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Correct (and Misleading) Arguments for Market-Based Pollution Control Policies

Larry Karp

The extent to which climate change policy will rely on market-based rather than command-and-control policies is a matter of current debate. This research shows why neither policy, in general, has a greater claim to being "environmentally friendly." However, market-based policies eliminate a type of regulatory uncertainty that arises under command-and-control policies. In addition, the anticipation that the regulator will use market-based policies leads to investment decisions that increase the value of markets.

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The growing concern over climate change has led to an increased interest in designing policies to reduce greenhouse gas emissions. Three aspects of the policy question are central. First, the actual cost of reducing emissions in the future will depend on the investment decisions that firms make in the near term. Second, the nature of the future policies, in particular whether regulators will use market-based or command-and-control policies, is currently uncertain. Third, the stringency of the policies (their "level") is also currently uncertain. New research from the Department of Agricultural and Resource Economics and Policy at UC Berkeley revisits the theory of environmental regulation and shows that a widely believed and plausible argument in favor of market-based policies is incorrect. It also shows that there are subtle and not widely recognized arguments in favor of market-based policies. The research therefore helps clarify the discussion of regulatory policy.

The current controversy over California law AB32 motivates this research. This law mandates future reductions in greenhouse gas (GHG) emissions. Chapter 5 of AB32 recommends the use of market-based mechanisms, without mentioning either taxes or tradable permits. The bill gives future regulators discretion over the manner of implementing the mandate. Governor Schwarzenegger had wanted the bill to guarantee a market-based mechanism; shortly after signing the bill, he issued an executive order forming a Market Advisory Committee to design a cap-and-trade market. Some sponsors of the bill considered this attempt to lock in the form of implementation inconsistent with the intent of the law. The bill also gives future policymakers discretion over the extent of implementation. Article 38599 gives the governor the right to adjust the targets "in the event of extraordinary circumstances, catastrophic events, or threat of significant economic harm." AB32 provides a clear signal that California intends to reduce GHG emissions. It exemplifies a situation where the form of the regulation is currently unknown, and where the economic costs of reducing emissions may determine the stringency of the regulation. It is in this context that our research seeks to sort out the correct from the misleading arguments in favor of market-based regulation.

Are Market-Based Policies "Environmentally Friendly"?

There are many different types of command-and-control policies, and several different types of market-based policies. For our purposes, it is enough to consider one of each type. Under the command-and-control policy, the regulator tells each firm in the industry how much of a pollutant it can emit. The market-based policy (cap-and-trade) also imposes a firm-specific emissions cap, but lets firms buy and sell emissions permits. When the regulator has information about the average industry-wide abatement costs, but does not know the individual firms' abatement costs, the market-based policy is more efficient. In some circumstances, there are important differences between different types of market-based policies, such as taxes or cap-and-trade. Our discussion abstracts from those complications. Therefore, in the setting that we consider, taxes and cap-and-trade policies lead to the same outcomes. For the sake of concreteness, we consider cap-and-trade rather than taxes.

The market-based policy enables firms to trade so that the low-cost firms do most of the abatement. Therefore, the market-based policy achieves any level of abatement more cheaply, compared to the command-and-control policy. This efficiency is the basis for the argument in favor of market-based policies. Arguments of efficiency do not persuade all environmentalists, some of whom instinctively distrust markets. An economist might be tempted to convince such a market-skeptic by claiming that the greater efficiency of the cap-and-trade promotes environmental objectives. The economist's argument might proceed along these lines:

The reduction of emissions benefits the environment, but it carries an economic cost. Market-based policies have a lower cost of achieving any level of emissions reductions, compared to command-and-control policies. Therefore, if society balances economic and environmental costs in order to achieve the optimal level of emissions reductions, it will choose a larger level of reductions when the regulator uses market-based rather than command-and-control policies.

This argument has a ring of plausibility, because it reflects the idea that if something is cheaper, we want more of it. Market-based policies (compared to command-and-control policies) make abatement cheaper, so the former policies should make society chose a higher level of abatement.

Economic theory is well suited to testing this kind of argument, because it uses mathematics to make the argument precise. Our research shows that this argument is not correct in general. Market-based policies certainly reduce the *average cost* of abatement, but they might either increase or decrease the *marginal (incremental) cost* of abatement. The optimal level of abatement depends on marginal, not average costs. Thus, a switch from command-and-control to market-based policies could either increase or decrease the optimal level of abatement. The direction depends on factors that are difficult to measure. The point, thus far, is that the economist should not attempt to persuade the market-skeptic that market-based policies are environmentally friendly. They may not be.

The economist should not attempt to persuade the market-skeptic that market-based policies are environmentally friendly.

Regulatory Uncertainty

There are, however, powerful arguments in favor of market-based policies that are not directly tied to efficiency, and are not widely known. The nub of the matter is that command-and-control policies give rise to "regulatory uncertainty," and market-based policies eliminate this type of uncertainty. In order to understand this point, it helps to consider a simple example. This example obviously does not capture the tremendous complexity of the real world, but it does help to illuminate something that would otherwise be obscure.

Suppose that an industry consists of a large number of firms, which are approximately the same; i.e., they have the same costs of reducing emissions. Each firm individually decides whether to invest in a new technology that requires an up-front payment, and which reduces their abatement cost. In the next period, the regulator knows the fraction of firms who made the investment, and announces a per-firm ceiling on emissions. The regulator is not able to give different firms different ceilings, because to do so would set up perverse incentives at the investment stage. Using this example, we want to see what differences arise under the command-and-control and the cap-and-trade policies.

First, consider the scenario where the regulator will use a command-and-control policy. In this case, each firm has an incentive to make the same investment decision as the other firms, for a rather obvious reason. If most of the other firms make the investment, then the industry-wide abatement costs will be relatively low, and the regulator will impose a tight ceiling on emissions. This tight ceiling makes the investment in cost-reducing technology attractive.

In contrast, if most firms do not make the investment, then the regulator will face an industry with high abatement costs, in which case it will be optimal to permit a high level of emissions. This high ceiling makes the investment unattractive. In other words, each firm wants to do what most of the other firms do. At an "equilibrium" no firm wants to change its investment decision, given the decisions of other firms. In the situation here, there are two equilibrium outcomes (in general): either all firms or no firms make the investment. In the former equilibrium, the regulation is strict and in the latter, the regulation is weak. These two equilibria are "equally likely" and they involve very different levels of regulation. From the standpoint of the individual firm, the difficulty of predicting what the industry will do translates into a difficulty in predicting what the regulator will do. Thus, the anticipation that the regulator will use a command-and-control policy creates regulatory uncertainty at the investment stage. Firms do not like uncertainty.

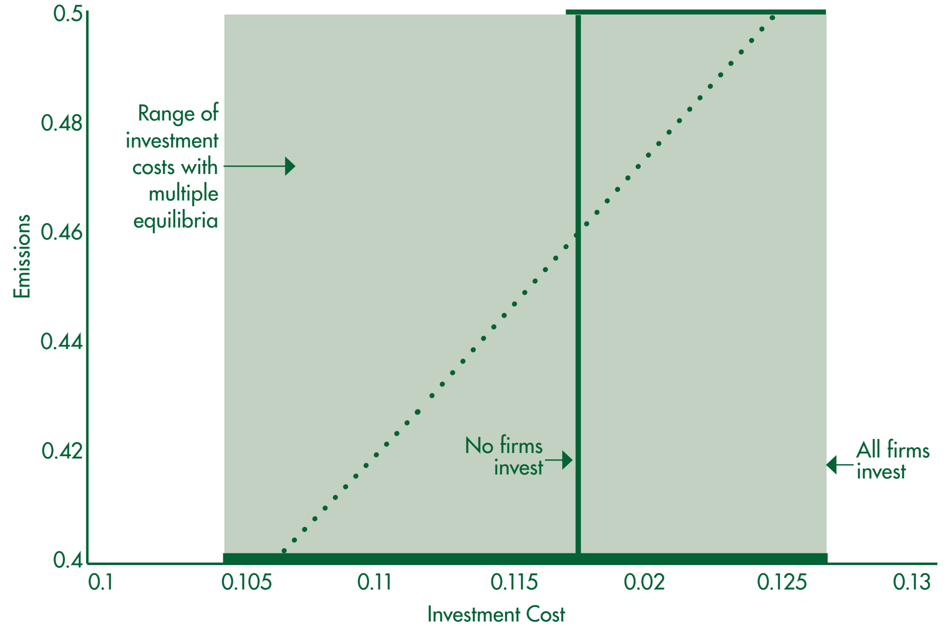
The cap-and-trade policy eliminates this uncertainty, because it leads to a unique equilibrium at the investment stage. As more firms decide to make the investment, the equilibrium price of permits falls. As the price of permits falls, a firm is less inclined to make the investment, because the firm knows that it has a cheap means of satisfying the emissions ceiling: buy permits. This fact leads to an equilibrium in which (in general) only a fraction of firms (rather than all firms or no firms) decide to invest.

This example illustrates another point. If firms anticipate that the regulator will use a command-and-control policy, then firms have an incentive to all make the same decision. As a consequence, firms that began with the same cost structure will continue to have the same cost structure. In this case, the gains from trade would be small, even if regulation permits trade. Thus, it appears that the inability to trade is unimportant. This conclusion is wrong, because it ignores the fact that the investment decisions depend on the regulatory policy. If firms anticipate that the regulator will use a cap-and-trade policy, in contrast, some firms will invest and other will not invest. Therefore, there will be substantial cost differences, leading to large gains from trade. The point here is simple: the anticipation that there will be a market causes firms to behave in a way that makes the market valuable.

A Numerical Example

Figure 1 uses a numerical example to illustrate the points made here. The cost of investment, together with the type of regulation, determines the fraction of firms that invest in equilibrium, and this fraction determines the socially optimal level of emissions. The figure graphs the equilibrium level of emissions as a function of the cost of investing in the technology, under different policy regimes. If all firms invest, the socially optimal emission level is 0.4 and if no firms invest, the optimal emissions level is 0.5. The shaded area identifies interval of investment costs for which there are two equilibria (either e=0.4 or e=0.5) when the regulator chooses the non-tradable emissions level after investment. There is a substantial range of costs for which there are multiple equilibria (indicated by the shading in the figure), and thus regulatory uncertainty. The positively sloped dashed curve shows the equilibrium level of emissions (as a function of investment costs) when permits are tradable.

Figure 1. The Equilibrium Level of Emissions as a Function of the Investment Costs, for Different Policy Regimes



The figure also illustrates the outcome in a third policy regime, where permits are not tradable but the regulator is able to credibly commit to a level of emissions before investment (thus eliminating the regulatory uncertainty). In this regime, if investment costs exceed the critical level indicated by the heavy vertical line, then in equilibrium no firms invest and e=0.5; if investment costs are below this heavy line, then all firms invest and in equilibrium e=0.4.

This example shows that, for a broad range of investment costs, the use of tradable permits rather than command-and-control has an ambiguous effect on the equilibrium level of emissions. The ranking of the level of emissions could go either way, regardless of whether the regulator announces the level of the emissions target before or after firms invest.

Conclusion

In summary, this research shows that one plausible argument in favor of market-based policies, the idea that these promote environmental goals, is not correct in general. However, there are two other arguments in favor of market-based policies that are seldom recognized. (i) Market-based policies eliminate the kind of regulatory uncertainty that arises under command-and-control policies. (ii) The anticipation that a regulator will use market-based policies causes firms to make decisions that increase cost differences and therefore lead to higher gains from trade.

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Faculty Profile: Larry Karp

Larry Karp
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Larry Karp earned his Ph.D. in Agricultural and Resource Economics at UC Davis, where his major fields were resource economics and econometrics. He taught at Texas A&M and Southampton University and joined the UC Berkeley ARE faculty in 1984, where he currently serves as department chair. He has served as associate editor or co-editor for leading journals in environmental economics, agricultural economics, and dynamics.

Larry has made fundamental contributions by applying dynamic methods to the study of agricultural, resource, and environmental problems. He has also made substantial contributions to the fields of industrial organization and international trade and development. He has contributed extensively to both theoretical and empirical literature, maintaining a steady stream of top publications for over twenty years.

Larry co-authored two of the earliest applications of optimal control methods to agricultural problems. This work derived the optimal decision rule for stocking and improving rangeland, and showed how to calculate the steady state distribution of range quality. It examined the general problem of optimal farm management where there exists the opportunity for multiple harvests within a season, and it quantified the value of better information about weather.

His recent work studies the optimal management of a pollutant that decays slowly over time (a "stock pollutant"), comparing taxes and cap-and-trade policies. This research extends previous results that apply to pollution that decays quickly ("flow pollutants"), and is essential for studying problems related to greenhouse gasses. This research finds that taxes are more efficient than cap-and-trade for the control of greenhouse gasses. An extension of this work takes into account that over time we can expect to have a better understanding of the relation between greenhouse gas stocks and economic/environmental damages. This anticipated learning leads to a small decrease in optimal abatement efforts, and it strengthens the argument for carbon taxes rather than quantity restrictions.

His current work on climate change emphasizes the role of "impatience" (or "time preference") in modeling climate policies. He has developed a model that takes into account the temptation of policymakers to procrastinate when deciding how to address climate change. One strand of this work considers the situation where the danger of an environmental catastrophe increases as the stock of greenhouse gasses increase. Using a more plausible description of how people really think about distant generations, Larry's work shows that the threat of catastrophe has significant effects on policy. The conclusion is that society should be willing to make considerable effort to reduce the risk. This result is controversial, since many economists have developed models that recommend only modest expenditures to address climate change.

Larry has published prolifically in dynamic games. His first paper on this topic examined the international grain trade as a dynamic game. When this paper was written, there was a lively debate about the ability of grain exporters to exercise market power. This paper, which was the first application of dynamic games in agricultural economics, showed how the dynamic supply response constrains the exercise of market power. Following this work, Larry co-authored a series of papers studying the interactions of buyers and sellers with market power in the international oil market. This work culminated in a widely cited Handbook chapter that explains dynamic consistency problems in the context of resource markets.

Larry has also made significant contributions in industrial organization theory, where his major contributions concern the idea that a monopoly producer of a durable good has a very limited ability to exercise market power, because of competition from the second-hand market. He has also written extensively in international trade and development. His work on delegation in customs unions shows that nations may want to delegate authority to set external tariffs to aggressive partners. Recent papers study the relation between property rights to natural resources and comparative advantage.

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Expert Opinion and the Demand for Wine

James Hilger, Greg Rafert, and Sofia Villas-Boas

We examine the impact of expert opinion on retail wine sales utilizing an experiment implemented on a national retail chain. A test store was selected to receive an expert-ranking label for selected wines. A comparable control store was also chosen. Sales effects of the ranking were examined and compared between test and control stores.

Product awareness and perceptions of product quality can have large effects on consumption patterns. Given the variety of methods employed by manufacturers and marketers to inform consumers of a product's quality, recent research has analyzed the extent to which product-quality information affects consumer behavior. This literature examines the effect of a variety of information types and sources, including branding, mandatory product labeling, and advertising. One additional method used to convey quality information to consumers is through so-called experts. For example, *Consumer Reports* tests a large number of products each year and publishes product reviews, and magazines such as *Wine Spectator* and *Wine Enthusiast* rate wine quality.

Most studies analyze the impact of expert opinion on consumer demand for goods for which the quality is only learned by consumers after consumption (the so called "experience goods"). However, these studies face a significant obstacle: products of high quality are likely to both receive high-quality ratings from experts and to be of high quality. As such, it is difficult to determine the extent to which consumer demand is affected by expert reviews, since to do so, the researcher must control for unobservable product quality. Yet even if expert reviews affect consumer demand for a particular good, demand may change because consumers respond to the quality signal in the review or alternatively, because consumers are merely alerted to the presence of that good.

Experimental Design and Data

The research goal is to examine the impact of expert opinion on retail wine purchases. To distinguish the effect of expert reviews from that of product quality, we utilize an experimental approach implemented at stores in a national retail grocery chain that cooperated with the research team. Wines in a retail store in Northern California were randomly chosen to display wine scores from a proprietary wine scoring system, and wine opinion labels were then displayed for one month during the spring of 2006. The retailer classifies the chosen treatment store as a high wine-revenue store, and the store has wine revenues that are greater than the revenues for most other stores operated by the retailer in California. Further, on average, the store is located in a wealthier area, has a greater amount of shelf space dedicated to the sale of wine, stocks more expensive wines, and sells more wine as a percentage of total grocery sales. To the extent that consumers in more wealthy areas and those buying more expensive wines are likely to be more fully informed regarding wine quality than consumers in other areas, we have selected a store that should reduce the likelihood of finding a significant treatment effect.

Wine scores from a proprietary wine scoring system were displayed in the treatment store for four weeks during the month of April 2006 for a random selection of wines. The wines chosen for the experiment were not selected from the total population of wines in the store since many wines do not receive wine scores from any of the wine-rating agencies. Instead, the wines were chosen from the population of wines stocked in the store that received wine scores. Of the total of 1,089 wines sold in the test store in March 2006, 476, or 44 percent, received wine scores from one of several potential wine-scoring agencies. Thus, by selecting 150 treatment wines, we treated 32 percent of the total population of potential candidates and 14 percent of all wines within the store.

To each treated wine, we affixed a label to the shelf below that indicated the score awarded the wine from the scoring system. Each label displayed information on the score received by a wine, the wine's price, as well as the name of the proprietary scoring system. Wine scores awarded by the scoring system can in theory range from 50 to 100, with 100 being the highest possible score. In practice, however, wine scores typically range between 75 and 100, with most wines receiving scores between 80 and 89.

We obtained weekly store-level sales data from the grocery chain for each wine sold in all Northern Californian stores. The data provided information on the number of bottles sold, the pre-discount price, the discount amount, and the wine variety. The weekly sales data were aggregated to the month-level for each store to generate total number of bottles sold per month, average pre-discount price, average post-discount price, and whether a bottle of wine was discounted in any one week during a given month. For those wines for which wine scores exist, we then merged wine score information from the proprietary wine score system with the wine sales data.

Due to differences between the retail chain's database of stocked wines and those wines actually stocked at the time of the experiment within the retail store, 112 wines were labeled in the test store. There are few differences between treated wines and untreated wines for which scores exist, as can be seen in Table 1. For example, the mean score for treated wines is equal to 84.1 while the mean score for untreated wines with scores is 83.7, and this difference is not significant. Further, the pre-treatment difference between price and quantity is not significantly different for these groups, thereby suggesting that the selection of the treatment wines was random. There are also not significant observable differences between treated wines and untreated wines for which scores are not available.

Empirical Strategy and Findings

Given the experimental design, we utilize a differences-in-differences approach to analyze the effect of the treatment on treated wines and to determine whether expert opinion provided quality information or simply highlighted the existence of treated wines. Specifically, we first examine the effect of the treatment on the treated wines by comparing the change in the sales of treated wines from the pre-treatment to treatment month in the test store, to the change in the sales of treated wines from the pre-treatment to treatment month in the control store.

Figure 1 illustrates the basic idea behind the difference-in-difference approach to identify the impact of the treatment via expert opinion labeling. Consider on the left, two bars corresponding to the number of bottles sold in store C (that was the store that did not change the way the products were displayed on the shelves), where the first bar corresponds to the before period, and the second bar corresponds to the bottles sold in C in the after period. In the middle of Figure 1, let us represent store T (the test store where we displayed expert opinion labels). The two bars correspond to the number of bottles sold in the before and in the after period, respectively. For store C, we perform a first difference consisting of the changes in bottles sold from the after period relative to the before period, and call that D_C. Next we do the same difference of after minus before sales for the test store, and call that difference D_T. The effect of our treatment consists then of the difference D_T-D_C, that is, the difference in these two differences. And in doing so, we assess the changes in the test store relative to the changes in the control store.

Table 1. Descriptive Statistics

	Treated Wines	Untreated Wines (With Scores)	Untreated Wines (Without Scores)
Score	84.1	83.7	
	[3.5]	[3.0]	
Quantity March (pre)	12.2	14.3	9.2
	[20.3]	[19.9]	[18.2]
Quantity April (post)	14.5	18.4	9.1
	[21.9]	[20.0]	[18.0]
Price (pre)	11.8	10.9	11.8
	[7.8]	[6.3]	[9.0]
Price (post)	12.5	11.6	11.9
	[10.3]	[7.2]	[8.9]
Percent Red	63.4	61.9	60.6
Number of Observations	**112**	**253**	**629**

Source: Retailer provided scanner data set.

We run the above analysis first on only those wines that received an expert opinion label. The dependent variable is the number of bottles of wine sold of a product in a store in a certain week, and the independent (explanatory) variables are (i) an indicator variable, *store,* that is equal to one for treated wines in the test store and equal to zero for treated wines in the control store, (ii) an indicator variable, *month*, that is equal to one during the treatment month and equal to zero during the pre-treatment month. The coefficient on *store* can be interpreted as a treatment group-specific effect, the one on *month* as a time trend common to the control and test stores, and the *(store***month)* coefficient can be interpreted as the true effect of the treatment. We control for potentially important other factors (covariates) such as promotions or discounts which, if omitted, could lead to a biased estimate of the treatment effect.

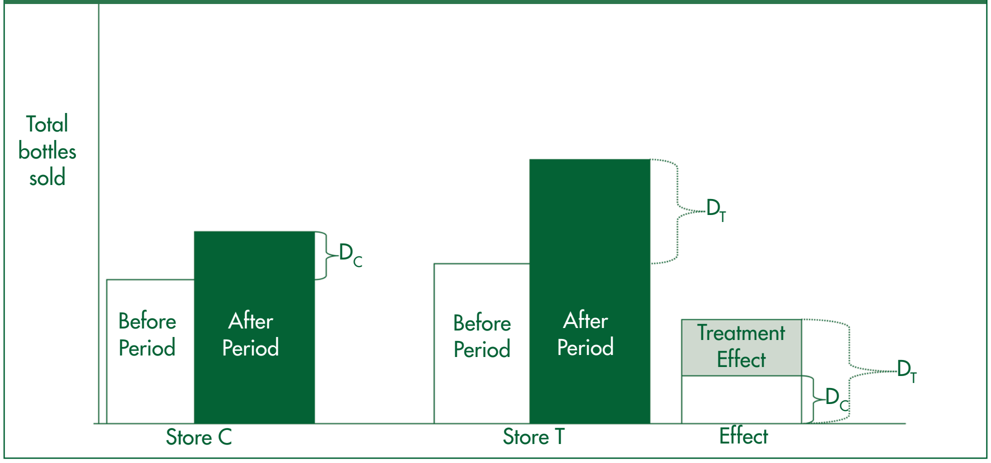
The average effect of the treatment on the treated wines is not significantly different from zero. The only variable which is significant is the promotion variable. It is always positive, indicating that a wine placed on promotion sometime during the month (where the minimum promotion length in the data is two weeks and the maximum is four weeks during a month) can expect on average to sell approximately 13 to 15 bottles more per month than if it were not discounted. Since non-promoted, treated wines sold an average of four bottles, this effect indicates that the average number of bottles sold of a treated wine increases by 425 to 475 percent when it is placed on promotion.

Although useful for examining the average treatment effect on the treated, the above investigation does not address the extent to which the expert opinion effect is related to quality information provision versus general publicity. To examine the manner in which consumers use expert opinion information, we include interactions between score, price, and the treatment. If expert opinion primarily provides quality information to consumers, then only those treated wines that received higher scores should experience an increase in quantity sold. Alternatively, if the primary effect of expert opinion labels is to alert consumers to the existence of a wine, then the treatment should have an impact irrespective of a wine's score. As above, to reduce the likelihood that the estimated treatment effects are biased, we include price and whether a wine was discounted in any one week during a given month, as well as interactions between price, score, discount, and the treatment.

We find that although there is no overall consumer response to expert opinion provision, a subset of highly reviewed wines experienced an increase in demand. In particular, the estimated effect on a treated, low-price wine of moving from low to high score lies between eight and 15 additional bottles sold during a given month. Given that low-priced, high-scoring wines sold an average of 26 bottles during March in the test store, sales increased by an average of 30 to 58 percent as a result of the treatment.

Although we are primarily interested in estimating the average treatment effect on the treated wines, we also estimate the average treatment effect on the untreated wines. Interestingly, we also find that as demand increased for a subset of treated wines, demand did not change for untreated wines. Thus, consumers either did not completely substitute towards treated wines or a sufficient number of consumers entered into the wine market to offset those consumers who substituted away from untreated wines.

Figure 1. Difference in Difference



Conclusions

Our results strongly suggest that expert opinion can affect the demand for wine by transmitting product-quality information to consumers. Results indicate that consumers utilize quality information provided by expert opinion labels, as opposed to solely using the label to learn of a wine's existence. Unlike most previous work that examines the impact of expert opinion on consumer demand, we are able to disentangle the endogenous relationship between product quality and expert opinion provision through the use of an experimental approach in a large national retail grocery chain. We randomly select 150 wines to display expert opinion information. Then we select a control store with similar characteristics to those of the test store. We are then able to examine both the effect of expert opinion on the overall demand for wine, and the role of expert opinion labels in providing quality information versus alerting consumers to the existence of a wine.

We find that on average, sales of wines with expert opinion information did not increase. However, we do show that low-priced, high-scoring wines experienced an increase in demand relative to other treated wines. These results are robust to the use of alternate control stores, the use of the alternate test store, and the variables included within the regressions. Further, these effects only exist during the treatment period, and are not found when other pre-treatment months are used as the treatment period. Although we can offer no definitive evidence, one potential explanation for the lack of a high-score effect for more expensive wines is that consumers who purchase expensive wines are more fully informed regarding product quality, and thus gain little information when expert opinion is displayed. Finally, we find that as demand increased for a subset of treated wines, demand did not change for untreated wines.

Our findings broadly suggest that expert opinion can provide quality information to consumers and that at least some consumers will use such information when making purchasing decisions. To the extent that certain consumers previously did not participate in the market due to a lack of product information, such information provision may allow the market to expand as new consumers enter. Further, as quality information is distributed and consumers learn which producers are associated with high-quality products, low-quality producers may increase their product quality to more effectively compete with high-quality producers. Both the relationship between information provision and consumer entry, and that between quality information and the quality provided by producers remain as interesting avenues for further research.

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California Water Quality: The Role of Agriculture

Hossein Farzin and Kelly Grogan

While California's agriculture has been vibrant and growing, the quality of the state's water bodies has weakened. However, despite the common perception that agricultural production is a principal culprit, our study shows that this is not generally true. It shows that only a very small portion of water pollutants attributed to agricultural production are actually positively correlated with agricultural production while the majority of the pollutants have *no* relationship, and some of them are even *negatively* correlated.

A 2004 assessment by the U.S. Environmental Protection Agency (Table 1) found that about 93 percent of the state's water is "impaired," a term that means the body of water cannot be used for at least one of its designated uses. These uses may include recreation, commercial fishing, agricultural water supply, drinking water supply, and wildlife habitat, among others. About five percent of assessed bodies of water are "threatened," meaning that there is a high probability that their designated uses will no longer be viable in the future. Only about three percent of the bodies of water assessed in the state are labeled "good," which means that the body of water can be used for all of its designated uses and none of these appear to be threatened. A variety of causes underlie these impairments, of which agriculture is commonly perceived to be a principal one. We have conducted a study to measure the relationship between a county's intensity of agricultural production and its water quality. A variety of water pollutants come from both agricultural and non-agricultural sources. Table 2 summarizes these sources.

As is apparent from Table 2, common water pollutants come from a variety of sources of which agriculture is only one. To complicate things further, all water within a watershed gets pooled together so it is not easy to know from which source the pollution is coming. Furthermore, different industries may have more effective mitigation of pollutants than other industries. Industry *A* may emit ten units of the pollutant each year but abate seven units, implying that only three units reach a body of water. Industry *B* may emit eight units but only abates two units, allowing six units of the pollutant to reach water bodies. As a result, industry *B* is responsible for a larger share of the water pollution even though industry *A* looks like a larger polluter.

To efficiently improve the state's water quality while facing budget constraints, policymakers should target the main sources of the pollutants instead of targeting any and all possible sources. As discussed, however, knowing the actual source can be difficult. One way to overcome these difficulties is to use regression analysis to see which factors are most highly correlated with levels of pollution.

Data

The water quality data for the study came from the EPA's STORET database. This database collects water quality data from a wide variety of sources such as the California Department of Water Resources, the EPA National Aquatic Resource Survey, the California Surface Water Monitoring Program, the California State Water Resources Control Board, and the National Park Service. Each sample in the STORET database represents one water sample that was taken from a specific location. Since most of the socioeconomic data are available at the county level, all samples were aggregated up to the county level by water body type and pollutant. For example, if county x had fifteen samples of nitrate levels in rivers, the mean, median, maximum, and standard deviation of these 15 samples were calculated. Similarly, if county y had 32 samples of sulfate levels in lakes, the mean, median, maximum, and standard deviation of these 32 samples were calculated. Each observation in the analysis that is reported below captures the underlying samples in this manner.

Agricultural production data came from the National Agricultural Statistics Service's County Agricultural Commissioners' Data, an annual report that contains the value of production by crop or animal product. The monetary values of crop and livestock production at the county level were obtained from these reports. To measure the intensity of production, these values were divided by the total land area of each county.

Unfortunately, measures of other economic activity, such as mining and industry, were not readily available at the county level. To make up for this, we included measures of a county's ethnic, gender, and age compositions. If an industry tends to employ a higher proportion of any of these groups, these variables will pick up those effects. We also included a measure of population density which will account for household sources of pollutants. Since the local population's demand for water quality influences local water pollution levels, we included measures of education and income. As important determinants of demand for environmental quality in general, these variables may

Table 1: Attainment Status of California's Water Bodies

Attainment Status	Miles	Percent of Assessed
Good	910.21	2.78
Threatened	1,507.16	4.61
Impaired	30,287.89	92.61
Total Miles Assessed	**32,705.26**	**100.00**

Source: U.S. EPA. 2004. National Assessment Database. *http://www.epa.gov/waters/ir/*

affect water quality. We included a time trend to account for statewide improvements or deterioration due to, for example, changes over time in water pollution standards, monitoring, enforcement, or related technologies. Finally, we account for naturally occurring variation of pollutants between different types of bodies of water such as rivers, oceans, lakes, and estuaries. All data is at the county level for 1993 to 2006.

Empirical Analysis

To determine the relationships between agricultural intensity and water pollution, we estimated three regression models for each of the agricultural pollutants listed above. These three models examined the statistical relationship between the mean, median, or maximum level of a pollutant and variables that one might expect to affect the pollution level. For example, we estimated the relationship between the mean level of ammonia and various measures of county and water body characteristics that might affect ammonia levels.

Table 3 presents the relationships between measures of agricultural production and water quality indicators. As hypothesized, only a portion of pollutants associated with

Table 2: Water Quality Indicators and Agriculture

Pollutant	Natural (Non-human) Sources	Industrial Sources	Agricultural Sources	Household Sources
Ammonia	no major sources	coke plant emissions and effluent, ceramic production, mining	fertilizer runoff, animal waste runoff	septic systems, cleaning products, sewage treatment plants
Arsenic[a]	erosion of natural deposits	glass and electronics production runoff	orchard runoff	no major sources
Copper	erosion of natural deposits	no major sources	Insecticide runoff	plumbing system erosion
Dissolved Oxygen	warm weather, runoff from forests	thermal pollution	runoff from pastures, cropland	fertilizer runoff, wastewater treatment plants
Magnesium	erosion of natural deposits	construction and electronic industry runoff	fertilizer runoff	no major sources
Mercury[b]	erosion of natural deposits	refinery and factory discharge	cropland runoff	landfill runoff
Nickel[c]	erosion of natural deposits	power plant and metal industry emissions	fertilizer runoff	waste incinerator emissions
Nitrate[d]	erosion of natural deposits	no major sources	fertilizer runoff	fertilizer runoff, septic tank leaching, sewage
Nitrite[e]	erosion of natural deposits	no major sources	fertilizer runoff	fertilizer runoff, septic tank leaching, sewage
Phosphorus	erosion of natural deposits	industrial effluent	fertilizer and manure runoff	sewage effluent
Specific Conductivity	erosion of natural deposits	industrial inputs	agricultural runoff	road salt
Sulfate	erosion of gypsum, volcanoes	mining runoff, fossil fuel combustion	fertilizer runoff	no major sources
Total Coliform	naturally present, animal fecal matter	none	animal waste	human and animal waste
Total Suspended Solids	natural soil erosion	industrial wastewater	soil erosion	soil erosion from construction sites, sanitary wastewater
Zinc	erosion of natural deposits	alloys, paints, batteries, car parts, electrical wiring	insecticide runoff	sewage sludge

Source unless otherwise noted: EPA. 2008. Drinking Water Contaminants. *www.epa.gov/safewater/contaminants/index.html*

[a] *Texas Cooperative Extension. 2008.* Dissolved Oxygen. *http://aquaplant.tamu.edu/contents/dissolved_oxygen.htm.*

[b] *Water on the Web. 2008.* Glossary. *http://waterontheweb.org/resources/glossary.html.*

[c] *USGS. 2006.* The Effect of Urbanization on Water Quality: Phosphorous. *http://ga.water.usgs.gov/edu/urbanpho.html.*

[d] *Michigan Department of Environmental Quality.* Total Suspended Solids. *www.deq.state.mi.us/documents/deq-swq-npdes-TotalSuspendedSolids.pdf.*

[e] *Central New York's New Real-Time Surface Water Quality Network. 2008.* Specific Conductivity. *www.ourlake.org/html/specific_conductivity.html.*

Figure 1: The Percent Increase in Water Pollutant Given a 20 percent or 40 percent Increase in Animal Production Intensity

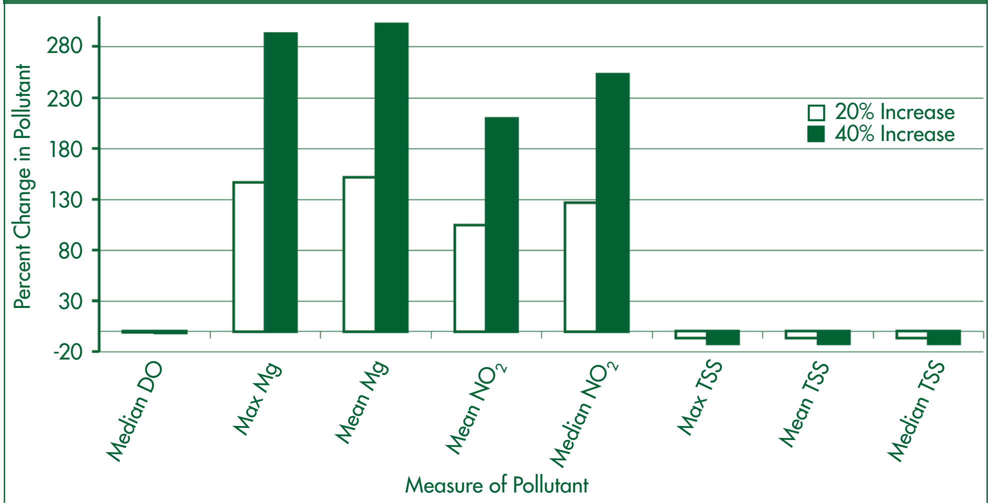


Figure 2: The Percent Increase in Water Pollutant Given a 20 percent or 40 percent Increase in Crop Production Intensity

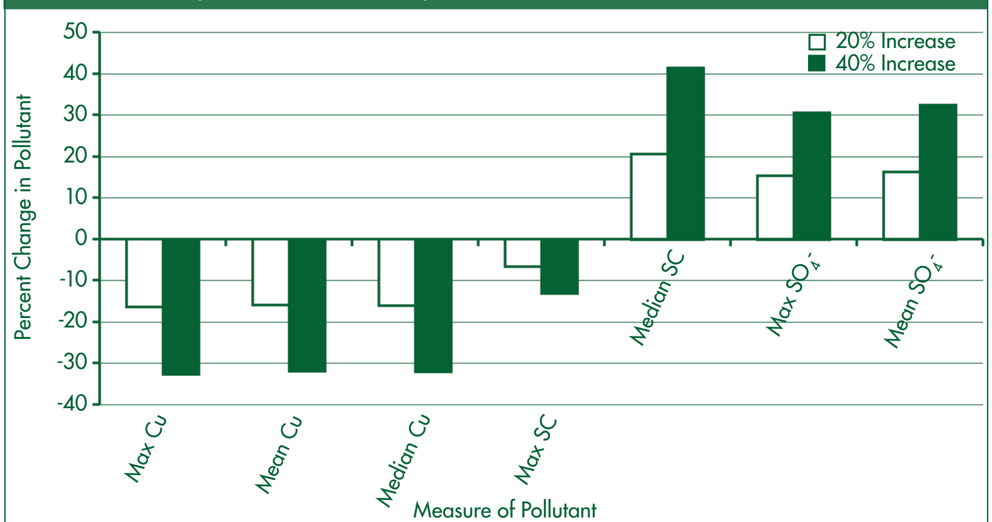
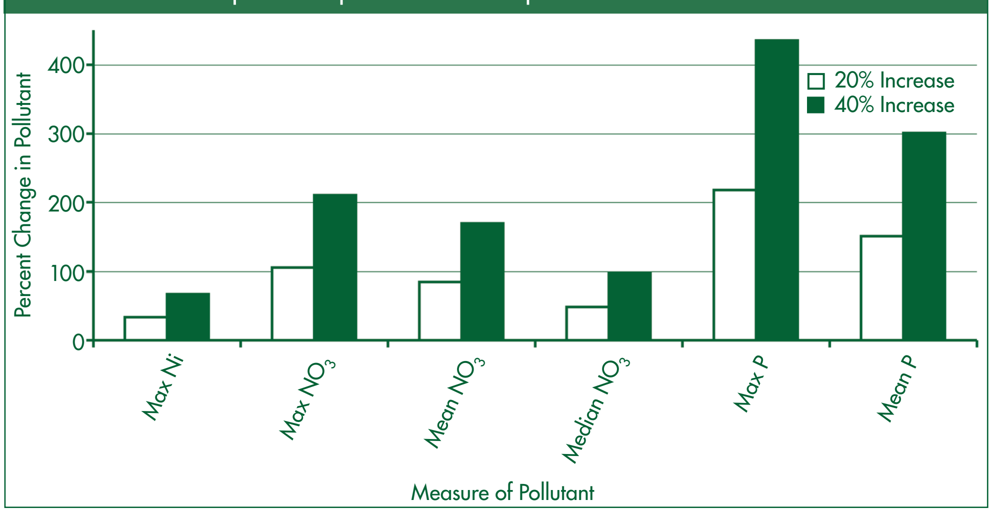


Figure 3: The Percent Increase in Water Pollutant Given a 20 percent or 40 percent Increase in the Hispanic Proportion of the Population



agricultural production are actually correlated with agricultural production in a statistically significant way.

We found that nitrites (NO_2^-) and dissolved oxygen (DO) depletion were positively correlated with the value of animal production per acre of county land. These correlations picked up the effect of animal-waste runoff. Animal waste contains nitrites, increasing the concentration of these nitrogen-containing ions in surrounding water. The nitrites, as well as other nutrients found in animal waste, encourage algal growth which decreases the concentration of oxygen in water. In areas with median levels of dissolved oxygen and nitrates, increasing the intensity of animal production by one percent decreases the quantity of dissolved oxygen by 0.02 percent and increases the concentration of nitrites by 5.23 percent.

While animal production is associated with worsened water quality with regards to dissolved oxygen and nitrites, total suspended solids (TSS) are negatively correlated with the value of animal intensity. This pollutant is associated with urban and suburban construction. Population density was positively correlated with this pollutant, suggesting that construction is a main source. It is possible that areas with high animal production such as Fresno and San Bernadino Counties are less likely areas for new development projects, perhaps due to the unpleasant odors of such operations. Thus, the negative impact of the animal-intensity variable may be picking up that effect.

The value of crop production per acre of county land was positively correlated with sulfate (SO_4^-) and specific conductivity (SC), a measure of the water's salt content. Increased sulfate concentrations in counties with high agricultural production are due to fertilizer runoff. Increasing the intensity of crop production by one percent is associated with a 0.81 percent increase in sulfate concentrations. Areas with high levels of agricultural activity like Tulare and San Joaquin counties have elevated specific conductivity due to the irrigation water applied to crops. All water, even fresh sources, contains some quantity of salts. Plants take up

Table 3: Correlation between Water Quality Indicators and Measures of Agricultural Activity

Pollutant	Impact of Crop Intensity	Impact of Animal Intensity	Correlation with Hispanic Population
Ammonia			
Arsenic			
Copper	-		
Dissolved Oxygen		-	
Magnesium		+	
Mercury			
Nickel			+
Nitrate			+
Nitrite		+	+
Phosphorous			+
Specific Conductivity	+		
Sulfate	+		
Total Coliform			
Total Suspended Solids		-	
Zinc			

** Blanks indicate no statistically significant correlation.*
*** (-) and (+) indicate statistically significant correlation at the 90 percent confidence level or more.*

the water, but leave the salts behind. With each irrigation application, more salts are added to the region's soil and surface water. In areas with median-specific conductivity values, increasing the intensity of crop production by one percent is predicted to increase specific conductivity by 1.03 percent.

Interestingly, value of crop production per acre of county land is negatively correlated with copper (Cu), a common ingredient in miticides. In California, mites are more common pests of some of the relatively lower-valued crops such as cotton and alfalfa than the higher-valued fruit and vegetable crops, so our value-weighted crop intensity measure likely picks up this phenomenon. It is also possible that farms growing higher-valued crops tend to implement mitigating measures, preventing the need for miticide use.

As a cautionary reminder while interpreting these results, it should be noted that the measure of agricultural activity used in the study weighs high-valued crops more heavily. As a result, if a certain pollutant is more heavily associated with lower-valued crops, or equally associated with all crops, the value measure will not pick up the effect of agriculture on the pollutant's level. One of the socio-economic variables we included in the analysis was the percent of a county's population that is of Hispanic ethnicity. Since this ethnic group makes up a large portion of the agricultural workforce, it is natural to suppose that this variable may be picking up the effect of agriculture. Interestingly, we found that this variable is positively correlated with nitrates, nitrites (NO_3^-), nickel (Ni), and phosphorous (P), pollutants often found in fertilizer runoff. Fertilizer is an input one expects to be used in all agricultural production and which might not vary as much with value of production as does something like irrigation.

Importantly, we find that ammonia, arsenic, mercury, total coliform, and zinc are all *uncorrelated* with measures of agricultural intensity. This suggests that due to health hazards of these toxins, mitigatory measures already in place work adequately, and policy should address the *non-agricultural* sources of these pollutants as possible.

Conclusions

While agriculture can be an easy target for those looking to place the blame for poor water quality, this study shows that agriculture is *not* the main culprit of some typical agricultural pollutants found in surface water. People commonly associate *soil erosion* with agriculture, and soil erosion leads to increased total suspended solids (TSS). We find that crops do not contribute to total suspended solids, and that animal production even appears to decrease TSS. Ammonia is another pollutant commonly associated with agricultural production, but we find no connection between the two when considering surface water. Some of the misconception with regard to agriculture and surface water quality may stem from agriculture's impact on *groundwater* quality. However, practices like agricultural buffers can prevent much surface water contamination, while few mitigative measures exist to protect groundwater.

Surface water pollutants like nitrites, nitrates, sulfates, phosphorous, and specific conductivity are, however, significantly positively correlated with agricultural production. This suggests that agriculturally targeted surface water quality programs should focus on these pollutants in counties with high agricultural intensities, while groundwater quality programs may need to target a wider range of pollutants.

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