Brewery and Winery By-Product Markets: Environmental and Economic Benefits

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ABSTRACT. Spent grains and grape pomace, by-products of beer and wine production, are wastes that, where economically feasible are commonly used as animal feed. In California, dairies are a local, high-value market for spent grains and pomace. We quantify the substantial resource and environmental consequences of repurposing these by-products for use as feed for dairy cattle. Breweries and wineries can also market by-product use as a sustainable effort that avoids waste. We develop and apply stochastic models of beer and wine supply and demand to simulate the economics effects of labeling products with recycled by-products as sustainably produced.

Key Words: winery sustainability, brewery sustainability, dairy feed rations, by-product feeds, brewery waste, spent grains, grape pomace

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Breweries and wineries often adopt practices to improve their "sustainability," where sustainability in this context means positive environmental or social responsibility contributions, while maintaining economic viability. Motivation for sustainability may be social responsibility or part of a broader marketing strategy to appeal to consumers and investors. A common practice in brewery and winery sustainability is recycling by-products as livestock feed.

This paper examines the economics of use by near-by dairy farms of the main by-products from breweries and wineries—spent grains and grape pomace. Spent grains are leftover grains from the brewing process and are rich in protein, fiber, and water-soluble vitamins. They are the largest by-product of brewing. Grape pomace is a mixture of seeds, stems, and skins produced after pressing and is the largest by-product of wine production.

We first show that access to these by-product feeds can be locally important to the economics of dairy farms and can have locally significant environmental and resource implications. We then develop a stochastic model to simulate effects on beer and wine demand and prices, caused by a positive impact on sustainability reputation, from expanding and marketing efforts to recycle these by-products for use as feed.

The relationship of breweries and wineries benefits livestock farms by providing a low-cost, local source of high-nutrient feeds. Farms demand a consistent supply of feed ingredients that vary little from batch to batch in nutrition or taste, are relatively cheap to store, and are available in sufficient quantities for a significant share of the ration. That said, many by-products are often used in feed rations seasonally. Because of transportation costs (due to high moisture content), spent grains and grape pomace are typically fed to livestock near the location of breweries and wineries, meaning the benefits are concentrated in the local economy.

We calibrate our simulations using data from breweries, wineries, and dairy farms in California, where all three industries are important in the Central Valley. In California, dairy farms are the largest market for spent grains and grape pomace. Not only is there a mutual economic benefit for dairies and breweries from by-product use, there are also opportunities for the brewing, winery, and dairy industries to market a positive environmental and resource contributions from the relationship. They tout reduced resource use and less pollution, including methane emissions.[1]

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[1] For example, see Green Cow Sustainable Dairies (2021).

Focusing on the beer and wine industries as examples of substantial by-product feed supplying industries, we estimate the resources saved from recycling by-products. To do this, we compare the nutritional contribution of the by-products to replacement feeds, estimate the resources needed to produce these alternative feeds, and quantify the emissions from by-products that would otherwise be diverted to landfills.

The revenue shares of spent grains in beer production and grape pomace in wine production are small, and the ration share in dairy feeds is also small. The revenue generated for breweries and wineries from selling by-products, and the cost savings for dairies, are not financially significant.[2] However, recycling by-products are more likely motivated by public relations or sustainability efforts. Furthermore, these efforts may be marketed and are likely to fetch premiums for beer and wine. Staples et al. (2020) find that U.S. consumers are willing to pay \$0.98 more per six-pack of beer that specifically advertises a brewery's landfill diversion practices; Carley and Yahng (2018) find that U.S. consumers are willing to pay \$1.30 more per 6-pack of beer that is brewed with sustainable practices; Loose and Remaud (2013) find that U.S. consumers are willing to pay \$1.06 to \$1.55 more for bottles of wine that claim to be environmentally responsible.

We derive and apply simulation models for the beer and wine industries. A model of a by-product supplying industry allows us to simulate the effects of an increase in consumers' willingness-to-pay resulting from a positive change to firms' sustainability reputations. A positive change to reputation could occur if California-produced beer and wine were labeled to advertise their efforts to recycle spent grains. Relevant expositions of this modeling approach include Alston and James (2002) and Wohlgenant (2011).[3] This paper provides the first estimate of the environmental implications of spent grains and grape pomace used as feed, as well as the economic implications from advertising these sustainability efforts.

Background

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[2] In the appendix, we develop a simulation model and provide results showing the minimal impact of a change in by-product recycling on the beer and wine industries.

[3] The simulation model in our appendix models two outputs (the primary good and its by-product), similar to Lee, Sumner, and Champetier (2019) who recently describe a system with two connected output markets and a general production possibility frontier (almonds and honey bees), and includes simulated confidence intervals, based on distribution assumptions about parameters.

In 2019, an estimated 621.7 million gallons of beer were produced in California (TTB, 2020), generating approximately 0.52 million tons of spent grains (1.67 pounds of spent grains per gallon of beer)[4]. The largest breweries in California—ABInBev, MillerCoors, Sierra Nevada, Firestone Walker, Lagunitas, and Stone Brewing—each recycle spent grains, primarily as livestock feed.[5] Table 1 details the production volume, percent of spent grains going to livestock, and location of these breweries; they account for 92% of total beer production in the state. A national survey of small breweries conducted by the Brewers Association found that 90% of spent grains are used as animal feed (Brewers Association, 2013), 7% are composted, and the remaining 3% goes to landfills or other uses. The survey also found that spent grain removal operations provided a net income, or were revenue-neutral, for 89% of small breweries—in some cases, breweries pay farms to take their spent grain. We estimate that the 93% of spent grains from all California breweries are recycled as animal feed, most of which are fed to dairy cows.

Breweries that recycle spent grain as animal feed often publicize their efforts to do so. Sierra Nevada Brewing, the largest craft brewery in California and seventh-largest brewing company in the United States, dedicates a section of its website to sustainability efforts (Sierra Nevada, 2021), stating they send spent grains to regional cattle and dairy farms within 75 miles of the brewery. Anheuser-Busch InBev, the largest beer producer in the United States, also has a section of their website dedicated to their sustainability efforts (ABInBev, 2021) and their history of selling spent grains to farms is well documented (Sustainable Brands, 2018; Berlinger, 2013). MillerCoors (MolsonCoors, 2019) Lagunitas Brewing Company (Lagunitas, 2021), Firestone Walker Brewing Company (Firestone, 2021), and Stone Brewing (Stone, 2021) also have sections on their website documenting their sustainability efforts, including recycling spent grains for use as livestock feed.

Similar to the beer industry, wineries and allied industries market the practice of recycling pomace as feed as part of their sustainability efforts. G3 Enterprises, a subsidiary of the

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[4] The TTB (2020) reports 554 gallons of taxable beer were produced in California in 2019, but does not report tax exempt production specific to California. Nationally, 6.7% of total beer production in 2019 was tax exempt. Assuming the percent of tax exempt beer in total production is approximately the same for California, we estimate total production to be 591 gallons.

[5] ABInBev has historically recycled spent grains as animal feed, but has recently adopted to technology to recycle spent grains for human food products (Gillespie, 2013; Poinski, 2021). MolsonCoors (the parent company of MillerCoors) closed their Irwindale, CA brewery in September 2020 (Peltz, 2020).

world's largest wine producer, E & J Gallo, promote their practice of converting pomace to feed as part of their sustainability efforts on their website (G3 Enterprises, 2021). They manage approximately 40% of California's grape pomace, which they sell to dairy farms and a small amount to livestock and poultry farms.

In 2019, 4.11 million tons of grapes were crushed for wine or grape juice in California (CDFA, 2020), generating roughly 1.03 million tons of pomace (25% the weight of grapes crushed). Responses from two major California wineries in the Central Valley indicate that 90-95% of their pomace is sold wet as dairy cattle feed (Wineries, personal conversation, 2020). Accounting for the lower utilization rate of grape pomace as a dairy feed in the North Coast region of California, we estimate that Central Valley wineries crushed 3.1 million tons of grapes and produced 0.775 million tons of pomace available for use on local dairies (grape pricing districts 9, 10, 11, 12, 13, 14 and 17, as defined in CDFA (2020)).

Composting of grape pomace is an option available to wineries that have the space to accommodate compost piles or windrows, with the compost later used as soil amendments on the vineyard (CalRecycle, personal conversation, 2020; Wineries, personal conversation, 2020). However, pomace produced on wineries in Napa and Sonoma may end up in landfill (Wineries, personal conversation, 2020) where options for composting or use as feed are less available. Pomace and spent grains are considered food waste, which emits 0.54 metric tons of carbon dioxide equivalent ($MTCO_2E$) per short ton of wet waste, according to the Environmental Protection Agency (USDA EPA, 2020).

In California, spent grains and grape pomace are predominantly used by dairies—1.7 million dairy cows produce about $7 billion in farm value of milk in the state. These cows consume grains, oilseeds and meals shipped in from the Midwest, hay and silage, produced mostly in California and a huge variety from the crop and food processing industries in California. About 90% of the dairy cows are in the San Joaquin Valley, much of the rest are east of Los Angles and in organic dairy farms along the Pacific coast north of San Francisco. Most of California's beer production is located in close enough proximity to these dairy farms to easily recycle spent grains for use as feed.

Resource and Environmental Consequences

We first estimate the environmental consequences of recycling spent grains and grape pomace for use as feed for dairy cows. We quantify the resources required to replace by-product feeds if they were entirely unavailable to dairies, and then we estimate increases in greenhouse gases if by-products were to be diverted to landfills.

We estimate the quantity of feed required to replace spent grains and grape pomace based on nutritional content and the number of acres and acre-feet of irrigation water needed to produce the alternative feeds. We cannot perfectly predict the mix of feeds that would replace spent grains or grape pomace, so instead, we assume they are replaced with one close non-by-product substitute. Spent grains are primarily a protein source, and we assume they are substituted with alfalfa hay, a high protein forage. The conversion from spent grains to a nutritionally equivalent quantity of alfalfa is based on crude protein content.

Grape pomace is low in protein and energy but high in fiber and is a low-cost source of dry matter in the ration, so it is suitable for dairy cow and heifer rations. We assume grape pomace is substituted with corn silage, which is locally produced high yielding forage, although it is a higher quality feed than pomace. The conversion from grape pomace to corn silage is based on dry matter content.

We estimate the resources required to replace the crude protein from spent grains and dry matter from grape pomace in lactating cow, dry cow, and heifer rations, assuming perfect substitution with alfalfa hay and corn silage in Table 2. If all 519.1 thousand tons of spent grains were replaced with alfalfa hay, 167.4 thousand tons of high-quality alfalfa hay with 22.8% crude protein would be needed, requiring 23.58 thousand acres and 94.31 thousand acre-feet of irrigation water for production. In 2019, there were 580 thousand acres of alfalfa hay harvested in California (USDA, 2020), therefore a 4.1% increase in acreage of alfalfa hay would be needed to replace spent grains.

Planted acres of alfalfa hay have been declining for many years, with acreage decreasing every year from 2012 through 2020. Planted acres have increased in just four of the past 21 years. However, the change in alfalfa acres required to replace spent grains is small compared to typical annual changes in alfalfa acres in the past. For example, the planted acres of alfalfa increased by 22% in 2021 relative to 2020 (USDA, 2021).[6]

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[6] Harvested alfalfa hay acreage increased in 2021 by 105 thousand acres in California. In September 2020, MolsonCoors closed the MillerCoors brewery in Irwindale; the brewery supplied its spent grains to nearby livestock. More than 6 thousand acres of alfalfa hay would be needed to replace the spent grains supplied by the brewery.

If all 740 thousand tons of grape pomace were replaced with alfalfa hay, 843 thousand tons of corn silage would be needed, requiring 31.3 thousand acres and 115 thousand acre-feet of irrigation water. In 2019, there were 415 thousand acres of corn silage harvest in California (USDA, 2020), therefore an 7.5% increase in acreage of corn silage would be needed to replace grape pomace. The corn silage acreage has been about 400 thousand acres since 2000 and often changes by more than 40 thousand acres from one year to the next depending upon expectations for the dairy market in the year ahead.

Spent grains and grape pomace diverted to landfills are significant sources of greenhouse gas emissions; we determine the amount of landfill emissions avoided by recycling these by-products for use as feed. We apply estimates of net emissions for food waste landfilling from the Environmental Protection Agency (USDA EPA, 2020). Net emissions for food waste landfilling consider emissions from transportation to the landfill, methane (CH_4) emissions at the landfill, avoided carbon dioxide (CO_2) emissions from energy recovery at the landfill, and carbon storage at the landfill. Greenhouse gas emissions are reported as the net emissions metric tons of CO_2 equivalents ($MTCO_2E$). According to the EPA, there is 2.94 $MTCO_2E$ emitted per short ton of dry food waste. Table 3 provides the net emissions of $MTCO_2E$ if all spent grains and grape pomace used as feed were diverted to landfills. We find that recycling spent grains avoids 397 thousand $MTCO_2E$; recycling grape pomace avoids 1979 thousand $MTCO_2E$.

Model

In this section we develop a model of supply and demand for beer and wine to simulate the effects of expanding by-product recycling for use as livestock feed and advertising these efforts on product labels. The model operates under the assumption that the price of by-products does not affect the price beer and wine—in the appendix, we develop and apply a simulation model that demonstrates this to be a reasonable assumption. We consider a general a system of demand and supply equations which we adopt separately for two beverages, beer and wine. For beer, it is logical to focus on sustainable beer production from California consumed in California, as every state has a sizeable beer industry. However, California accounts for nearly 90% of U.S. wine production (Wine Institute, 2021). Therefore, when defining parameters for our wine model, we consider all sustainable wine produced in California consumed within the United States.

For simplicity, we consider two categories for a beverage: sustainably produced by recycling by-products and all other production. Our model makes the simplifying assumption that costs and premiums associated with sustainable production are paid by consumers and producers—that is, we do not incorporate intermediary prices for wholesalers or distributors.

$$D_{SUS} = D_{SUS}(P_B, P_{SUS}; \beta), \tag{1}$$

$$D_B = D_B(P_B, P_{SUS}), \tag{2}$$

$$S_{SUS} = S_{SUS}(P_{SUS}; \theta), \text{ and} \tag{3}$$

$$S_B = S_B(P_B) \tag{4}$$

The subscript SUS refers to California-produced sustainable beverages (again, beverage being either beer or wine) and B the beverage not sustainably produced; D is the quantity demanded of the beverage, S is the quantity supplied, and P is its price. Equation (1) represents demand for sustainable beer in California or sustainable wine in the United States, where β is a shift in willingness-to-pay for sustainable beer as a result of product labeling. Equation (2) represents demand for in California not sustainably produced in California, and wine in the United States not sustainably produced in California. Equation (3) represents sustainable beverages supplied by California producers to California for beer, to the United States for wine, where θ is the increase in cost to producers from recycling by-products and labeling products. Equation (4) represents other beer supplied to California, or other wine supplied to the United States.

We totally differentiate the system of equations and express them in log-differential form. This gives us the following:

$$dlnD_{SUS} = \eta_{SUS}(dlnP_{SUS} - \beta) + \eta_{SUS,B}dlnP_B \tag{5}$$

$$dlnD_B = \eta_{B,SUS}dlnP_{SUS} + \eta_B dlnP_B \tag{6}$$

$$dlnS_{SUS} = \epsilon_{SUS}(dlnP_{SUS} - \theta) \tag{7}$$

$$dlnS_B = \epsilon_B dlnP_B \tag{8}$$

$$dlnD_{SUS} = dlnS_{SUS} \tag{9}$$

$$dlnD_B = dlnS_B \tag{10}$$

Using this set of six equations, we simulate how the market for beer or wine adjusts to a change in demand from advertising sustainability practices.

Assuming homothetic separability, which restricts the elasticities of demand with respect to group expenditure to be equal to 1,we can represent the own- and cross-price elasticities for sustainable and other beverages as functions of their expenditure shares, the own-price elasticity of demand, and the elasticity of substitution between the two beverage types (Edgerton, 1997; James and Alston, 2002):

$$\eta_{SUS} = \omega_{SUS}\eta - (1 - \omega_{SUS})\sigma \tag{11}$$

$$\eta_B = (1 - \omega_{SUS})\eta - \omega_{SUS}\sigma \tag{12}$$

$$\eta_{SUS,B} = (1 - \omega_{SUS})(\eta + \sigma) \tag{13}$$

$$\eta_{B,SUS} = \omega_{SUS}(\eta + \sigma) \tag{14}$$

Here, ω_{SUS} is expenditure on sustainable beverages as a share of expenditure on the beverage, η is the own-price elasticity of demand for the beverage, and σ is the elasticity of substitution between sustainable and other beverages.

The equilibrium solutions to the model for the prices and quantities of sustainable and other beverages are expressed below.

$$dlnP_{SUS} = (-\eta_{SUS}\beta + \epsilon_{SUS}\theta)/\left[\epsilon_{SUS} - \eta_{SUS} - \eta_{SUS,B}\eta_{B,SUS}/(\epsilon_B - \eta_B)\right] \tag{15}$$

$$dlnP_B = \eta_{B,SUS}(-\eta_{SUS}\beta + \epsilon_{SUS}\theta)/\left[(\epsilon_{SUS} - \eta_{SUS})(\epsilon_B - \eta_B) - \eta_{SUS,B}\eta_{B,SUS}\right] \tag{16}$$

$$dlnD_{SUS} = \epsilon_{SUS}\left((-\eta_{SUS}\beta + \epsilon_{SUS}\theta)/\left[\epsilon_{SUS} - \eta_{SUS} - \eta_{SUS,B}\eta_{B,SUS}/(\epsilon_B - \eta_B)\right] - \theta\right) \tag{17}$$

$$dlnD_B = \epsilon_B\eta_{B,SUS}(-\eta_{SUS}\beta + \epsilon_{SUS}\theta)/\left[(\epsilon_{SUS} - \eta_{SUS})(\epsilon_B - \eta_B) - \eta_{SUS,B}\eta_{B,SUS}\right] \tag{18}$$

Data and Parameters

This section details the notation and definitions for parameters needed to simulate a demand shift for sustainable beer and wine as a result of labeling that promotes efforts to recycle by-products. Table 4 provides a summary of descriptions and parameter values pertaining to beer, and Table 5 pertaining to wine. The tables include quantities, prices, shares, function shift parameters, and elasticities.

Beer

California breweries produced 621.7 million gallons of beer in 2019 and exported (to other countries and other states) 225.4 million gallons (TTB, 2020). According to the Beer Institute (2020), roughly 701 million gallons of beer were consumed in 2019.[7] This means roughly 396.3 million gallons of beer were brewed in California for consumption in California, and 304.7

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[7] Total consumption in 2019 is based on consumption from October 2018 through September 2019 because data for the last 3 months of 2019 are not available.

million gallons were imported from other states or countries. We estimate 93% of the spent grains from California production are recycled for use as animal feed (primarily for use on dairies). However, roughly 99% of the spent grains are recycled for some purpose. Therefore, 392.3 million (D_{SUS}, S_{SUS}) gallons of beer produced in California could label their products as sustainably produced on the basis of recycling by-products, and there are 308.7 million gallons of other beer (D_B, S_B) consumed in California.

There are numerous beer styles and package types that range widely prices. We borrow from Fan and Yang (2021), who use Nielsen scanner data to aggregate and homogenize prices across styles and packages to equivalents of 12-packs of 12-ounce beers, and estimate the average price for 12-pack equivalent to be roughly \$11 in 2016 in California. Inflating this price to 2021 dollars using the CPI, and converting dollars to gallons, we estimate the average price of beer to be \$11.12 per gallon (P_{SUS}, P_B). Currently there is no price differentiation between sustainable and other beer, and we assume prices of beer from out of state are roughly the same as those produced in California, thus the expenditure share (ω_{SUS}) for sustainably produced beer is 56%.

Staples et al. (2020) run a choice experiment to estimate US consumers' willingness-to-pay for sustainability attributes in beer. They find that beer drinkers are willing to pay \$0.98 more per six-pack of beer that is labeled to promote landfill diversion practices (i.e., recycling spent grains), a premium of approximately 10% of the average six-pack price in their study. They acknowledge this is likely an upper bound for the attribute. Based on this finding, and to allow for the possibility of no increase in willingness-to-pay, the demand shift parameter (β) ranges from 0% to 10% as a percent of the price of beer.

We show in the appendix that recycling spent grains has no meaningful effect on the price of beer—not to mention that recycling spent grains is often a revenue positive endeavor (Brewers Association, 2013). However, costs may still exist for adopting sustainability labels. Labeling is subject to approval by the TTB, must adhere to FDA rules, and may require certification of sustainability claims. These costs are typically low, but they could pose barriers to smaller breweries. Therefore, we allow the cost shift parameter (θ) to vary from 0% to 5%.

Our parameter for the price elasticity of demand for beer (η) comes from Hart and Alston (2020), who estimate it to be roughly -0.1. Using equations (11) – (14), we estimate the elasticity of demand for sustainable beer (η_{SUS}) to be -0.496, other beer (η_B) to be -0.604, and the cross-price elasticities to be $\eta_{SUS,B} = 0.396$ and $\eta_{B,SUS} = 0.504$. These calculations rely on an estimate of the elasticity of substitution between sustainable and other beer (σ). An estimate of this parameter does not exist in recent literature. The beer market in California is saturated with choice, therefore the substitution parameter may be highly elastic. However, other factors such as brand loyalty and preferences for locally produced beer would at least partially offset the effect of product selection, and results from Hart and Alston (2020) imply a low elasticity of substitution (although they do not explicitly calculate the parameter) We set $\sigma = 1.0$, but in the appendix we allow this parameter to vary from 0.5 to 2.0 to test the sensitivity of our simulation to highly inelastic and highly elastic substitution parameters.

The elasticity of supply of beer produced in California ($\epsilon_B, \epsilon_{SUS}$) is highly elastic (10), meaning a sustained expected reduction in price of 1% could cause a 10% reduction in quantity supplied. Breweries can readily adapt production to moderate price and cost conditions over a horizon of a few years.

Wine

California wineries crushed 4.11 million tons of grapes in 2019 (CDFA, 2020). Grapes crushed in the Coastal regions of California, including and Sonoma and Napa Counties are not commonly used as dairy feed because hauling is expensive to move pomace to the dairies that are typically more than 100 miles (160 km) distant. In the Central Valley of California, 3.1 million tons of grapes were crushed in 2019, producing 0.76 million tons of pomace, based on one ton of pomace per four tons of grapes (Lapsley, James, personal conversation, 2020). Roughly 95% of pomace in the Central Valley is sent to dairies (Wineries, personal conversation, 2020). Therefore, we estimate roughly 75% of pomace from grapes crushed in California are sent to dairies. In 2020, 1.034 billion gallons of wine were consumed in the United States, and 571 million gallons of these were produced in California (Wine Institute, 2021). Therefore, we estimate 428 million gallons of wine (D_{SUS}, S_{SUS}) consumed in the United States were produced sustainably by means of recycling grape pomace in California, and 606 million gallons of other wine (D_B, S_B) were consumed in the United States.

According to the Wine Institute (2021), the retail value of wine sold in the United States in 2020 was \$66.8 billion, or roughly \$65 per gallon (P_{SUS}, P_B). We assume there is no price differentiation between sustainable wine from California and other wine prior to labeling, therefore the expenditure share (ω_{SUS}) for sustainably produced wine from California is 41.4%.

In a choice experiment, Loose and Remaud (2013) find that U.S. consumers are willing to pay \$1.06 to \$1.55 more for bottles of wine that claim to be environmentally responsible, a premium of 5–7%. In their study, wines were of French origin and therefore the environmental benefits were not realized domestically. Consumers may be willing to pay a higher premium for local environmental benefits; thus we do not view this premium as an upper bound. As with beer, we are also interested in simulating the model with no increase in willingness-to-pay, thus we allow the demand shift parameter (β) to range from 0% to 10%.

We show in the appendix that recycling grape pomace has no meaningful effect on the price of wine. However, as described previously for beer, there may be costs associated with labeling and certifying sustainability costs. Once again, we allow the cost shift parameter (θ) to vary from 0% to 5%.

Fogarty (2010) performs a meta-analysis of demand estimations for beer, wine, and spirits, and reports an own-price elasticity of demand for wine of -0.55 in the United States. The elasticity of demand for wine from California is much more elastic as it may be substituted for other wine from the United States or the rest of the world. Fuller and Alston (2012), estimate the elasticity of demand for wine (and wine grapes) from California using various estimates of price transmission. We adopt their intermediate estimate of -5.3 for our simulations, which is based on a price transmission of 0.5 between California and other markets. Using equations (11) – (14), we estimate the elasticity of demand for sustainable wine (η_{SUS}) to be -5.124, other wine (η_B) to be -5.176, and the cross-price elasticities to be $\eta_{SUS,B} = -0.176$ and $\eta_{B,SUS} = -0.124$. These calculations rely on an estimate of the elasticity of substitution between sustainable and other wine (σ). An estimate of this parameter does not exist in recent literature. We refer again to Fuller and Alston (2012), who set the elasticity of substitution of California wine grapes across high, medium, and low quality regions to be either 3, 5, 10. We use the intermediate value of 5, and test the sensitivity of our results to values of 3 and 10 in the appendix.

The elasticity of supply of wine supplied to the United States ($\epsilon_B, \epsilon_{SUS}$) is somewhat elastic (2), but not nearly as elastic as beer. Wineries are able to adapt production over the span of several years, but they are dependent on weather conditions and restricted by the fact that grape vines are perennial plants that typically take multiple years to provide substantial yields.

Results

Simulation results for a shift in demand for sustainable beer are reported in Table 6, and results for a shift in demand for sustainable wine are reported in Table 7. For both beer and wine, we perform a series of nine simulations, allowing the demand shift parameter, β, to take on values of 0, 0.05, and 0.10, and the cost shift parameter, θ, to take on values of 0, 0.01, and 0.05. Each simulation represents a different combination of shift parameters.

Interpretation of results is straight forward, here we discuss results from simulations 3, 5, and 7. Simulation 3 represents the worst-case scenario from the perspective of producers, where the cost shift parameter is high, equal to 5%, and there is no demand shift for sustainably produced beer or wine from California. In this scenario, quantity demanded for sustainably produced beer from California decreases by 2.28% in California, and quantity demanded for other beer in the state increases by 2.27%. The price of sustainable beer increases by 4.77%, and the price of other beer increases by 0.23%. With a cost increase of 5%, sustainable breweries in California would see an increase in revenue less than the increase in cost—the net increase in revenue for sales of sustainable beer in California is 2.38%, . In this worst-case scenario, implications for sustainable wineries in California are worse. U.S. quantity demanded for sustainably produced wine from California decreases by 7.19%, and quantity demanded for other wine decreases by 0.05%. The price of sustainable wine increases by 1.40%, the price of other wine decreases by 0.02%, and revenue decreases by 5.89%.

In Simulation 5, the demand shift parameter is 5% and the cost shift parameter is 1%. This simulation represents the scenario most supported by existing literature on willingness-to-pay for sustainably produced beer and wine, with the expected cost of labelling and certification. California quantity demanded for sustainably produced beer increases by 1.91%, and quantity demanded for other beer increases by 0.57%. The price of sustainable beer increases by 1.19%, the price of other beer increases by 0.06%, and the revenue from sustainable beer sold in California increases by 3.13 %. Compared to beer, the quantity effects for wine are smaller, and the price effects are larger. U.S. quantity demanded for sustainable wine from California increases by 5.76%, and quantity demanded for other wine decreases by 0.13%. The price of sustainable wine from California increases by 3.88%, the price of other wine decreases by 0.07%, and the revenue from sales of California produced sustainable wine increases by 9.86%.

Finally, we discuss results from simulation 7, where the demand shift is parameter is 10% and there is no change in cost. This represents the best-case scenario from the perspective of producers, where the change in willingness-to-pay for sustainable beer and wine is at the upper bound supported by existing literature, and there is no cost to suppliers for changing labels to advertise sustainable production. The resulting increase in quantity demanded sustainable beer in California is 4.74 %, and quantity demanded of other beer increases by 0.23%. Price of sustainable beer increases by 0.47 %, the price of other beer increases by 0.02%, and the revenue from sales of sustainable beer increases by 5.23%. Quantity demanded of sustainable wine from California increases by 14.39%, and quantity demanded of other wine decreases by 0.25%. The price of sustainably produced wine from California increases by 7.20%, the price of other wine decreases by 0.12%, and the revenue from sales of sustainable wine produced in California increases by 22.62%.

Discussion

We examined the environmental and economic effects of recycling by-products, specifically spent grains from beer production and grape pomace from wine production, for use as animal feed, and promoting sustainability efforts on packaging. We find the economic effects from recycling these by-products are negligible, but the environmental effects are much more substantial. And although recycling spent grains and grape pomace does not generate meaningful revenue, advertising these efforts on product labels has significant demand implications.

Spent grains and grape pomace are locally available feed sources for dairies in California that replace local forage that would be grown otherwise, thereby saving land and water for other industries. Water, especially, is an already scant resource in the Central Valley of California where most recycling of spent grains and grape pomace for use as feed takes place. We estimate that annually, spent grains save 23.6 thousand acres and 94.3 thousand acre-feet of water that would otherwise be needed to produce alfalfa hay, and grape pomace saves 31.3 thousand acres and 115 thousand acre-feet of water that would otherwise be needed to produce corn silage as replacement feeds for dairy cattle in California. Recycling spent grains and grape pomace also reduces potential greenhouse emissions. If these by-products were diverted to landfills instead of being used as feed, they would emit a combined total of 2376 thousand $MTCO_2E$ annually—the equivalent emissions of 517 thousand passenger vehicles.

The costs of recycling spent grains and grape pomace are low. In fact, it is often more cost effect for breweries and wineries to recycle by-products than to discard them. By doing so they avoid the costs of hauling tons of waste to landfills, and typically they generate revenue by selling the by-products. This potential revenue stream is negligible compared to the price of beer and wine, and in the appendix, we develop a simulation model that demonstrates recycling these by-products has no economically meaningful effect on beer and wine markets.

However, breweries and wineries often market on their websites their relationships with local farms to prove their sustainability efforts and to prove their efforts to support local agribusinesses. If these efforts were to be promoted via product labels, they would likely attract premiums from consumers. Results from our simulations suggest that for a labeling cost of 1% and shift in willingness-to-pay for sustainable products of 5%, quantity demanded of sustainable beer would increase by 1.9%, price would increase by 1.2%, and revenue from sales of sustainable beer in California would increase by 3.1%. The 1.9% increase in spent grains would save an additional 448 acres and 1790 acre-feet of water, and would avoid 7540 $MTCO_2E$ annually.

The same cost and demand shifts for wine would increase quantity demanded of California produced sustainable wine by 5.8%, increase its price by 3.9%, and increase revenue from sales in the United States by 9.9%. The 5.8% increase in grape pomace would save an additional 1820 acres and 6670 acre-feet of water, and would avoid 115 thousand $MTCO_2E$ annually.

Recycling spent grains does not affect the price of beer, nor does recycling grape pomace affect the price wine. However, it is a low-cost practice that meaningfully reduces resource use—an especially important consideration in areas such as the Central Valley in California where agricultural land and water is scarce and faces many competing needs. And the greenhouse gas emissions avoided by the practice are globally meaningful. Although California breweries and wineries publish their sustainability efforts, they do not promote these efforts on product labels. Doing so would positively affect the price and overall demand for sustainable beer and wine produced in California.

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Table 1. Beer and Spent Grain Production in California, 2019

Brewery	County	Beer (gallons, millions)	Spent Grains (tons, thousands)	Use as feed (%)
ABInBev	Los Angeles	228.4	190.7	90
MillerCoors	Los Angeles	157.9	131.9	100
ABInBev	Solano	108.5	90.6	90
Sierra Nevada	Butte	31.8	26.6	100
Firestone Walker	San Luis Obispo	16.3	13.6	75
Lagunitas	Sonoma	15.6	13.0	95
Stone Brewing	San Diego	10.8	9.1	95
Others		52.3	43.7	90
Total		621.7	519.1	93

Notes: Production data from 2019 Monthly Alcohol Returns Report (TTB, 2020). Estimates of spent grains use as feed based on survey of spent grain recycling (Brewers Association, 2013), websites of breweries, and personal correspondence with breweries.

Table 2. Tons of forage, acres, and irrigation water required to replace spent grains and grape pomace

By-Product	Quantity by-product (tons, thousands)	Substitute forage (tons, thousands)	Area (acres, thousands)	Irrigation water (acre-feet thousands)
Spent Grains	519	*Alfalfa hay* 167	23.6	94.3
Grape Pomace	740	*Corn silage* 843	31.3	115

Notes: Values for alfalfa hay, corn silage, and spent grains dry matter and crude protein from NRC (2001). Value for dry mater of grape pomace from Heuzé and Tran (2020). Fresh weight of spent grains fed on California dairies in 2019, calculated from California beer production (TTB, 2020), a conversion rate of 1.67lb of spent grains per gallon of beer, and 45% of spent grains fed on dairies (Brewers Association, 2013). Fresh weight of grape pomace calculated from wine grapes crushed in grape pricing districts 9, 10, 11, 12, 13, 14, and 17 as defined in CDFA (2020), and a fresh weight pomace yield of 25% (Lapsley, James. Personal conversation, 2020). Fresh weight alfalfa hay yields 7.1 tons per acre (USDA, 2020), uses 4-acre-feet of irrigation water on average (Long et al., 2015). Corn silage yields 27 tons per acre (USDA, 2020) and uses 3.7-acre-feet of irrigation water (Mitchel et al., 2015).

Table 3. Landfill Emissions for Spent Grains and Grape Pomace

By-product	Dry matter by-product to landfills (tons, thousands)	MTCO$_2$E (thousands)
Spent Grains	135	397
Grape Pomace	673	1979

Notes: Dry matter makes up roughly 26% of spent grains fresh weight (Thomas et al., 2010), 91% of grape pomace fresh weight. Estimated emissions are based on the net landfilling emissions for food waste, 2.94 MTCO$_2$E per short ton of dry waste (converted from 0.54 MTCO$_2$E per short ton of wet waste as calculated by the EPA (USDA EPA, 2020; USDA EPA, 2021).

Table 4. Beer Supply and Demand Model Parameters: Definitions, Values, and Sources

	Parameter definition	Value	Sources
D_{SUS}, S_{SUS}	Quantity of sustainable beer brewed in California for California consumption, million gallons	392.3	*
D_B, S_B	Quantity of other beer consumed in California, million gallons	308.7	*
P_{SUS}, P_B	Price of beer, $/gallon	11.12	(Fan and Yang, 2021)**
β	Demand shift for sustainable beer, percent of price	0–10%	(Staples et al., 2020)
θ	Supply shift for sustainable beer, cost as percent of price	0–5%	***
η	Elasticity of demand for beer	-0.1	(Hart and Alston, 2020)
η_{SUS}	Elasticity of demand for sustainable beer	-0.604	Author calculation
η_B	Elasticity of demand for other beer	-0.496	Author calculation
$\eta_{SUS,B}$	Cross-price elasticity for sustainable beer w.r.t. change in price of other beer	0.396	Author calculation
$\eta_{B,SUS}$	Cross-price elasticity for other beer w.r.t. change in price of sustainable beer	0.504	Author calculation
σ	Elasticity of substitution between sustainable and other beer	1.0	Author estimate
ω_{SUS}	Expenditure share of California produced sustainable beer	56%	*
$\epsilon_B, \epsilon_{SUS}$	Elasticity of supply for beer	10	*

*Author calculation based on production, import, and export data (TTB, 2020) and California beer consumption (Beer Institute, 2020), survey of spent grain recycling (Brewers Association, 2013), spent grain recycling claims on websites of large breweries, and personal correspondence with large breweries.

**Converting the average price of $11 for 12-packs of 12-ounce cans of beer in California in 2016 to dollars per gallon at a rate of 1 12-pack to 1.125 gallons gives a price of $9.78 per gallon. Inflating by the CPI to 2021 dollars results in price of $11.12 per gallon.

***Author estimate based on (Brewers Association, 2013) and industry characteristics.

Table 5. Wine Supply and Demand Model Parameters: Definitions, Values, and Sources

	Parameter definition	Value	Sources
D_{SUS}, S_{SUS}	Quantity of sustainable wine from California for U.S. consumption, million gallons	428	*
D_B, S_B	Quantity of other wine consumed in United States, million gallons	606	*
P_{SUS}, P_B	Price of wine at retail, $/gallon	65	(Wine Institute, 2021)
β	Demand shift for sustainable wine, percent of price	0–10%	(Loose and Remaud, 2013)
θ	Supply shift for sustainable wine, cost as percent of price	0–5%	**
η	Elasticity of demand for California wine	-5.3	(Fuller and Alston, 2012)
η_{SUS}	Elasticity of demand for sustainable wine	-5.124	Author calculation
η_B	Elasticity of demand for other wine	-5.176	Author calculation
$\eta_{SUS,B}$	Cross-price elasticity for sustainable wine w.r.t. change in price of other wine	-0.176	Author calculation
$\eta_{B,SUS}$	Cross-price elasticity for other wine w.r.t. change in price of sustainable wine	-0.124	Author calculation
σ	Elasticity of substitution between sustainable and other wine	5	(Fuller and Alston, 2012)
ω_{SUS}	Expenditure share of California produced sustainable wine	41%	*
$\epsilon_B, \epsilon_{SUS}$	Elasticity of supply for wine	2	**

*Author calculation based on grape crush data (CDFA, 2020), surveying wineries for pomace recycling (Wineries, personal conversation, 2020), and wine production and consumption data (Wine Institute, 2021).

**Author estimate based on underlying industry situation.

Table 6. Summary of Simulated Impacts on the Beer Industry from a Demand Shift for Sustainable Beer, Percentage Changes

Variable	Symbol	Change	Change	Change
Shift Parameters		**1:** $\beta = 0$, $\theta = 0$	**2:** $\beta = 0$, $\theta = 0.01$	**3:** $\beta = 0$, $\theta = 0.05$
Sustainable beer quantity	$dlnQ_{SUS}$	0.00%	-0.46%	-2.28%
Other beer quantity	$dlnQ_B$	0.00%	0.45%	2.27%
Price of sustainable beer	$dlnP_{SUS}$	0.00%	0.95%	4.77%
Price of other beer	$dlnP_B$	0.00%	0.05%	0.23%
Revenue change from sustainable beer		0.00%	0.49%	2.38%
Shift Parameters		**4:** $\beta = 0.05$, $\theta = 0$	**5:** $\beta = 0.05$, $\theta = 0.01$	**6:** $\beta = 0.05$, $\theta = 0.05$
Sustainable beer quantity	$dlnQ_{SUS}$	2.37%	1.91%	0.09%
Other beer quantity	$dlnQ_B$	0.11%	0.57%	2.38%
Price of sustainable beer	$dlnP_{SUS}$	0.24%	1.19%	5.01%
Price of other beer	$dlnP_B$	0.01%	0.06%	0.24%
Revenue change from sustainable beer		2.61%	3.13%	5.10%
Shift Parameters		**7:** $\beta = 0.1$, $\theta = 0$	**8:** $\beta = 0.1$, $\theta = 0.01$	**9:** $\beta = 0.1$, $\theta = 0.05$
Sustainable beer quantity	$dlnQ_{SUS}$	4.74%	4.28%	2.46%
Other beer quantity	$dlnQ_B$	0.23%	0.68%	2.49%
Price of sustainable beer	$dlnP_{SUS}$	0.47%	1.43%	5.25%
Price of other beer	$dlnP_B$	0.02%	0.07%	0.25%
Revenue change from sustainable beer		5.23%	5.77%	7.83%

Table 7. Summary of Simulated Impacts on the Wine Industry from a Demand Shift for Sustainable Wine, Percentage Changes

Variable	Symbol	Change	Change	Change
Shift Parameters		**1:** $\beta = 0$, $\theta = 0$	**2:** $\beta = 0$, $\theta = 0.01$	**3:** $\beta = 0$, $\theta = 0.05$
Sustainable wine quantity	$dlnQ_{SUS}$	0.00%	-1.44%	-7.19%
Other wine quantity	$dlnQ_B$	0.00%	-0.01%	-0.05%
Price of sustainable wine	$dlnP_{SUS}$	0.00%	0.28%	1.40%
Price of other wine	$dlnP_B$	0.00%	0.00%	-0.02%
Revenue change from sustainable wine		0.00%	-1.16%	-5.89%
Shift Parameters		**4:** $\beta = 0.05$, $\theta = 0$	**5:** $\beta = 0.05$, $\theta = 0.01$	**6:** $\beta = 0.05$, $\theta = 0.05$
Sustainable wine quantity	$dlnQ_{SUS}$	7.20%	5.76%	0.00%
Other wine quantity	$dlnQ_B$	-0.12%	-0.13%	-0.17%
Price of sustainable wine	$dlnP_{SUS}$	3.60%	3.88%	5.00%
Price of other wine	$dlnP_B$	-0.06%	-0.07%	-0.09%
Revenue change from sustainable wine		11.05%	9.86%	5.01%
Shift Parameters		**7:** $\beta = 0.1$, $\theta = 0$	**8:** $\beta = 0.1$, $\theta = 0.01$	**9:** $\beta = 0.1$, $\theta = 0.05$
Sustainable wine quantity	$dlnQ_{SUS}$	14.39%	12.95%	7.20%
Other wine quantity	$dlnQ_B$	-0.25%	-0.26%	-0.30%
Price of sustainable wine	$dlnP_{SUS}$	7.20%	7.48%	8.60%
Price of other wine	$dlnP_B$	-0.12%	-0.13%	-0.15%
Revenue change from sustainable wine		22.62%	21.40%	16.42%