Agricultural and Resource Economics
UPDATE
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS • UNIVERSITY OF CALIFORNIA
V. 19 no. 4 • Mar/Apr 2016

Vinum Verum Viribus? Systematic Errors in Wine Alcohol Labels

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Vinum Verum Viribus: Wine True Strength

Using international data for 18 vintages, we find systematic differences between the actual and stated alcohol content of wine. Our results suggest that rising alcohol content of wine may be a nuisance by-product of producer responses to evolving market and production environments.

Also in this issue

In the next issue

Our recent (December 2015) article in the *Journal of Wine Economics*, "Splendide Mendax: False Label Claims about High and Rising Alcohol Content of Wine," sparked a flurry of media attention around the world. (For example, see articles by Sarah Kapton in the *Daily Telegraph* and Tom Withdraw in the *Daily Mail* in December 2015, and by Roberto Ferdman in the *Washington Post* in January 2016.) In that article, we analyzed data from the Liquor Control Board of Ontario (LCBO), Canada, which tests every wine imported into that province and records several characteristics, including the actual and stated alcohol content.

Drawing on our analysis of 91,432 observations of individual wines tested by the LCBO, we reported two main findings, the second of which attracted the most attention. First, over the years 1992–2009, the alcohol content of the wines trended up, with an overall average increase of about 0.5 percentage points on a base of 12–13% by volume. Second, we found systematic patterns of differences between the actual alcohol content of wines and the alcohol content reported on the label, with labels tending to understate the alcohol content for higher alcohol wines. For instance, of the total of 14,218 California wines in our sample, 8,880 (62.5%) understated the alcohol content.

These labeling errors may be economically significant, even if they do not exceed legal tolerances. Wineries may have incentives to understate or overstate the alcohol content if they perceive a market preference for a particular range of alcohol content for a given style of wine. Other reasons may include tax avoidance; for instance, the U.S. tax rate is $1.07 per gallon for wine with 14% alcohol or less, and $1.57 per gallon for wine above 14% but less than 21% alcohol.

While every bottle of wine reports alcohol content on the label, the tolerances are wide. United States law allows a range of plus or minus 1.5 percentage points for wine with 14% alcohol by volume or less, and plus or minus 1.0 percentage points for wine with more than 14% alcohol by volume, and other countries have similarly large tolerances. These are wide bands compared with the relevant range of variation in the marketplace—the vast majority of wine consumed as table wine has between 12% and 15% alcohol.

Significantly, however, the tolerance for labeling errors does not permit misclassifying wine between tax categories in the United States. It is not legal to label wine as having more than 14% alcohol if it has 14% or less, and it is not legal to label wine as having 14% or less if it has more than 14% alcohol. In our sample of U.S. wines, 1,412 (9%) are labeled as having 14% alcohol or less, when it is actually over 14%, and 299 (2%) are labeled as having more than 14% alcohol when it is actually 14% or less. It would be illegal to sell these wines with those labels in the United States.

Table 1. Average Alcohol Content by Country of Origin of Wine				
	Number of	Alcohol % by Volume		
Year	Observations	Actual	Reported	Difference
Old World				
France	25,404	13.0	12.9	–0.10
Italy	19,806	13.0	12.9	–0.09
Spain	2,993	13.4	13.2	–0.21
Portugal	2,321	13.0	12.9	–0.05
Total	**50,524**	**13.0**	**12.9**	**–0.10**
New World				
Argentina	1,778	13.8	13.6	–0.24
Australia	9,617	13.7	13.7	–0.09
Canada	4,113	12.8	12.6	–0.13
Chile	3,744	13.7	13.4	–0.27
New Zealand	2,125	13.2	13.2	–0.06
South Africa	3,347	13.5	13.4	–0.09
United States	16,184	13.9	13.7	–0.23
Total	**40,908**	**13.7**	**13.5**	**–0.17**
World	91,432	13.3	13.2	–0.13
Under-reported alcohol	52,178	13.6	13.2	–0.42
Over-reported alcohol	29,461	12.9	13.2	0.32
Correct alcohol %	9,793	13.1	13.1	0.00

Rising Alcohol Content and the Role of Climate

Wines from cooler places tend to have less alcohol than wines from hotter places, and in general "Old World" wines, predominantly from Europe, tend to have less alcohol than "New World" wines, mainly from the Americas, Australia, and South Africa. On average, in our sample, Old World wines have about 0.63 percentage points less alcohol than comparable New World wines, and white wines typically have about 0.50 percentage points less alcohol than red wines.

In our sample, between 1992 and 2007 the average alcohol content of wine trended up for both red and white wine, regardless of its country of origin. Among countries and between colors of wines, the size of the average increase ranges from about 0.2 to 2.0 percentage points, with an overall average increase of about 0.50 percentage points.

What does climate change have to do with any of this? Not much, as far as we can tell. We acquired region-specific climate data for 1992–2008 from several sources, mainly the NOAA National Climatic Data Center, and created an index of heat during the growing season for each wine-producing country or region.

We estimated a variety of models in which we regressed alcohol content against trend variables, and country- and region-specific factors as well as this heat index. We found that holding other factors constant, a one-degree Fahrenheit increase in the average growing season temperature everywhere in the world would cause the average alcohol content of wine to increase by only 0.05 percentage points.

The main lesson from these results is that increases in growing season temperature do not account for much of the growth in the average alcohol content of wine, for two reasons. First, temperature did not increase by very much in most places over the time period of our data. Second, our estimates suggest that a relatively large change in the heat index, outside the range observed in this paper, would be required to bring about an appreciable increase in the alcohol content of wine. These findings parallel those from our earlier work, in which a similar heat index for California contributed very little to explaining increases in either the sugar content of California winegrapes or the alcohol content of California wine.

Actual versus Reported Alcohol

Table 1 shows the average values for reported and actual alcohol content and the discrepancies between them, country by country and for the entire, pooled sample. The average difference—the reported minus actual alcohol content—was –0.13% alcohol by volume, over all samples. Wine from every country on average had higher actual content than was declared on the label, and the average understatement was relatively large for wines from the countries with higher average alcohol content (i.e., the United States, Australia, Spain, Chile, and Argentina).

Of course, these average values mask a lot of variation within countries and between red and white wines, and some of these details were the subject of further analysis in our longer paper (Alston et al. 2015). Importantly, the average figures conceal the fact that in many instances, the labels overstate the alcohol content of wine, even though it is understated on average, as displayed in the lower part of Table 1.

In over half of the observations (52,178, or 57.1% of the total), alcohol content was understated by 0.01 percentage points or more. For this group, on average, the actual alcohol content was 13.6% and the reported alcohol content was 13.2%, with a discrepancy of 0.42 percentage points.

A discrepancy of 0.4 percentage points might not seem large relative to an actual value of 13.6% alcohol by volume, but is much more significant compared with the typical range for wines in a particular category. For instance, Napa Valley Cabernet Sauvignon might be expected to have alcohol content within the range of 13.5–14.5% alcohol by volume, and an average error of 0.4 percentage points is high in the context of this range.

The size of the understatement was similar between red and white wines. The patterns are somewhat different if we further split the data in this group between the New and Old World sources; Old World wine labels understated the alcohol content to a smaller extent than New World wine labels.

Labels for a significant, albeit smaller, number of wines (29,461, or 32.2% of the sample) erred in the opposite direction, overstating the true alcohol content by 0.01 percentage points or more. On average, the actual alcohol content for this group was 12.9% by volume, and the reported alcohol percentage was 13.2%, with a discrepancy of 0.32 percentage points. Within this group, the size of the overstatement was similar between red and white wines, and similar between the New World and Old World sources.

A little over one-tenth of the useful sample—9,793 observations—were wines with reported alcohol within 0.01 percentage points of the actual alcohol. In this category, Old World red wine had an average alcohol content of 13.0% by volume; Old World white, 12.5%; New World red, 13.6%; and New World white, 13.1%.

Demand for Labeling Errors?

It is relatively inexpensive to measure the alcohol content of wine reasonably precisely, although some of the devices used may entail larger measurement errors. To comply with tax regulations, at least in the United States, it is necessary to provide information on alcohol content. More important, alcohol content is also an element of quality control in winemaking. Consequently, we expect that commercial wineries, for the most part, have relatively precise knowledge of the alcohol content of the wines they produce.

Some tolerance for error in wine alcohol labels is appropriate for several reasons. One reason is to allow for measurement error, since the instruments (and perhaps their users) are not always perfectly precise. Probably the most common method for wineries is the ebulliometer, which compares the boiling temperature of water and the boiling point of wine, to determine the alcohol concentration (which lowers the boiling point). Amerine and Joslyn (1951) claim +/– 0.2% accuracy for the method. Random measurement error at this rate cannot account for systematic bias to the extent we observe in our data.

In addition, commercial reality dictates some tolerance to allow for the fact that wine labels may have to be printed months in advance of the final determination of the content of the particular wine, and therefore must be based on predictions made at the time of ordering the labels. Also, a particular label may have to apply to multiple lots of the “same" wine that vary in their alcohol content. Even so, a tolerance of +/– 1.5 percentage points seems generous.

Winemakers can manage the alcohol content and other characteristics of the wine, at a cost, but cannot cheaply vary the quantity of alcohol independently from other characteristics. For instance, to achieve riper, more intense, fruit flavors may require longer “hang times” for grapes that also imply more concentrated sugar and higher alcohol wine.

Consumers may happily pay a premium for the resulting flavors yet prefer not to have (or, at least, know about) the concomitant increase in alcohol content. In such a setting, it may be profitable for the winery to give the consumer both the desired wine characteristics and the preferred label information, by understating the true alcohol content.

Wineries may have incentives to understate or overstate the alcohol content if they perceive a market preference for a particular range of alcohol content for a given style of wine.

We base this speculation in part on discussions with several winemakers who have told us informally that they chose to understate the alcohol content on a particular wine label, within the range of error permitted by the law. They made this choice because they believed it would be advantageous for marketing the wine to have a stated alcohol content closer to what consumers would expect to find in a high-quality wine of the type in question.

Similar phenomena can be observed in other settings. In some of our own as-yet unpublished work, we have observed that when supermarkets offer pre-cut pieces of cake in standardized package sizes (e.g., 12 oz), typically the actual size of the piece is much larger than the stated size—well more than could be rationalized by a desire to avoid offering an undersized piece (Figure 1 on page 4). This phenomenon is consistent with a theory that the buyer would rather have a large piece of cake but imagine it is smaller and less caloric, and the seller (generously) provides what they buyer wants.

Figure 1. Which Price Matters: Dollars or Calories?

4.5 oz

520 calories

Serving Size: 1 Slice (127g) (4.5 oz.)		
Amount per Serving		
Calories 520	Calories from Fat 243	
		% DV
Total Fat 27g		42%
Saturated Fat 4.5g		22%
Cholesterol 80mg		27%
Sodium 510mg		21%
Total Carbohydrate 63g		21%
Dietary Fiber 2g		8%
Sugars 36g		
Protein 7g		14%
Vitamin A 50%		Vitamin C 0%
Calcium 4%		Iron 10%
Thiamine 20%		Riboflavin 15%
Niacin 10%		Folic Acid 20%
Unofficial Points+: 14 (Old Points): 12	**@DietFacts.com**	

Percent of Calories from:
Fat: 46% Carb: 48.5% Protein: 5.4%
(Total may not equal 1000% due to rounding)

Carrot cake from a supermarket in Davis: $2.49

Stated Weight = 7 oz (198g)
Implies 805 calories and $5.69/lb

Actual Weight = 13.2 oz (373 g)
Implies 1,518 calories and $3.12/lb

The Role of Prices

The propensity for mislabeling wine may vary with the price of wine. One reason is that the tax rates might vary with alcohol content. For instance, as noted, in the United States the Federal excise tax rate increases by $0.50 per gallon for wine having more than 14% alcohol. For the lowest-priced wines, which may sell at wholesale for only a few dollars per gallon, an additional $0.50 per gallon is a significant disincentive for producing wines having more than 14% alcohol, whereas for premium wines, this tax difference is negligible. Also, characteristics such as intense ripe flavors of wine that are associated with high ratings by some experts and tend to be correlated with higher alcohol content may be less demanded in entry-level wines than in premium wines.

To examine this possibility, we estimated our model using the 17,862 observations for the years 1992–2007 for which we have prices. Our results indicate that the reporting error increases with increases in the price of wine. The predicted reporting error for a wine selling for $40 per bottle or more is 0.26 percentage points higher than that for a wine selling for less than $10.

Conclusion

Our findings support the idea that winemakers may be tweaking alcohol content on the label to reflect their perceptions of market norms and expectations for the alcohol percentage for a given type of wine (defined by variety, place of origin, and so on). Given the rise in wine alcohol over our study period and the negative press and reviews for high-alcohol wines, it is not too surprising to see winemakers tending to err in the direction of understating the alcohol content of some types of wines, in ways that the law allows. The wide error tolerances provided by the current U.S. law took effect in 1949. Perhaps it is time to review that policy.

Alston, J.M., K.B. Fuller, J.T. Lapsley, G. Soleas, and K.P. Tumber. "Vinum Verum Viribus? Systematic Errors in Wine Alcohol Labels." *ARE Update* 19(4) (2016): 1-4. University of California Giannini Foundation of Agricultural Economics.

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For additional information, the authors recommend:

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Honey Bee Colony Strength in the California Almond Pollination Market

Brittney Goodrich and Rachael Goodhue

Honey bee colony strength is an important factor in almond pollination decisions due to increased pollination efficiency of larger colonies. Growers use contract provisions to secure a minimum level of colony strength, thus making strength an influential component of the overall colony supply and demand which has not been considered in previous economic analyses.

In recent years, high per-colony almond pollination fees have focused almond growers on the specifics of their pollination contracts. A primary component of almond pollination contracts, along with the price per hive and number of hives contracted, has become the strength of honey bee colonies. The industry measures colony strength by counting the number of active frames of bees, where an active frame meets one of two criteria: bees cover at least 75% of both sides of a standard frame of comb within the hive, or at least four bees per square inch of comb.

Colony strength is an important consideration for almond growers in their pollination decisions because honey bee colonies exhibit increasing returns to scale in pollination. Sheesley and Poduska found that a colony with eight active frames (an 8-frame colony) will collect on average 2.5 times more pollen than one with four (a 4-frame colony). A 12-frame hive collects on average nearly 60% more pollen than three 4-frame hives. (Technically speaking, a "hive" is the physical structure that contains a "colony" of honey bees, although the two words are interchangeable.)

In light of larger colonies' increased efficiency in pollination, Sheesley and Poduska suggested developing a multiple tier pricing system for almond pollination that would incentivize beekeepers to provide colonies of high strength. We learned from a survey at the 2015 Almond Conference that such incentive contracts have become a common practice. In 2015, more than 20% of the respondents used pollination contracts that included incentives for high colony strength.

We asked growers about specific colony strength stipulations in their pollination agreements. Over 45% of growers used a colony strength specification of an 8-frame average. This large share suggests the existence of a standard colony strength for almond pollination. However, colony strength specifications deviated above and below this standard, and many growers reported no frame count stipulation at all.

Despite the importance of colony strength in almond pollination contracts, colony strength has not been acknowledged as an economic decision tool, distorting economic interpretations for many reasons. Surveys often collect pollination fee data without considering colony strength; therefore, previous economic analyses of pollination markets utilized averages of pollination fees across all colony strengths. These average fees misrepresent the distribution of almond pollination fees by overstating fees for low colony strength while understating fees for high colony strength.

Colony strength influences pollination fees in a given almond pollination season due to the strong correlation between colony strength and the overall number of colonies available for almond pollination. Beekeepers make pollination contract decisions before observing realizations of winter mortality rates and colony strength for almond pollination. Consequently, they may not receive sufficient compensation for their efforts in years when overall industry colony strength is poor.

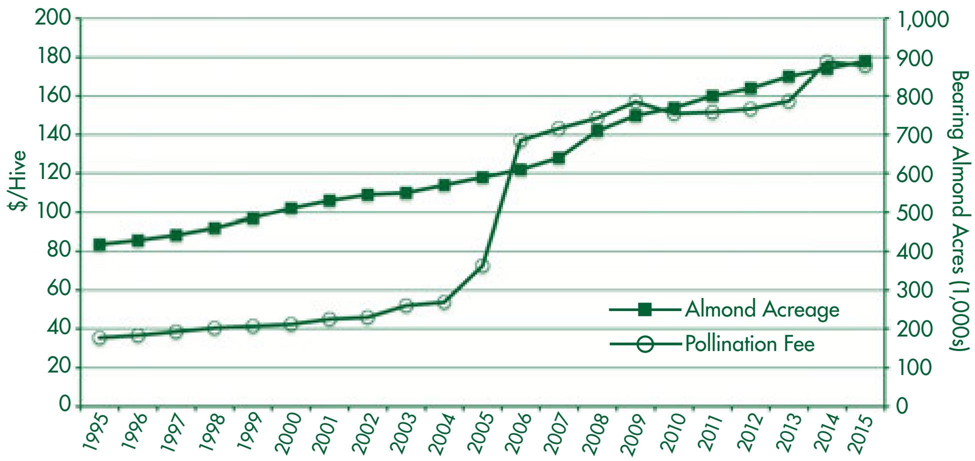
Relatively fixed hive densities despite pollination fee fluctuations have perplexed many economists. Rucker, Thurman, and Burgett (2012) provided two possible explanations for this phenomenon: pollination costs represent only a small share of total production costs and the lack of knowledge of marginal yield benefits from pollination. However, we demonstrate that a factor not previously considered by economists easily explains why hive densities may not fluctuate: the substitutability of colony strength and hives/acre in pollination efficacy.

We define pollination efficacy as the number of almond blooms pollinated per acre, so pollination efficacy is the input of interest to almond growers, not hives per se. The pollination efficacy of the rule-of-thumb two hives/acre density differs considerably for average colony strengths of 4-frames and 8-frames. In the absence of information regarding colony strength, hive densities convey little information regarding pollination efficacy preferences. As a primary choice variable for almond growers and beekeepers in pollination contracts, colony strength is an important component of the economics of managed pollination services.

Almond Pollination Fees

Over the last decade, per-hive almond pollination fees have increased (Figure 1 on page 6). Fees jumped substantially between 2005 and 2006 and increased steadily before and after those years. A combination of supply and demand issues can explain the upward trend in fees. Beekeepers' costs of supplying hives for almond pollination have increased due to Colony Collapse Disorder (CCD) and other health inhibitors (e.g., varroa mites), which reduce the

Figure 1. Per-Hive Almond Pollination Fees and Bearing Almond Acreage, 1995–2015



Source: California State Beekeepers Association Pollination Fee Surveys; USDA NASS; Almond Board of California 2015 Almond Almanac

number of viable hives and the strength of surviving ones. Higher overwintering losses for beekeepers have led to a costly and uncertain supply of colonies.

Meanwhile, almond acreage has expanded steadily over the last decade (Figure 1). Bearing almond acreage in 2016 required approximately two million colonies for pollination—76% of the honey-producing colonies in the United States during 2015.

Honey Bee Colony Strength as an Input Choice

In a perfect world, an almond grower would pay a price per honey bee and employ honey bees until the price per bee equals the value of employing an additional bee in terms of the bee's contribution to the almond orchard's yield. However, this method is impossible for many reasons, not least because no individual bee can be tracked and the bee does not necessarily forage on the almond orchard in which its colony is placed.

Fortunately, due to the clustering nature of honey bees in a hive, industry participants use a less costly standard of measurement to estimate the efficiency of a colony in pollinating a particular orchard: counting the number of active frames within a hive. This efficiency measure allows growers to substitute between average colony strength and the total number of colonies in a particular orchard.

Colony Strength for Almond Pollination: Inspections and Contract Provisions

Almond growers and beekeepers typically make pollination arrangements months before beekeepers observe overwintering losses and colony strength. In response to the associated risks, almond pollination contracts have played an increasingly important role in the procurement of hives for almond pollination, and third-party colony strength inspections routinely occur in many almond pollination transactions. Inspections are typically associated with contract provisions: to verify the almond grower received the strength she paid for or to calculate monetary bonuses/penalties to allocate to the beekeeper based on his delivered colony strength.

Either the almond grower or the beekeeper can initiate an inspection by a private third-party operation or, in major almond-producing counties, the County Agricultural Commissioner's office for a fee. The party requesting the inspection typically pays for the inspection.

Colony strength inspections for almond pollination occur after hive placement in the orchard. The inspections cover a random sample of 10–25% of hives to arrive at an average frame count for the hives supplied by the beekeeper. Examination of only a sample of hives occurs because it takes time (and therefore money) to inspect honey bee hives for colony strength. The responsible party must pay the inspector(s) anywhere from $20–100/hour and may also pay for the inspection certificate for each orchard/beekeeper (an additional $30–40 per requested certificate). On average, almond growers at one inspection operation paid an additional $1.50–$2.00 per inspected hive.

Regardless of who pays for the inspection itself, an inspection can be costly to the beekeeper due to the possibility of colony loss. Inspectors must carefully replace hive equipment while inspecting a colony so that its queen remains unharmed. Killing a colony's queen results in the loss of the colony, inhibiting or even eliminating its pollination services for the remainder of almond bloom. All parties involved find it desirable to disturb as few of the hives as possible.

Table 1. Sample Almond Pollination Incentive-Based Contract

Almond Pollination Pricing Schedule		
Benchmark Colony Strength: 8-Frame Average	Bonus/Frame Above Benchmark (Max Bonus=$20)	Penalty/Frame Below Benchmark
$175	$10	$15
Beekeeper Per-Hive Payments		
Beekeeper	Average Frame Count	Price/Hive
Beekeeper #1	9.5 Frames	(1.5x10)+175=$190
Beekeeper #2	7 Frames	$160
Beekeeper #3	11.5 Frames	$195

Table 2. 2015 Almond Pollination Fees by Colony Strength Contract Type

2015 Almond Pollination Fee/Hive Summary			
Colony Strength Contract Stipulation	Average	Min	Max
None	$165.22	$140.00	$180.00
Average of 8 Frames or Less	$169.66	$135.00	$215.00
Average of More Than 8 Frames	$179.36	$150.00	$200.00

Inspections may be used for verification in both fixed-compensation and incentive-based contracts. Fixed-compensation contracts between the grower and beekeeper provide a fixed pollination fee for all contracted colonies. This contract embeds a specified minimum average frame count that the beekeeper must meet. A grower may request a third-party inspection to verify the minimum average frame count is met, but this does not always happen.

Incentive-based contracts provide a base pollination fee for colonies of a benchmark colony strength in terms of frames per hive. If the actual average frame count found in the inspection exceeds the benchmark, the beekeeper receives a bonus per colony for the number of frames above the benchmark (frequently a maximum bonus will exist). If the colonies fall below the benchmark strength, the beekeeper receives a penalty per colony for the number of frames below the benchmark strength. Table 1 presents an example of an incentive-based contract with resulting per-hive pollination fees for three beekeepers with different frame counts.

A minimum frame count may also be specified in the contract. The beekeeper receives no pollination fees for any colonies failing to meet the minimum frame count. The minimum frame count stipulation in a contract presents an incentive for less variable colony strength. With this provision in a contract, a grower penalizes the beekeeper for providing extremely low strength colonies even if the beekeeper's average frame count exceeds the specified average frame count in the contract.

Colonies for almond pollination can also be procured with no colony strength specifications or as "field run" colonies, and as such would not typically be subject to colony strength inspections. By specifying colonies as "field run," beekeepers are not required to thoroughly inspect and merge small colonies prior to placement in almond orchards to achieve more uniform colony strength for pollination. On average, field run colonies will have acceptable colony strength (6-8 frames although this is not likely specified in the agreement), but colony strength may vary significantly across hives.

Pollination Prices by Colony Strength

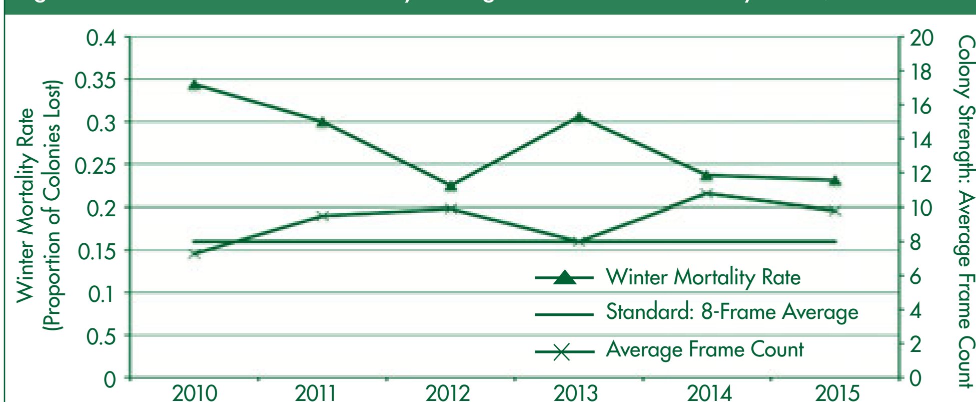
Previous work on the economics of managed pollination services relies on average per-hive pollination fees from various surveys. This use of an average price assumes homogeneous colony strength when in reality industry use of multiple colony strength specifications means that fees represent colonies contracted at different strengths.

Table 2 displays average pollination fees per hive by different colony strength stipulations reported by growers in our survey for the 2015 pollination season. The mean pollination fee per hive for contracts specifying high colony strength significantly differs from the means of both the contracts specifying low and no colony strength. Growers paid on average a 5.7% premium for colonies above the standard colony strength.

The most frequently reported pollination fee in 2015 was $180 and provides an illustrative benchmark when comparing the pollination fees across colony strength categories. Nearly 60% of growers with high colony strength contract provisions reported pollination fees above $180, while only 13% of growers with low colony strength contracts reported fees above $180. None of the growers with no colony strength stipulations disclosed pollination fees greater than $180. The relationship of grower-reported fees to the benchmark price for 2015 supports the notion of fee differences across the three categories of colony strength.

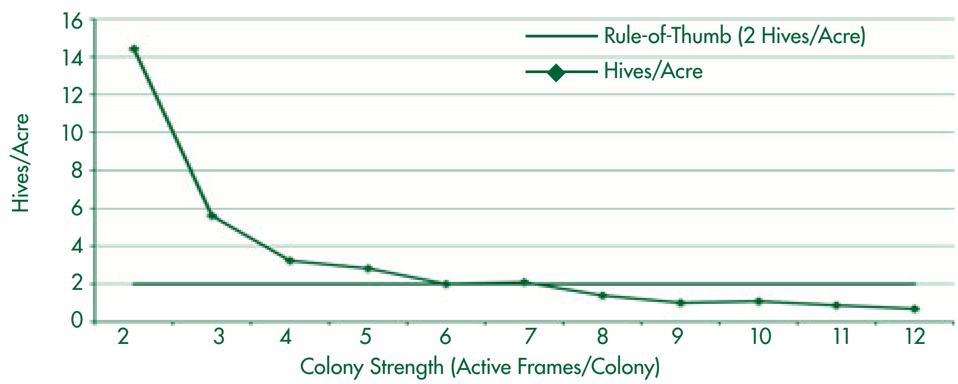
Almond pollination fees thus differ based on the average frame count stipulated in the contract. Additional issues likely complicate reported fees when not accounting for colony strength. Figure 2 displays the average frame counts across all hives inspected during almond bloom by The Pollination Connection, a third-party colony strength inspection operation, and the average winter mortality rates each year from thousands

Figure 2. Almond Pollination Colony Strength and Winter Mortality Rates, 2010–2015



Source: The Pollination Connection; Bee Informed Partnership Winter Loss Surveys

Figure 3. Honey Bee Hives/Acre and Colony Strength Pairs that Pollinate the Equivalent of Two Hives/Acre with Six Active Frames



Source: Sheesley and Poduska (1970)

of beekeepers across the U.S. reported by the Bee Informed Partnership. Average winter mortality rates indicate the number of colonies available for almond pollination because California almond pollination occurs toward the end of winter across most of the country.

Figure 2 shows that the average frame count across the sample of colonies in each almond pollination season correlates inversely with the U.S. winter mortality rate. Thus, fewer colonies available for almond pollination corresponds with beekeepers likely experiencing higher costs of meeting colony strength requirements. This creates the potential for extreme price fluctuations for colonies contracted close to almond pollination after winter mortality rates and colony strength have materialized. The low number of high strength colonies may force a grower to pay a high price even for colonies that fall below the industry standard strength.

The relationship between colony strength and winter mortality rates potentially strains beekeepers financially in many ways, especially those whose contracts specify high colony strength. Beekeeper revenues may decrease due to the decreased number of colonies from high winter mortality rates, while the costs of supplying high strength colonies may increase. Additionally, if a beekeeper is not able to meet the contracted colony strength, the almond grower may impose a monetary penalty on the beekeeper. Therefore, ignoring colony strength in any given almond pollination season omits an important element of supply.

As discussed previously, colony strength plays a role in the almond grower's decision concerning the number of hives to stock per acre. Figure 3 plots the colony strength-hive density combinations that pollinate the equivalent of two 6-frame hives per acre using Sheesley and Poduska's pollen count analysis. A clear non-linear relationship exists between the number of hives per acre and colony strength. Less than one 12-frame hive per acre will pollinate the equivalent of two 6-frame hives. Consequently, growers can substitute hive density and colony strength to find their optimal level of pollination efficacy per acre. As with reported average pollination fees, reported hive densities lack information when colony strength is not considered.

Conclusion

Disregarding colony strength ignores a major component of the supply of honey bee colonies for almond pollination. The high correlation of colony strength during almond pollination with winter mortality rates may disproportionately impact the supplies of the different colony strength grades available for almond pollination. For example, high winter mortality rates lead to a lower supply of colonies overall for almond pollination, but the ratio of high to low strength colonies available may also be smaller relative to low winter mortality years. The disproportionate supply changes complicate economic analysis because reported pollination fees per hive are affected by colony strength. This effect could be intensified if growers view multiple low strength colonies as an imperfect substitute for a single high strength colony.

Additionally, in expected rainy years for almond bloom, such as California's 2016 El Niño winter, almond growers may increase colony strength specifications while holding hives/acre constant to insure against fewer honey bee flight hours during bloom. This creates an uneven demand shift across different colony strengths, therefore convoluting reported pollination fees when ignoring colony strength. It would be beneficial to collect colony strength information alongside pollination fee and hive density variables to obtain a more accurate picture of the economics of pollination markets.

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Taxing Bottled Water as an Environmental Policy

Andrew Stevens, Peter Berck, and Sofia Berto Villas-Boas

Litter from plastic water bottles is an environmental concern for cities and states throughout the country. One potential policy response to this issue is to implement a consumer tax on bottled water in hopes that the subsequent reduction in total sales translates into less litter. We explore evidence from Washington state to analyze how effective and efficient a consumer tax on bottled water is as an environmental policy.

Lightweight polyethylene terephthalate (PET) bottles—such as those used for bottled water—make up a sizeable share of litter in the United States. These bottles are manufactured using petroleum, do not break down in the environment, and create significant problems for animals both on land and in lakes, rivers, and oceans.

Because of these bottles' negative environmental effects, many cities and states have implemented some sort of policy to reduce litter from PET bottles. For example, California has a 5-cent-per-bottle deposit and refund system. Taking a different approach, the city of Chicago has a 5-cent-per-bottle tax on all bottled water.

Any tax on a consumer good will simultaneously reduce sales of that good and raise tax revenue. Knowing which of these two effects will be stronger depends on consumers' demand for the good. If consumers' demand is elastic, they will greatly reduce the quantity of the good they purchase, and the government will collect relatively little tax revenue. On the other hand, if consumers' demand is inelastic, they won't reduce the quantity they purchase by very much and the government will collect a lot of tax revenue.

In 2010 Washington state imposed a tax on bottled water in order to both reduce bottle litter and raise government revenue. Six months after the tax was imposed, voters rescinded the tax through a ballot initiative. This gives us a unique opportunity to study how consumers respond not only to the introduction of a bottled water tax, but also to its removal. Our findings allow us to assess how effective and efficient a bottled water tax is as an environmental policy compared to a deposit and refund system.

Washington's Tax on Bottled Water

Prior to 2010, bottled water was exempt from sales tax in Washington state. Early that year, Governor Christine Gregoire proposed that the state end bottled water's exemption and begin collecting taxes on bottled water sales. Gregoire cited PET bottles' negative environmental effects as a primary justification for the change.

The Washington legislature ultimately approved the Governor's proposal, and bottled water was subjected to sales tax beginning on June 10, 2010. In response, the American Beverage Association began a $16 million campaign to overturn the legislature's decision. Ballot Measure 1107, passed by Washington voters on November 2, 2010, did just that. Bottled water thus regained its tax-exempt status on December 2, 2010.

To summarize, bottled water was subject to sales tax in Washington for approximately six months—from June to December 2010. The size of this sales tax varied across different areas of the state and ranged from 6.5% to 9.5%. (State sales tax was a flat 6.5%, but many local municipalities had added additional local sales taxes on top of that.) The average Washington consumer faced a sales tax around 9%.

Consumer Response

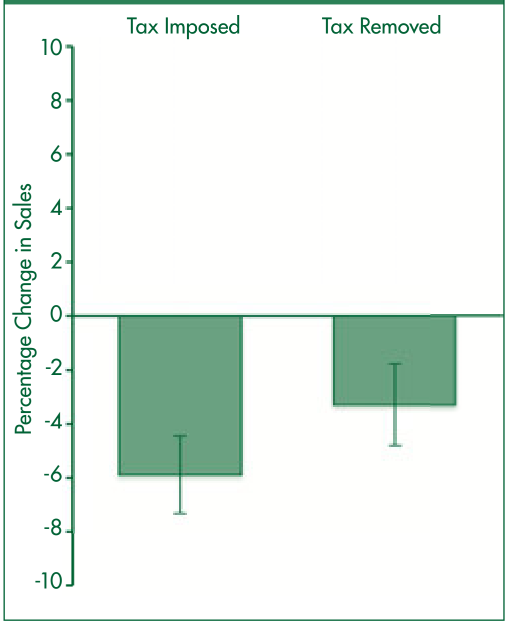
To study how consumers responded to Washington's tax on bottled water, we analyze weekly scanner-level bottled water sales data from a large national retailer. We observe data from over 160 stores in Washington and over 100 stores in Oregon and Idaho. By comparing sales in Washington (where there was a new tax on bottled water) to sales in Oregon and Idaho (where there was no tax change), we are able to isolate the effect of the tax from other forces that might have affected bottled water sales such as weather, seasonality, or sector-specific supply shocks.

We conduct our analysis using sales data starting in January 2007 and ending in May 2012. This allows us to compare how bottled water sales changed during the tax period (June–December 2010) and the post-tax period (December 2010–May 2012) relative to the pre-tax period (January 2007–June 2010) while controlling for observable and unobservable drivers of demand such as local temperature, product-store fixed effects, and shelf prices.

We find that, when bottled water was taxed in Washington state, total sales decreased by 5.9% relative to the pre-tax period. Furthermore, when the tax was later rescinded, total sales remained 3.3% below pre-tax levels. Figure 1 summarizes these findings. The solid green line in the center of each bar represents a 95%-confidence interval for each estimated effect.

It is particularly interesting to note that consumer demand for bottled water did not fully rebound to pre-tax levels in the post-tax period. There are several possible explanations for this behavior.

Figure 1. Percentage Change in Washington Bottled Water Sales Relative to the Pre-Tax Period (Includes 95% Confidence Intervals)



First, it is possible that, during the tax period, consumers mentally internalized higher prices for bottled water and did not completely readjust when the tax was removed. Second, it is possible that the political narrative around taxing bottled water raised awareness about PET bottles' negative environmental effects. Consumers may have internalized those messages and reduced their demand for water in plastic bottles.

In either case, our results suggest that a consumer tax can have a persistent effect on sales even after it is removed.

Exploring Different Tax Rates and Levels of Household Income

Thanks to the richness of our data, we are able to dig deeper into how the tax on bottled water affected different consumer groups in different ways. In particular, we explore (1) how consumers responded to different levels of the tax, and (2) how consumers' responses differed across different levels of household income. We find that the estimates presented in Figure 1 hide significant variation across these groups.

We begin by exploring the effects of different tax rates. Each store in our data is located in a region with its own level of total (state plus local) sales tax. Two of our stores are in an area where the sales tax was 6.5%, and the remaining stores were split between areas with sales tax rates of 8%, 8.5%, 9%, and 9.5%. This allows us to estimate the effect of taxing bottled water for each of these five tax rates separately.

Figure 2 presents our estimates of how consumers responded to the tax on bottled water for each tax rate. The first thing to note here is that our results in Figure 1 are being driven by consumers in areas with higher tax rates. In particular, on the imposition of a sales taxes of 9% or 9.5%, consumers reduce their purchases of bottled water by 7.3% or 6.6%, respectively. In addition, our estimates for these high-tax consumers are the only ones that are statistically distinguishable from zero at a 95% confidence level. Figure 2 tells a similar story for the removal of the bottled water tax: consumers in high-tax areas continue to buy less bottled water compared to the pre-tax period, while consumers in low-tax areas do not seem to respond to the tax (or its removal) much at all.

Figure 2. Percentage Change in Washington Bottled Water Sales Relative to the Pre-Tax Period, Separated by Tax Rate (Includes 95% Confidence Intervals)

The results in Figure 2 make a lot of sense: the higher the tax, the bigger the consumer response. However, as in the previous section, the fact that sales do not completely rebound after the tax is removed suggests some sort of behavioral response on the part of consumers. This is consistent with recent research on the topic of tax salience. Briefly, researchers have found that consumers do not seem to respond fully to taxes if they do not show up in a product's shelf price. Instead, consumers may actually mis-optimize by relying on imprecise mental rules of thumb or repeated purchasing habits.

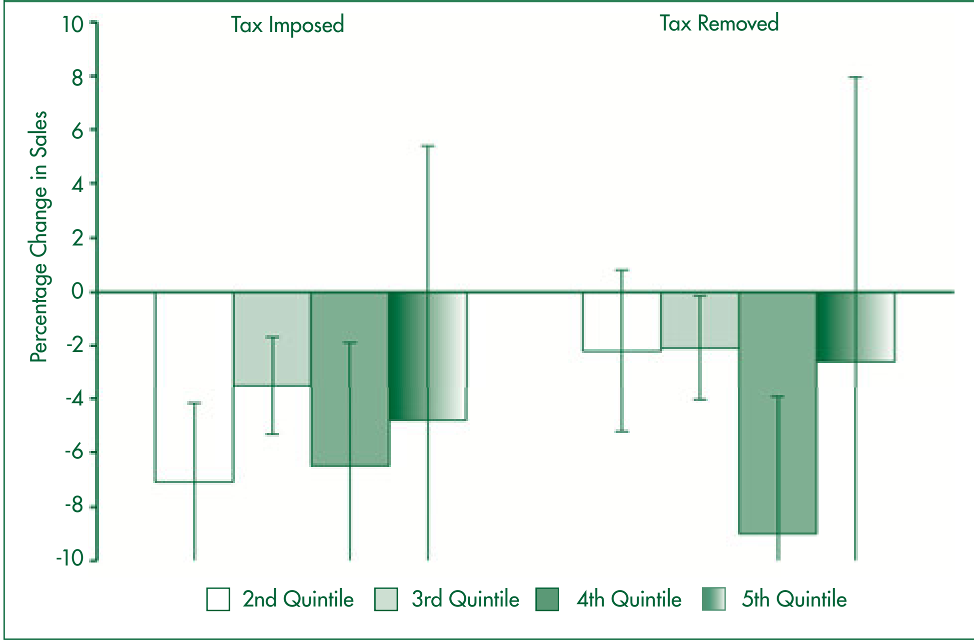
We next explore how consumers with different levels of income respond to the tax on bottled water. While we do not directly observe individual consumers' incomes, we can exploit the fact that different stores in our data are located in areas with different levels of household income. In particular, we match each store to its zip code and find the median household income for that zip code.

We split up our sample into the five national household income quintiles as defined by the 2009 Consumer Expenditure Survey, where the quintiles correspond to after-tax annual household incomes of $9,956, $27,275, $45,199, $71,241, and $149,951, respectively. None of the stores in our data are in first-quintile areas, so we focus on quintiles two through five.

Figure 3 presents how consumers with different incomes responded to the tax on bottled water. The overall pattern remains clear: consumers of all incomes reduce their consumption of bottled water when it becomes taxed, but do not completely restore their consumption to pre-tax levels after the tax is removed.

Beyond this main pattern, figure 3 highlights some interesting differences across consumer income levels. First, since relatively few of the stores in our data are located in fifth-quintile areas, our estimates for the top income group are statistically imprecise. Second, the lack of consumer "rebound" after the tax is removed seems to be driven almost entirely by consumers in areas with fourth-quintile incomes. These upper-middle class households may be particularly responsive to the environmental messaging that initially accompanied the bottled water tax.

Figure 3. Percentage Change in Washington Bottled Water Sales Relative to the Pre-Tax Period, Separated by Quintile of Median Household Income (Includes 95% Confidence Intervals)



Policy Implications

Our analysis shows that, for an average tax increase of approximately 9%, consumers reduced their consumption of bottled water by only about 6%. This suggests consumers have a price elasticity of demand for bottled water in the neighborhood of -0.67. Since consumers' demand for this good is relatively inelastic, we conclude that a sales tax on bottled water is more effective at raising revenue than it is at reducing consumption and, consequently, litter.

Using some back-of-the-envelope calculations, we estimate that Washington's tax would reduce the sales of bottled water at our retail chain by approximately 143,000 bottles per year. To put that number in context, we estimate the total number of bottles sold by the chain each year in Washington is over 2.43 million. Also, it is important to note that a sales reduction of 143,000 bottles does not translate into a litter reduction of 143,000 bottles; many PET bottles are already recycled or disposed of as waste.

In contrast to Washington's tax, refund schemes like California's deposit and refund system are specifically targeted to controlling litter and are much more effective and efficient at achieving that goal. For instance, in California, 70% of all PET bottles sold in the state are redeemed for a refund. The money for these refunds comes from the 30% of bottles sold that are not redeemed. For only cents per bottle, California achieves a 70% redemption rate while a 9% tax in Washington only reduces bottle sales there by 6%. If the policy objective is solely to reduce PET bottle litter, a consumer tax is a poor mechanism to achieve that goal.

Concluding Thoughts

Bottled water products are coming under ever-increasing scrutiny for their negative environmental impacts. Cities and states across the country are exploring different policy proposals for limiting PET bottle litter and reducing bottled water consumption. Our research suggests that a consumption tax on bottled water is a relatively ineffective and inefficient method for reducing bottle waste compared to other policy mechanisms such as deposit and refund schemes. However, a tax on bottled water could be effective at raising considerable tax revenue, depending on the size of the relevant tax base.

Stevens, Andrew, Peter Berck, and Sofia Berto Villas-Boas. "Taxing Bottled Water as an Environmental Policy." *ARE Update* 19(4) (2016): 9-11. University of California Giannini Foundation of Agricultural Economics.

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Agricultural and Resource Economics
UPDATE
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS • UNIVERSITY OF CALIFORNIA

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Agricultural and Resource Economics UPDATE

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Published by the Giannini Foundation of Agricultural Economics

http://giannini.ucop.edu

ARE Update is published six times per year by the Giannini Foundation of Agricultural Economics, University of California.

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