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Energy Prices, the Financial Crisis, and Their Implications for Land Policies in California

Junjie Wu, Steven Sexton, Joel Ferguson, and David Zilberman

The more than doubling of fuel prices between 2001 and 2006, combined with lax lending practices, triggered the collapse of the housing market that ultimately led to the Great Recession of 2008. In California, commuter communities with relatively lower income and located greater distances from the coastal urban centers suffered the largest declines in housing value and highest rates of foreclosure. Our analysis suggests that relaxing land use regulation to improve housing opportunities in urban centers will increase the resilience of the housing market, while policies that raise energy costs will increase its vulnerability (at least in the short run).

The Great Recession of 2008 devastated the lives of many communities and individuals in California and elsewhere. The recession was preceded by a major collapse in the housing market, especially in California, which triggered the bankruptcy of major banks. There is a broad agreement that the 2007 housing crisis triggered the 2008 economic recession. The Financial Crisis Inquiry Commission concluded that “It was the collapse of the housing bubble . . . that was the spark that ignited a string of events, which led to a full-blown crisis in the fall of 2008.”

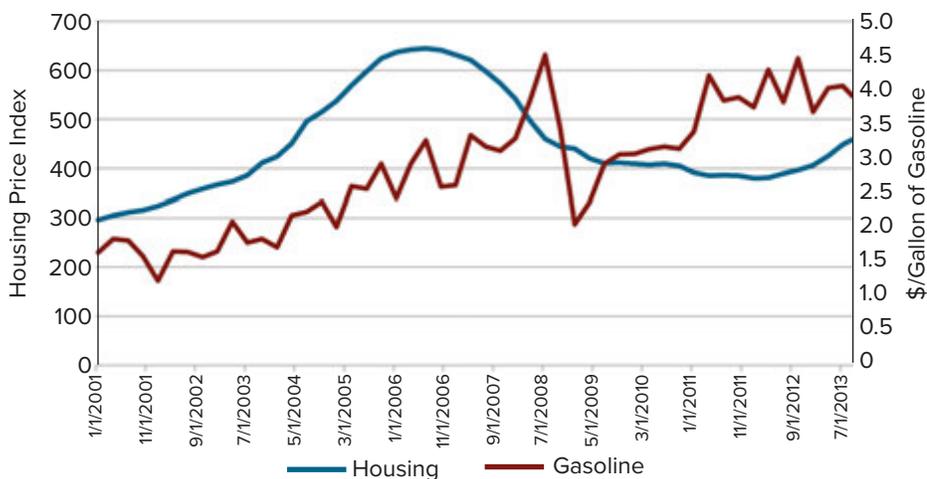
According to Steven Levy, director of the Center for Continuing Study of the California Economy, “[California was the] epicenter of the housing bubble, and . . . the epicenter of the fallout.” California’s rate of bankruptcy was almost twice the national rate. A broad set of policies was introduced to tighten regulation of financial markets and lending practices to ensure against future collapses in the housing market.

In this paper, we argue that a more than doubling in gasoline prices between 2001 and 2006 precipitated a housing

market collapse across the U.S. that induced mortgage defaults and triggered the Great Recession. As most Californians intuitively understand, distance to city centers like San Francisco and Los Angeles greatly determines home value because greater distances imply longer and costlier commutes. This principle of urban economics dictates that as commute duration or transportation costs rise, home values will fall with distance from city centers. A spike in gasoline prices could cause home values to tumble in suburban and exurban bedroom communities occupied mostly by commuters, who tend to have relatively lower income than homeowners in cities.

Our analysis suggests that continuous urban sprawl makes California’s housing market vulnerable to future energy price shocks that may be triggered by market forces or government policies. We will proceed with a conceptual exposition of our perspective, followed by an analysis of the impact of energy price shocks on the housing market in California, and conclude with a policy discussion.

Figure 1. Gasoline and Housing Prices in California 2001–2014



Sources: U.S. Federal Housing Finance Agency and US Energy Information Administration

The Link Between Energy and Housing Prices

We can demonstrate the effect of gasoline prices on home values with a simple model of homeownership and location decisions. Suppose a household has the choice of renting in the city or owning a house in the suburbs. A household prefers to rent in the city if the benefit of the housing services in the city minus the rent is greater than the benefit of the housing services in the suburbs minus commute costs and other costs of homeownership, including net mortgage costs, opportunity cost of the down payment, maintenance, insurance, taxation, and depreciation or appreciation. A household that has decided to own a house will select the location that maximizes the benefit from housing services minus the costs of ownership and commuting.

We assume that households vary in their income and bid on houses at different locations. The price at each location is the willingness to pay of the household that values living at that location the most. Given other factors, the value of living away from the urban center is declining in transportation costs. Therefore, house prices decline with distance, and, thus, relatively low-income households are likely to rent in the city or purchase homes in

commuter communities farther away from the cities.

Moreover, a reduction in transportation costs may lead to an increase in the value of houses, especially those farther away, and to the expansion of the urban boundary. Housing may compete with agricultural and industrial land uses, and a reduction in transportation costs makes housing relatively more valuable compared to other uses.

An increase in the cost of commuting is likely to reduce the price of houses away from the city because buyers are willing to pay less for such houses as the net benefits from living at those locations decline. A large gasoline price shock that causes such home values to decline substantially may lead homeowners to go “underwater.” That is, the value of their houses may be less than their remaining mortgage debt. The likelihood of being underwater amid a gasoline price shock increases in distance from the urban center, all else held constant.

Homeowners farther from the city face a choice of staying in their homes or defaulting and moving away. Those who realize that the costs in terms of transportation and mortgage are greater than the benefit of holding their house will declare bankruptcy. The vulnerability of a homeowner to energy

price shocks is greater the larger the amount of the mortgage debt that they owe. At a given location, a household is more likely to be underwater if they paid a low down-payment, the term of their mortgage is longer, they are new homeowners, or the depreciation in the value of the house is greater relative to other homeowners.

The extent of the vulnerability to high energy shocks depends on the distribution of the population across space. The size of the population that is vulnerable to energy price shocks is likely to increase with the number of households located farther from cities. The distribution of a population is affected by zoning policies.

Zoning regulations that limit the expansion of housing near employment centers are likely to lead to the development of large commuter communities farther from urban centers. The pairing of market forces that lead to a spike in energy prices with land-use policies that cause low-income individuals to reside farther away from employment centers may lead to drastic disruption of real estate and financial markets.

The Case of California

Before the housing market collapse in 2008, California realtors described a “drive ‘til you can buy” phenomenon in which families drove away from city centers until they found communities with homes they could afford. In the greater Los Angeles and San Francisco metropolitan areas, some commuters travel 50–100 miles or more to and from work each day. Many of the bedroom communities in California were built relatively recently or experienced rapid growth before the housing bust. Lax lending practices that required low down payments from homeowners but large loan payments increased the likelihood of bankruptcy.

Between 2002 and 2008, nominal gasoline prices rose from \$1.38 per gallon to \$4.15. To a commuter traveling 3,000

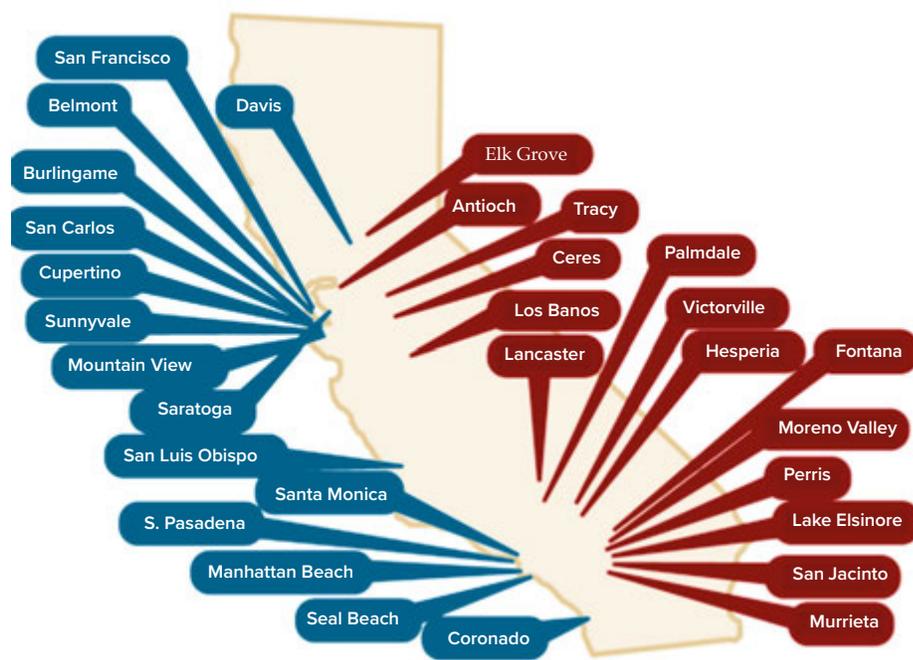
miles per month in a 20 miles-per-gallon vehicle, transport costs increased \$415 per month. To a commuter traveling 4,500 miles per month in a less efficient 15 miles-per-gallon vehicle, transport costs increased by \$831 per month. These dramatic increases in commuter costs, especially when considered to be permanent, would significantly depreciate the value of the house and drive the homeowner underwater. Such a combination of deteriorating cash flow and asset situations are sufficient to cause a low-income family to consider defaulting on a loan.

Studies show that seven of the vulnerable communities in California were among the 20 metropolitan areas nationwide with the highest rates of foreclosure activity in 2010, including Modesto (3rd), Riverside-San Bernardino-Ontario (6th), Stockton (7th), and Merced (8th). Seven of the other eight cities with greatest shares of homes underwater were California communities like Merced, Vallejo, and Riverside, whose workforces commute to relatively distant major cities.

In Figure 2, we define two groups of California cities according to foreclosure rate during the financial crisis. The 15 cities with the lowest rate of foreclosure form the resilient group and the 15 cities with the highest rate of foreclosure form the vulnerable group. As Figure 2 suggests, the vulnerable group is located mostly inland, and the resilient group is mostly located along the coast and proximal to San Francisco or Los Angeles.

Complementary to Figure 2, we show in Table 1 characteristics of the cities with the highest and lowest rates of foreclosure in 2008. The average distance to the urban core of the resilient group is 28.8 miles, whereas the vulnerable group averages 67 miles. Average family income is \$44,690 in the vulnerable group and \$120,344 in the resilient group. The average amount spent on gasoline in the vulnerable cities jumped from about \$1,723 in 2000

Figure 2. Resilient (Blue) and Vulnerable (Red) Cities in California



Source: RealtyTrac and CoreLogic

to about \$4,600 in 2008.

The average housing price drop was 57% in the vulnerable group and 6% in the resilient group, and foreclosure rates were 15.78% in the vulnerable group and 0.74% in the resilient group. The foreclosure rates reached a peak between 2008 and 2010, but were still very high in 2011. In that year, Stockton had the second-highest foreclosure rates, Modesto was third, and seven out of the 20 metropolitan areas with the highest foreclosure rates in the U.S. were in California.

Regional and urban planning strategies that restrict growth exacerbate vulnerability to energy price shocks in California. These strategies result in strict zoning policies that impede housing construction in major urban centers with growing employment opportunities. These policies push lower-income families to far-flung bedroom communities. For example, San Francisco limited the height of housing buildings and approved only a fraction of the required housing requests, leading to a growing gap between demand and supply for housing in the Bay Area. As Silicon Valley has grown, these policies

have contributed to urban sprawl, resulting in the expansion of communities in the Central Valley. Likewise, housing expanded rapidly in the Inland Empire of Southern California, yielding lengthy commutes into Los Angeles.

Conclusion and Implications

These data and our model of housing location decisions suggest energy price shocks triggered the housing crisis of 2007 that caused the Great Recession. While others have investigated the energy price shock on the economy through its impacts on employment and consumption costs, we identify a new channel through which energy price shocks affect the financial market and the macroeconomy. We find that lax lending practices yielded a cohort of low-income homeowners located far from cities who were vulnerable to energy price shocks. While price volatility is not generally considered an important determinant of economic growth because of opportunities to smooth such volatility, highly leveraged households may not be able to withstand such volatility—particularly those who do not perceive the shocks

through their impacts on transport costs and housing prices.

The 2018 French Yellow Vest Movement ignited by fuel carbon tax hikes underscores how significantly climate policy and energy costs can affect the livelihood of low-income households. One great challenge of climate change policy is reducing greenhouse gas emissions associated with commuting without hurting vulnerable populations. We challenge researchers, policymakers, and urban planners to change guidelines, zoning regulations, and incentives for urban developers so that more people can live near their workplaces in urban centers to avoid the burden and social costs of heavy commuting.

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For additional information, the authors recommend:

Wu, J., S. Sexton, and D. Zilberman, 2019. "Energy Price Shocks, Household Location Patterns, and Housing Crises: Theory and Implications." *Energy Economics* 80(May): 691-706.

Table 1. California City Characteristics by 2010 Foreclosure Rate

| Rank | City | Distance To Nearest City (miles) | Mean Commute (minutes) | Annual Foreclosure Rate (%) | Nearest City | Mean Income (\$) | Gas Cost Increase 2000-2008 |
|--|-----------------|----------------------------------|------------------------|-----------------------------|--------------|------------------|-----------------------------|
| a. Highest Rates of Foreclosure | | | | | | | |
| 1 | Victorville | 84.8 | 33.72 | 20.40 | LA | 42,485 | 3,051 |
| 2 | Murrieta | 65.4 | 35.99 | 18.96 | SD | 72,422 | 2,910 |
| 3 | Los Banos | 79.7 | 39.20 | 18.48 | SJ | 43,370 | 2,827 |
| 4 | San Jacinto | 85.2 | 31.62 | 17.40 | LA | 35,600 | 2,989 |
| 5 | Palmdale | 62.6 | 42.48 | 17.28 | LA | 47,699 | 3,065 |
| 6 | Elk Grove | 16.7 | 30.75 | 16.92 | Sac | 59,878 | 2,759 |
| 7 | Lake Elsinore | 70.6 | 39.78 | 16.68 | LA | 42,111 | 3,124 |
| 8 | Tracy | 63.0 | 40.43 | 16.56 | SF | 49,207 | 2,823 |
| 9 | Perris | 72.2 | 36.74 | 16.44 | LA | 36,056 | 2,973 |
| 10 | Lancaster | 69.5 | 33.57 | 14.40 | LA | 42,657 | 2,886 |
| 11 | Fontana | 49.8 | 37.80 | 13.80 | LA | 38,347 | 2,504 |
| 12 | Moreno Valley | 64.4 | 33.91 | 13.68 | LA | 38,358 | 2,718 |
| 13 | Antioch | 45.3 | 42.06 | 12.48 | SF | 45,953 | 3,156 |
| 14 | Ceres | 94.6 | 26.99 | 12.12 | SJ | 37,184 | 2,538 |
| 15 | Hesperia | 79.5 | 37.30 | 11.16 | LA | 39,018 | 3,249 |
| | Average | 66.9 | 36.16 | 15.78 | | 44,690 | 2,905 |
| b. Lowest Rates of Foreclosure | | | | | | | |
| 1 | Davis | 15.3 | 20.75 | 0.48 | Sac | 63,478 | 2,211 |
| 2 | Cupertino | 48.0 | 25.81 | 0.48 | SF | 126,859 | 2,244 |
| 3 | Seal Beach | 29.6 | 30.63 | 0.60 | LA | 70,675 | 2,218 |
| 4 | Mtn. View | 12.9 | 20.91 | 0.60 | SJ | 95,252 | 1,879 |
| 5 | Santa Monica | 15.8 | 25.00 | 0.60 | LA | 101,401 | 1,501 |
| 6 | Burlingame | 15.8 | 27.06 | 0.72 | SF | 218,989 | 2,146 |
| 7 | Manhattan Beach | 21.1 | 29.20 | 0.72 | LA | 204,052 | 1,772 |
| 8 | Coronado | 6.4 | 17.39 | 0.72 | SD | 99,032 | 2,831 |
| 9 | S. Luis Obispo | 185.0 | 15.60 | 0.84 | SJ | 61,319 | 2,130 |
| 10 | San Carlos | 24.4 | 26.69 | 0.84 | SF | 131,613 | 2,252 |
| 11 | Saratoga | 13.4 | 26.40 | 0.84 | SJ | 260,549 | 2,812 |
| 12 | So. Pasadena | 8.6 | 27.44 | 0.84 | LA | 91,396 | 1,782 |
| 13 | San Francisco | 1.0 | 26.16 | 0.96 | SF | 87,099 | 1,583 |
| 14 | Sunnyvale | 11.8 | 23.86 | 0.96 | SJ | 89,544 | 1,811 |
| 15 | Belmont | 23.3 | 28.37 | 0.96 | SF | 103,908 | 2,320 |
| | Average | 28.8 | 24.75 | 0.74 | | 120,344 | 2,099 |

Source: Wu, J., S. Sexton, and D. Zilberman, 2019. "Energy Price Shocks, Household Location Patterns, and Housing Crises: Theory and Implications." *Energy Economics* 80(May): 691-706.

to be temporary. In 2008, few anticipated the fracking boom that would usher in a period of relatively cheap energy. Instead, headlines debated when oil production would peak.

There is a growing number of policy initiatives aiming to relax zoning restrictions and otherwise promote housing construction. These policies will expand housing supply and

presumably moderate growth of home prices, but they will not diminish the vulnerability of inland communities to increases in commute costs. Policies intended to further reduce carbon emissions in California, like gasoline or carbon taxes and renewable fuel standards, could be regressive in the sense that their cost could be borne disproportionately by suburban homeowners

California Farmers Change Production Practices As the Farm Labor Supply Declines

Zachariah Rutledge and J. Edward Taylor

A recent survey by UC Davis and the California Farm Bureau Federation discovered that California farmers are finding it increasingly difficult to recruit workers. As a result, they are continuing to raise wages and make changes to their production practices.



Results from the authors' survey confirm that farmworkers are becoming harder to find and retain, and farmers are going to have to adapt in an era of labor scarcity.

It's no secret that California is a powerhouse when it comes to specialty crop production. As the leading agricultural producer and farm employer in the United States, California's farms and ranches produced over \$57 billion worth of agricultural goods in 2016, including more than 400 different commodities.

Fruit, vegetable, and horticulture (FVH) crop production accounted for 53% (\$29.8 billion) of the value of all agricultural production in the state and 68% of non-animal agricultural production. California produces two-thirds of the nation's fruits and one-third of its vegetables. These crops require a substantial amount of manual labor to cultivate and harvest, and California farmers employ an army of workers to get their products to market.

Since the mid-20th century, California farmers have relied on an abundant supply of immigrant workers from rural Mexico, which has encouraged the expansion of labor-intensive crop production. However, mounting evidence suggests that the era of farm labor abundance is coming to an end, and this is having ripple effects throughout the state's agricultural sector.

California farmers have reported farmworker shortages for over a decade, and some farmers have left crops rotting in the fields due to a lack of available workers during harvest time. Recent studies provide evidence that the pool of available Mexican farmworkers is shrinking for a variety of structural reasons. These include changes in demographics, increased educational attainment among rural youth in Mexico, and better nonfarm

opportunities both in Mexico and the United States. Thus, there is every reason to think that the negative trend could continue.

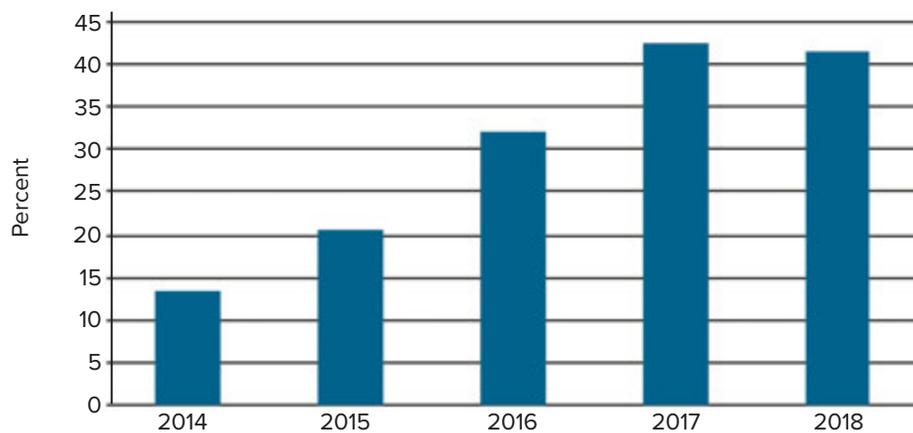
The average farm wage in California exceeds the mandated minimum wage. However, estimates suggest that real farm wages will have to increase by more than 10% over the next 10 years in order to maintain the same number of workers that are currently in the farm workforce (See Charlton et al., 2019a). Higher labor costs top the list of concerns for labor-intensive crop farmers, who already operate on tight profit margins.

Economic theory predicts that higher wages will induce farmers to adopt more labor-saving technologies and production practices and create incentives for new labor-saving research and development. In practice, rising farm wages have induced the adoption of labor-saving technologies, such as mechanical harvesters, that dramatically reduce the number of workers needed to produce some crops (See Charlton et al., 2019b). Technologies that eliminate the need for farmworkers to hand-harvest most FVH crops are currently not available. Although public institutions and private companies are hard at work developing them, farmers are relying on other adjustment mechanisms to deal with labor-availability issues.

Survey Overview

UC Davis partnered with the California Farm Bureau Federation (CFBF) to conduct a survey called "Adapting to Farm Labor Scarcity Survey." This voluntary online survey was sent out to CFBF members and various affiliated grower groups in January 2019. More

Figure 1. Percent of Farmers Experiencing a Labor Shortage During the Past Five Years



Authors' calculations from the "Adapting to Farm Labor Scarcity Survey" data.

than 1,000 California farmers participated in the survey, and 720 crop and dairy farmers completed the entire questionnaire.

The survey was designed to elicit information about production practices for farmers' main crop and county, based on the share of their total agricultural sales. Farmers responded from 54 of the 58 California counties, and over 70% of respondents reported producing fruits, vegetables, or nuts.

During 2018, the median survey respondent grew 125 acres in her main crop and county, employing five year-round workers and 10 seasonal workers. The median fruit and vegetable producer grew 107 acres of her main crop in her main county, while employing six year-round workers and 27 seasonal workers.

Farmworker Availability and Wages

Of the 749 farmers who identified their main county and crop, 58% reported not being able to obtain all the workers they needed at some point during the past five years (i.e., between January 1, 2014 and December 31, 2018). Over the past five years, the incidence of labor shortages reported by farmers increased three-fold, from 14% to 41% (see Figure 1).

Horticulture farmers (who produce ornamental, floral, and nursery crops) and wine grape farmers reported the highest incidence of labor shortages. Nevertheless, a substantial share of row-crop, grain, hay, and tree nut farmers also reported having some type of labor shortage, indicating that labor availability problems are not restricted to FVH crop production.

Not all farmers reported a labor shortage, but nine out of ten reported having to raise wages in order to obtain enough workers at some point during the past five years. Figure 2 shows that 31% of farmers reported having to raise wages in 2014, but this percentage jumped to 79% in 2018.

Farm Labor Contractors and the H-2A Visa Program

Farmers who find it more difficult to recruit workers may enlist the services of farm labor contractors (FLCs) or apply to legally contract foreign workers through the U.S. Government's H-2A visa program. Our survey reveals that both are becoming increasingly prevalent in California as a way to deal with farm labor scarcity.

Data from the Quarterly Census of Employment and Wages reveal that the share of California's farm workforce employed by farm labor contractors has increased steadily since the

1990s. Previous research found that the upward trend in FLC use during the 1990s could be explained in part by the passage of the Immigration Control and Reform Act of 1986, which imposed fines and jail time for farmers who knowingly hire undocumented workers. Because FLCs are the official employer of record, they potentially can buffer farmers from risks related to immigration and labor law violations. Nevertheless, if Immigration and Customs Enforcement (ICE) targets an FLC, the farmer who employs the FLC may still suffer from a shortage of employees.

Our survey reveals that farmers currently use FLCs to mitigate the risk of not being able to find enough workers. Sixty-four percent of respondents reported using an FLC at some point during the past five years, with 27% of respondents reporting that it was the first time they had used one. Of the 463 farmers who provided a reason for using an FLC, 65% said they used the FLC to make sure they had enough workers, 43% said they did so to reduce the administrative burden associated with employing workers, and 28% reported some other reason.

Traditionally, California farmers' use of the H-2A temporary guest-worker visa program has been very low; farmers complained about the bureaucracy and costs associated with the program. Nevertheless, their use of the program quadrupled in the last decade. Only 6% of respondents reported using the H-2A temporary guestworker visa program to bring in workers during the past five years; however, the vast majority of these reported using it for the first time during that period, revealing a recent surge in H-2A use. Most farmers who used the H-2A visa program reported that they did so to make sure that they had enough workers, again revealing an increasing need to deal with the risk of not being able to maintain an adequate farm workforce.

Labor-Intensive Crop Mix

Farmers reported changing the acreage dedicated to the production of their main crop, too. Of the 721 farmers who responded to this question, 31% reported making a change in acreage outside of a typical crop rotation at some point during the past five years. Five percent of respondents reported switching some acreage out of labor-intensive crops into non-labor-intensive crops.

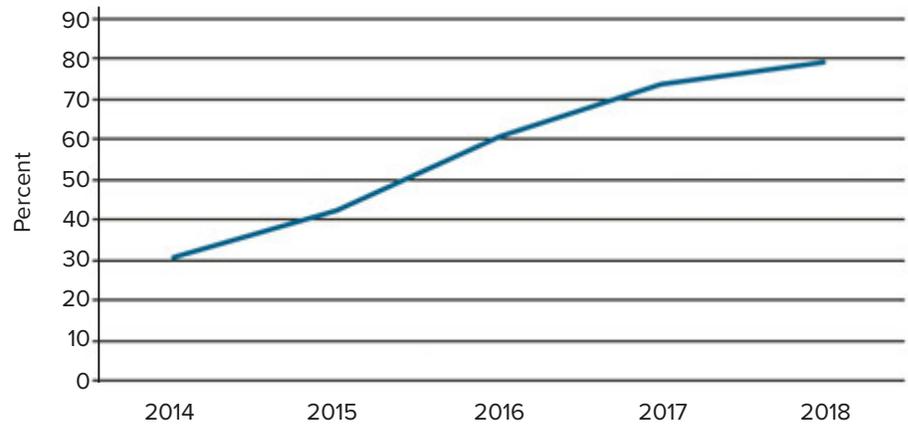
Of those farmers who switched some acreage from labor-intensive crops into non-labor-intensive crops, 78% switched acreage into nuts, and 22% switched acreage into row crops, grain, or hay. Although the survey results do not provide evidence of dramatic changes in the crop mix, they do suggest that at least some farmers are responding to labor scarcity by reducing the amount of acreage dedicated to the production of labor-intensive crops in favor of crops that permit mechanical harvesting.

Changes in Cultivation Practices

Issues related to labor availability have also caused farmers to change their cultivation practices. More than one-third (39%) reported making a change to at least one of their usual cultivation practices at some point during the past five years. Of those who changed cultivation practices, 80% said they did so either because there were not enough workers or because of rising labor costs.

Figure 3 shows that the percentage of farmers who changed cultivation practices because of labor availability increased from 7% in 2014 to 25% in 2018. The most common changes included reductions in pruning or weeding, followed by delayed pruning or weeding. However, 8% of farmers reported having to delay or reduce harvesting because there were not enough workers available, suggesting

Figure 2. Percent of Farmers Who Raised Wages to Attract Enough Workers



Authors' calculations from the "Adapting to Farm Labor Scarcity Survey" data.

that the inability to find workers during harvest time has affected their ability to generate revenue.

Labor-Saving Technology Adoption

As workers become harder to retain and wages continue to rise, the use of labor-saving technologies is becoming more attractive to California farmers. Fifty-eight percent of farmers indicated that they had used a technology that reduced their reliance upon farmworkers at some point during the past five years, including over one-third (37%) who reported using one for the first time.

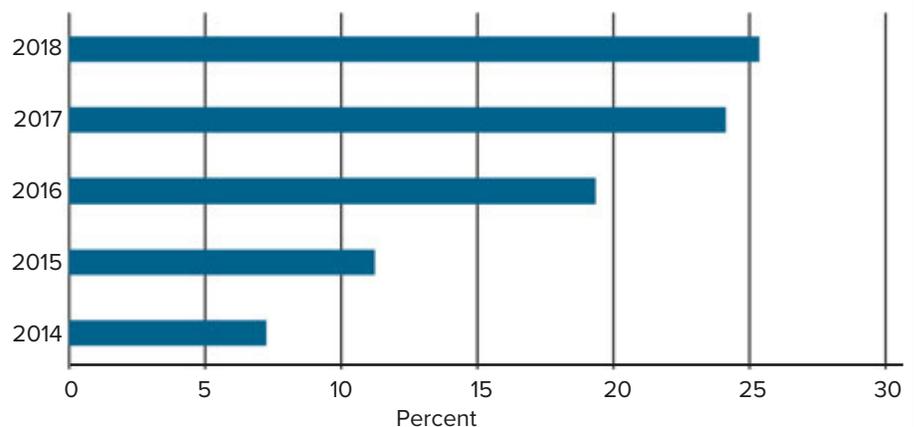
Of those who used a labor-saving technology for the first time, 72% reported using it because of rising

labor costs, and 54% used it because there were not enough workers (see Figure 4). The two most common labor-saving technologies adopted were mechanical harvesters and specialized tractor attachments. Other common responses included mechanical planters, pruners, weeders, thinners, and automated irrigation technologies.

Conclusion

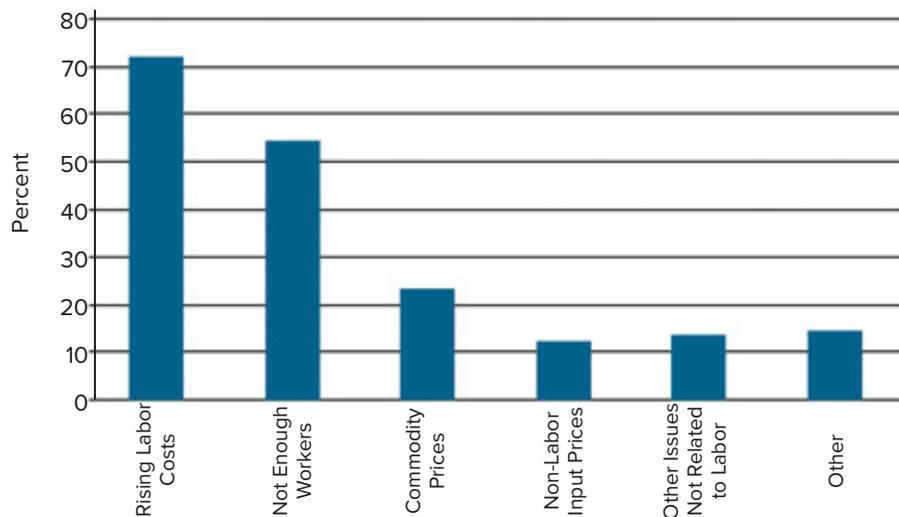
The results from the UCD-CFBF "Adapting to Labor Scarcity Survey" largely confirm the handwriting on the wall: farmworkers are becoming harder to find and retain, and farmers are going to have to adapt in an era of labor scarcity. Farm work is physically demanding and often pays less

Figure 3. Percent of Farmers Who Changed Cultivation Practices Because of Labor Availability



Authors' calculations from the "Adapting to Farm Labor Scarcity Survey" data.

Figure 4. Reasons for Adopting a Labor-Saving Technology



Authors' calculations from the "Adapting to Farm Labor Scarcity Survey" data.

than nonfarm jobs entailing a similar degree of physical labor. Data from the National Agricultural Workers Survey reveal a recent upward trend in the share of farmworkers who engage in work off the farm, suggesting that employment in other sectors of the economy is becoming an increasingly attractive alternative to farm work.

In all countries, as incomes and nonfarm employment rise, workers—particularly young people—leave the farm. Farmers have continued raising wages in an attempt to attract and retain workers, but it is clear that this has not resolved the problem.

Over the past five years, an increasing share of California farmers report using a farm labor contractor to mitigate the risk of not being able to find enough workers. Although the H-2A visa program is not widely used, California farmers are increasingly using it to gain access to foreign workers.

Some farmers have switched acreage out of FVH crop production into less labor-intensive crops, including nuts, row crops, grain, or hay, and a substantial share have changed cultivation practices because they could not find enough workers. Most farmers report using a technology that

reduced their reliance upon workers during the past five years, including many who started using a labor-saving technology for the first time during this period.

If the trends highlighted by our survey continue, farmers undoubtedly will become more reliant upon technologies that automate labor-intensive tasks, and they will find themselves under increasing pressure to seek ways to produce more crops with fewer workers.

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Livestock Guardian Dogs: Do the Benefits Outweigh the Costs for Sheep Producers?

Ellen M. Bruno and Tina L. Saitone

We evaluate the economic viability of livestock guardian dogs (LGDs) as a tool to reduce predation of sheep by coyotes. Cost-effectiveness hinges largely on the ability of the dogs to eliminate coyotes as a threat, which is driven by site-specific factors. Our results suggest that the benefits of LGDs do not always outweigh the costs.

California has the second-largest sheep inventory in the U.S., but it has declined by 34% in the last two decades, more than double the national rate over the same period. Predation is a major threat to the economic viability of sheep production in California and one of the top reasons that producers leave the industry. In the U.S., coyotes pose a persistent problem, contributing over 50% of the total kills attributed to all predators. To combat these losses, ranchers have utilized an extensive suite of lethal and non-lethal tools to reduce predation. Both lethal and non-lethal tools are costly and require ongoing effort. All vary in efficacy and come with their own sets of challenges.

Many ranchers recognize the need to use both lethal and non-lethal tools in conjunction because lethal predator suppression methods are often insufficient in isolation. Suppression of a coyote population via lethal control for an extended period of time does not cause the total population to decrease. Coyote populations can rebound to pre-lethal-control densities within three to five years because reproductive success and pup survival improve when populations are lower. Plus, remaining predators quickly move into areas where lethal control has removed competition.

Public opposition to lethal control has also increased the pressure placed on

ranchers to adopt non-lethal methods. Concerned with livestock-predator conflicts and maintaining ecosystem diversity, some conservation biologists and animal rights activists have become increasingly vocal about their opposition to all available lethal depredation tools. As a result, certain jurisdictions, like Marin County, have discouraged lethal control and implemented programs to offset the costs associated with non-lethal tools. Yet, the elimination of lethal control reduces the flexibility with which producers can respond to the threat of predators, further threatening ranchers' economic viability.

Livestock guardian dogs (LGDs) are one of the most common non-lethal tools adopted by sheep producers and have generally been shown to be effective at reducing predation. However, their efficacy varies by the type of predator, terrain, and dog-to-ewe ratio. A lack of information surrounding the profitability associated with the adoption of different tools impedes ranchers' efforts to manage predation problems caused by wildlife. Despite the promise of LGDs, little work has been done to quantify the benefits associated with reduced predation via LGDs and compare these benefits to the costs in a comprehensive way.

We performed a comprehensive economic assessment of LGDs as a depredation tool using data from a University of California research station in Mendocino County, CA. We utilized detailed data collected over five years that allowed us to capture previously unknown components, such as the rate of lamb and ewe mortality, culling of LGDs, and labor hours associated with maintenance, allowing us to provide the first estimate of the cost-effectiveness of LGDs in the United States.

Study Location

The Hopland Research and Extension Center (HREC) is home to the University of California's sheep research flock. HREC maintains exceptional records along all three margins required for this study: the tagging and tracking of individual sheep, which allowed us to calculate reproductive rates and attribute losses to predators, detailed production data, including weights and market values that enabled the quantification of benefits of flock preservation, and, lastly, cost data on feed, veterinarian expenses, and labor associated with LGDs. We used HREC data spanning 2013 to 2017 to estimate the cost-effectiveness of LGDs on a representative commercial sheep operation of 500 breeding ewes with an average reproductive rate of 1.12 lambs per ewe per year.

Research suggests that a livestock guardian dog can provide protection for approximately 100 ewes in most settings. Thus, we modeled five LGDs on the representative operation. Based on these stocking rates, we compared the present value of expected future benefits (i.e., reduced lamb and ewe losses) with the present value of costs associated with investing in and maintaining LGDs. Future expected benefits and costs were discounted to the present at a rate of 3% over a seven-year period, the useful life of an LGD.

Estimated Benefits of LGDs

The main component of benefits associated with adopting LGDs as a depredation tool comes from the ewe and lamb losses that would have occurred in the absence of the LGDs. We estimated that the deployment of LGDs reduced lambs lost to coyotes by 43% each year at HREC. Given a representative breeding ewe flock of 500

Table 1. Timeline and Discounted Values (\$) for Components of Benefits and Costs from Using Five LGDs to Protect Lambs and Ewes

| Components | Value | | | | | | | |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| | Year 0 | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 |
| Benefits | | | | | | | | |
| Reduced Lamb Predation | 0 | 0 | 1,133 | 2,200 | 2,136 | 2,074 | 2,014 | 1955 |
| Reduced Ewe Predation | 0 | 0 | 461 | 896 | 870 | 844 | 820 | 796 |
| Costs | | | | | | | | |
| Investment | 2,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Food | 0 | 3,170 | 3,078 | 2,988 | 2,901 | 2,816 | 2,735 | 2,655 |
| Veterinarian | 0 | 1,019 | 990 | 961 | 933 | 906 | 879 | 854 |
| Replacement | 0 | 133 | 123 | 135 | 79 | 78 | 85 | 94 |

Note: All displayed values have been discounted to the present at a rate of 3%.
Source: Authors' calculations

and reproductive rate of 1.12, LGDs are anticipated to reduce lamb predation by 27 head per year. During the study period, the average sale price for feeder lambs was \$1.37/lb and lambs were sold at an average weight of 65 lbs. Thus, savings from reduced lamb predation were estimated to be \$2,404 per year.

We also found that the deployment of LGDs corresponded to a drop in ewe predation of 25% per year, or four ewes each year on the representative operation. HREC sold running age ewes, i.e., females incorporated in commercial breeding flocks, for an average price of \$244.75 per head. The prices HREC received for these animals reflects the net (i.e., after cost) value of their remaining useful life as a capital asset, which includes producing lambs and wool, and their salvage value (i.e., value at the time of cull and slaughter). The estimated savings associated with reduced ewe predation totaled \$979 per year.

Given that LGDs are investments that have an average useful life of seven years, we must calculate all expected future benefits associated with LGDs over that time period with appropriate adjustments for the time value of money. The present value of the total anticipated savings associated with reduced lamb and ewe predation over

the seven-year horizon was estimated to be \$16,200, given our 3% discount rate.

Estimated Costs of LGDs

LGDs are considered capital investments that depreciate over time. In the initial period, the rancher faces the purchase costs, which vary by the breed and age of dog at the time of purchase. While puppies are less expensive to purchase initially, they involve substantially higher costs to train and are not effective immediately. For our analysis, we assumed dogs were purchased as puppies for \$400 each for a total initial investment of \$2,000 for five pups. We assumed these young LGDs were not effective at reducing predation in their first year and only 50% effective during their second year.

When calculating the costs, it is also necessary to include the risks associated with mortality and necessary culling of the LGDs. Evidence suggests that 45% of LGDs died or were put down during their useful life, with the risk being higher for pups. Assuming the mortality rate for each LGD in a given year was 11% if younger than 38 months and 5% if 38 months or older, then the present value of expected total replacement costs would be \$728, which is 36% of the initial purchase cost of \$2,000.

Maintenance costs for LGDs include dog food and veterinary expenses. Over the five years we observed at HREC, veterinarian costs averaged \$210 per dog per year and food averaged \$654 per dog per year. In total, the discounted present value of anticipated costs associated with using five LGDs as a non-lethal depredation tool over the investment's useful life totaled \$29,612.

Table 1 summarizes the different components that enter the benefit and cost calculations in each time period. The limited effectiveness of pups in their first two years are reflected by the lack of benefits realized in years 1 and 2. All displayed values are discounted.

Net Present Value

We estimated the discounted stream of future expected net benefits to assess the economic viability of investing in LGDs, illustrated by Figure 2, and found that costs exceeded benefits by a total of \$13,412 over the seven-year period. This translates to a benefit/cost ratio of about 0.55.

There are three important things to keep in mind when interpreting this result. First, HREC may have experienced lower efficacy rates than one may expect on the typical commercial sheep operation in the Western U.S. Past surveys on the effectiveness of LGDs have shown 68% of respondents reporting that LGDs eliminate predation entirely. In this scenario, a total of 65 lambs and 12 ewes would have been saved by LGDs from coyote predation, relative to the pre-control baseline. Thus, savings from reduced lamb and ewe predation would be \$5,788 and \$2,937 per year, respectively. Under these conditions, the present value of benefits would exceed the costs by \$12,164 over the seven-year period, equivalent to a benefit-cost ratio of 1.41.

LGD effectiveness is dependent on a number of site- and operation-specific

factors including size of pasture, changes in elevation, tree cover, perimeter fencing, ewe-to-LGD ratio, and the discount rate. In order to enhance the potential efficacy of LGDs, producers may need to make changes to other aspects of their operation, which may have additional costs. LGD ability and efficacy also depend on genetics and training. As noted, many dogs do not have the temperament or proclivity for protection and need to be culled. Thus, producers considering incorporating dogs onto their operations need to include the likely costs associated with cull and mortality when considering this investment.

Second, labor-related expenses are an important and variable cost component that can be tricky to quantify. If caring for LGDs is easily incorporated into a rancher's daily activities, then labor costs may be minimal. At HREC, however, reported labor costs averaged \$1,584 per dog per year. But given that these data come from a University facility, employee wages and benefit rates are likely to exceed those a ranch operator would attribute to his own time and effort. Inclusion of labor costs would decrease the benefit/cost ratio.

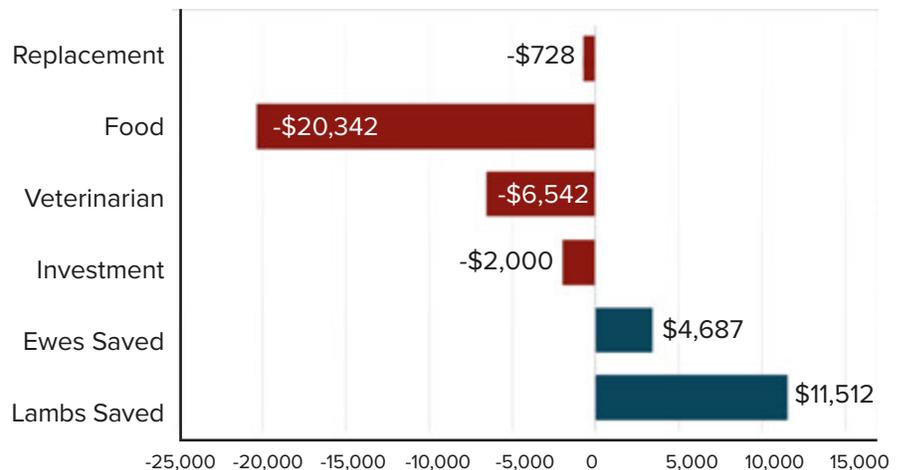
Finally, these results are dependent on other changing factors, such as the lamb and ewe sale prices. We derive the benefits of reduced predation from average sales prices for lambs and ewes, which vary from year to year. To the extent that prices change dramatically over time, so too will the value of the services that LGDs are anticipated to provide.

Management Implications

Predator control is a necessary component of sheep production. Lethal control faces public resistance and cannot always cause persistent impacts to predator populations, but the economic implications of adopting non-lethal tools are not yet well understood.

LGDs have been shown to decrease and, in some cases, eliminate sheep

Figure 1. Net Present Value of Expected Benefits and Costs from Using Livestock Guardian Dogs to Protect Lambs and Ewes



Note: Values are shown for a representative flock of 500 breeding ewes with five LGD that achieve reductions in lamb [ewe] predation of 43% [25%]. Costs are in red and benefits in blue.

Source: Authors' calculations

predation by coyotes. However, it is important to recognize that the costs associated with the purchase and maintenance of LGDs may outweigh the benefits for certain sheep operations. Results from this study, calibrated from data at HREC, showed that the benefit/cost ratio was 0.55, i.e., the benefits of LGDs did not cover the costs, despite valuing additional labor costs associated with dog management at zero.

Sheep producers who are considering the purchase of LGDs, or those who already have LGDs and are interested in their return on investment, need a few pieces of data to make this determination. Market lamb and ewe prices are typically well known to producers and can be used, in conjunction with efficacy rates from this study, to estimate the benefits of LGDs.

On the cost side, producers would need to make some logical forecasts about the time required to maintain LGDs, given their operation specifics. The costs associated with food and veterinary maintenance from this study could serve as a reasonable forecast for these costs on commercial operations. Also, using guidance from the literature included herein, producers could calculate the likely dog cull and mortality costs over the LGD's useful life.

Finally, an operator-specific discount rate should be chosen. Combining these pieces of information would provide a producer with estimated benefit and cost information critical to their investment decision and economic viability.

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For additional information, the authors recommend:

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