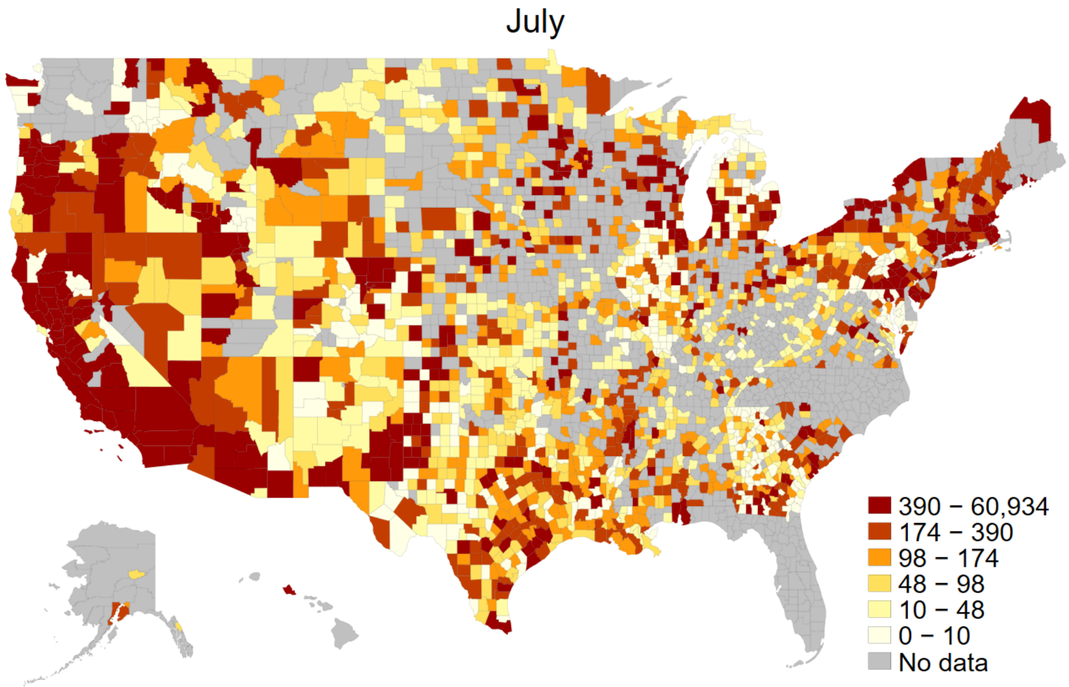


Figure 2: Geographic Variation in Fruit, Vegetable, and Horticultural Employment in Peak Month

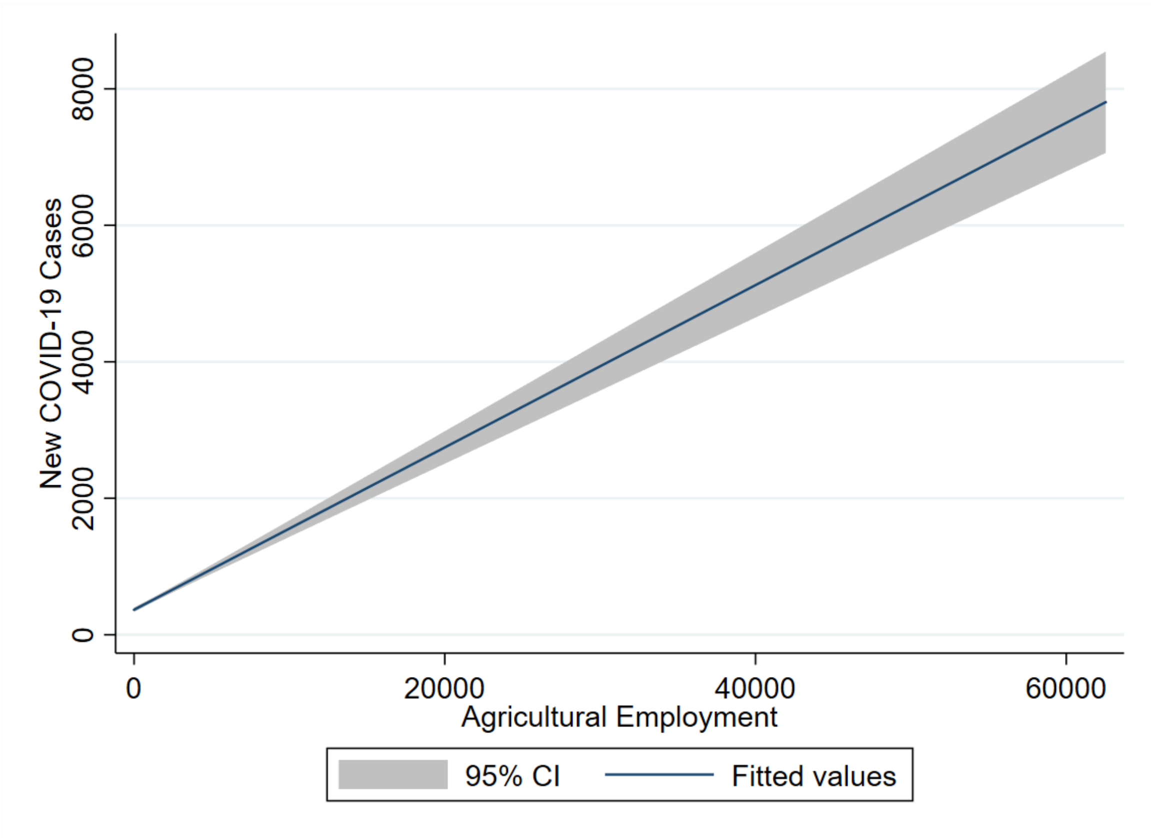


Figure 3: Correlation between Monthly Agricultural Employment and New COVID-19 Cases (County Level Observations)

Comparison of Temperatures 2017, 2020

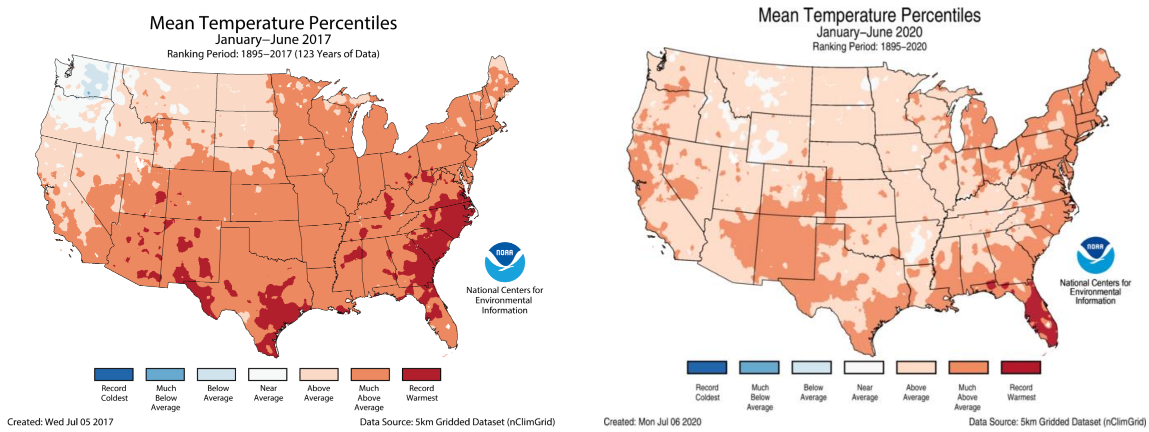


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Figure 4: Comparison of Temperatures in 2017 and 2020

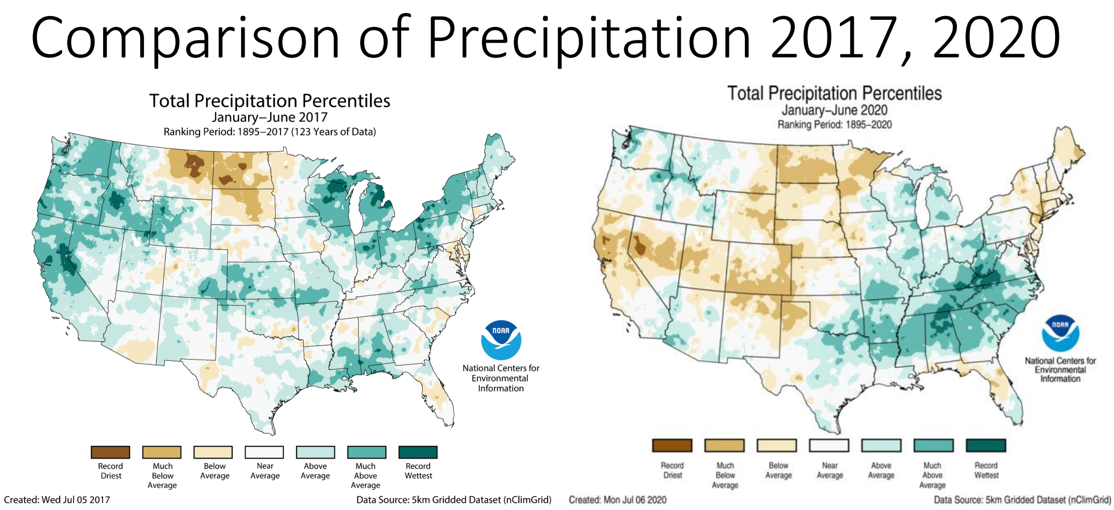


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Figure 5: Comparison of Precipitation in 2017 and 2020

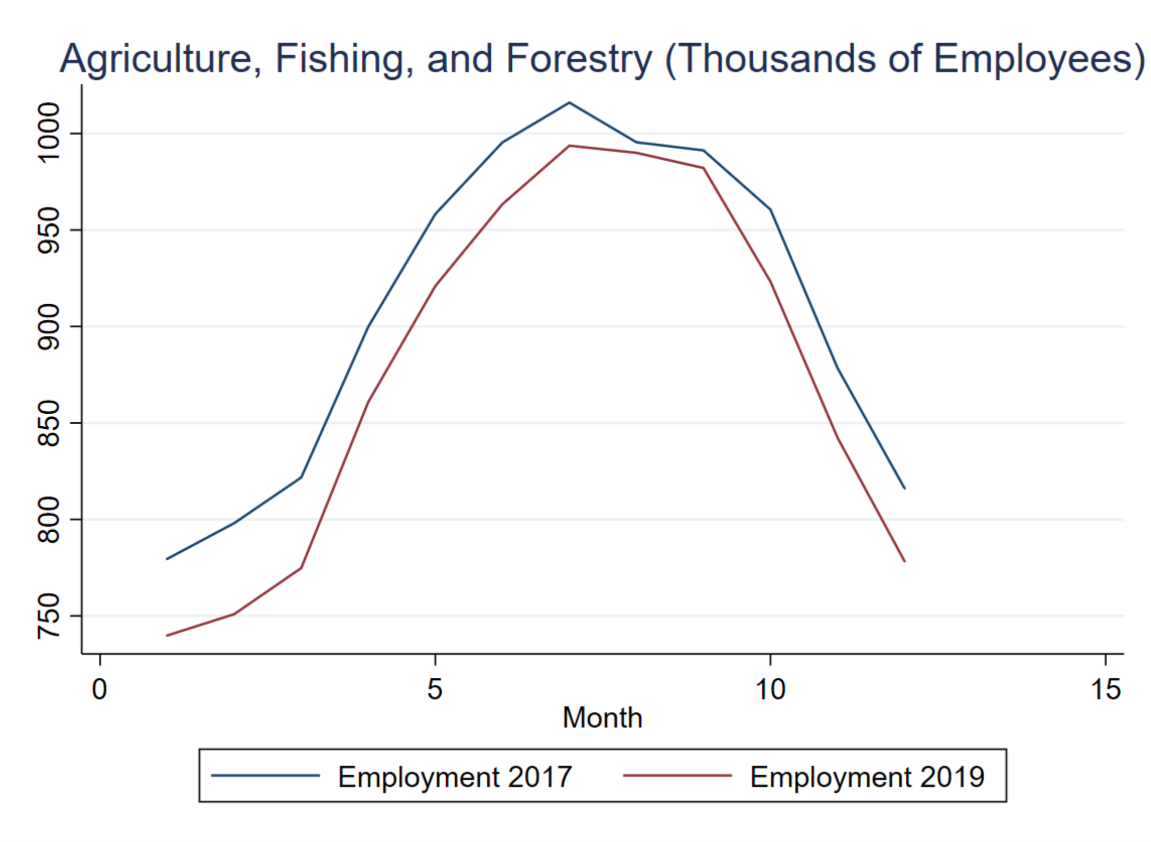


Figure 6: Comparison of Fruit, Vegetable, and Horticultural Employment between 2017 and 2019

Table 1: Association between Monthly Changes in Expected Agricultural Employment and COVID-19 Cases

| | (1) COVID Cases | (2) COVID Cases | (3) COVID Cases | (4) COVID Deaths | (5) COVID Deaths | (6) COVID Deaths |
|---|---|---|---|---|---|---|
| A. Agriculture, Forestry, Fishing, and Hunting Employment (Hundreds of Expected Workers) | | | | | | |
| Agricultural Employment | 13.75* | 10.01* | 6.40* | 0.11 | 0.15 | 0.04 |
| | (7.984) | (5.529) | (3.462) | (0.241) | (0.185) | (0.120) |
| B. Fruit, Vegetable, and Horticultural Employment (Hundreds of Expected Workers) | | | | | | |
| FVH + FLCs | 35.26*** | 31.88*** | 21.08*** | 0.59** | 0.68*** | 0.42*** |
| | (10.890) | (5.543) | (4.417) | (0.226) | (0.147) | (0.119) |
| Other Ag Employment | -4.26 | -8.23 | -4.59 | -0.29 | -0.29 | -0.25 |
| | (5.786) | (5.623) | (3.042) | (0.278) | (0.267) | (0.193) |
| C. Employment by Crop (Hundreds of Expected Workers) | | | | | | |
| Berries | 43.86*** | 57.76*** | 49.93*** | 2.02*** | 2.06*** | 1.81*** |
| | (14.255) | (16.654) | (13.090) | (0.550) | (0.663) | (0.587) |
| Other Non-Citrus Fruit | 66.99** | 81.16** | 86.56*** | 0.19 | 0.29 | 0.70 |
| | (31.650) | (36.154) | (26.894) | (0.923) | (0.940) | (0.537) |
| Vegetables | -60.93 | -163.56 | -90.21 | -6.98 | -6.41 | -3.68 |
| | (135.855) | (119.687) | (99.479) | (5.980) | (4.995) | (3.907) |
| Greenhouse | 1715.56*** | 1034.36* | 1030.19 | 53.68 | 55.34 | 57.95 |
| | (576.610) | (599.792) | (630.764) | (34.127) | (38.212) | (41.333) |
| Nursery & Floriculture | -30.46 | -4.47 | -2.35 | 2.08 | 2.08 | 1.60 |
| | (27.536) | (32.010) | (31.031) | (2.694) | (2.801) | (2.494) |
| FLCs | 32.70 | 17.16 | -16.80 | 0.16 | 0.24 | -0.74* |
| | (30.214) | (22.650) | (13.794) | (0.709) | (0.720) | (0.417) |
| Other Ag Employment | -5.52 | -6.90 | -0.73 | -0.10 | -0.10 | -0.01 |
| | (4.289) | (4.401) | (2.138) | (0.199) | (0.175) | (0.119) |
| Month FE | Y | Y | N | Y | Y | N |
| State-by-Month FE | N | N | Y | N | N | Y |
| Non-Farm Employment Controls | N | Y | Y | N | Y | Y |
| Observations | 15126 | 15126 | 15126 | 15126 | 15126 | 15126 |

Robust standard errors clustered at the state. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. FVH Employment includes employment on orange groves, citrus groves, greenhouse, nursery, and floriculture production, vegetable and melon farming (excluding potatoes), apple orchards, grape vineyards, strawberry farming, other berry farming, fruit and tree nut combination farming, and non-citrus fruit farming. Vegetables include melons but not potatoes. Other Ag Employment includes all other employment categorized under NAICS code 11 (Agriculture, Forestry, Fishing and Hunting). All specifications include county fixed effects.

Table 2: Association between Expected Agricultural Employment and COVID-19 Cases in California Only (Employment Measured in Hundreds of Workers)

| | (1) Cases | (2) Cases | (3) Deaths | (4) Deaths | (5) Hospitalizations per Day | (6) Hospitalizations per Day |
|---|---|---|---|---|---|---|
| Berries | 46.09 | 3.64 | 1.73 | 0.82 | 1.76 | 0.74 |
| | (103.130) | (35.117) | (2.836) | (1.443) | (2.872) | (1.451) |
| Other Non-citrus Fruit | 79.85** | 107.96*** | 0.94 | 1.01 | 2.17** | 2.04*** |
| | (37.264) | (38.320) | (1.169) | (1.122) | (0.951) | (0.656) |
| Vegetables | -8.23 | 89.81 | -1.49 | 0.99 | -2.76 | 0.13 |
| | (213.320) | (130.734) | (5.312) | (3.255) | (6.099) | (3.409) |
| Greenhouse | 1637.13 | 489.19 | 43.61 | 37.36 | 10.21 | 30.80 |
| | (4294.843) | (2369.719) | (95.405) | (62.357) | (75.913) | (63.312) |
| Nursery & Floriculture | 38.46 | 299.04 | 8.20 | 11.80 | 7.30 | 7.48 |
| | (167.291) | (291.557) | (5.260) | (7.838) | (11.124) | (8.115) |
| FLCs | -7.00 | -5.99 | -0.69 | -0.54 | -0.54 | -0.33 |
| | (64.658) | (32.888) | (1.510) | (0.871) | (1.469) | (0.865) |
| Other Ag Employment | -2.54 | 5.01 | 0.03 | 0.15 | 0.15 | 0.28 |
| | (11.290) | (10.863) | (0.322) | (0.309) | (0.329) | (0.332) |
| Observations | 441 | 441 | 441 | 441 | 441 | 441 |

Robust standard errors. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All specifications include county fixed effects and month fixed effects.