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The Conflicting Effect of Obesity and Undernourishment on Average Life Expectancy

Sangeeta Bansal, Shivani Gupta, Jacob Lefler, and David Zilberman

There is a growing concern regarding the health effects of increasing global obesity rates, and micro-level studies demonstrate that obesity reduces life expectancy. We conducted a macro study at the country level relating average life expectancy with obesity rates and other factors. Our analysis suggests that increased obesity prevalence may increase life expectancy when obesity rates are low and malnutrition is significant. Our results also suggest that higher obesity rates increase life expectancy in developing countries, but reduce life expectancy in some developed countries, such as the U.S., which suffer from high obesity rates.

Historically, societies were concerned about undernourishment, hunger, and starvation amongst populations. The severe prevalence of undernutrition in many countries of the world led to research and policy focus on malnutrition. Nations and international organizations directed efforts towards providing more calories and alleviating hunger. In the last 50–60 years, however, obesity prevalence has emerged as a new health hazard.

Obesity has reached epidemic proportions globally, with more than 1.9 billion adults estimated to be overweight and at least 650 million of them qualifying as being obese. For an individual, overweight and obesity are associated with a higher risk of non-communicable diseases such as diabetes and hypertension. World Health Organization (WHO) (2018) reports that at least 2.8 million people die each year as a result of being overweight or obese. The rising overweight and obesity prevalence imposes a heavy burden on countries. Once associated with high-income countries, overweight and obesity have reached the low- and middle-income countries. WHO estimates of age-standardized obesity prevalence indicate a rise in obesity prevalence for almost every country in the world during the past two decades.

Table 1 presents overweight and obesity prevalence, and its percentage change, among select high-income and low- and middle- (L&M) income countries between 2005 and 2015. For many low- and middle-income countries, the percentage increase in the overweight and obesity prevalence has been well above 30%, which is alarming. The global attention now is on mitigating obesity prevalence. Countries are worried that rising obesity levels could impose substantial health and financial burdens. Concerns about obesity have led to policies such as sugar, fat, and soda taxes that aim at reducing the consumption of calories. There are also regulations aiming to limit the sugar content of processed foods and drinks.

An individual is classified as underweight, overweight, obese, or normal weight according to Body Mass Index (BMI), which is defined as an individual's weight in kilograms divided by the square of his height in meters. As per WHO classification, a person is obese if BMI is greater than 30, overweight if BMI is between 25–30, in the normal weight category if BMI is in the range of 18.5–25, and underweight if BMI is below 18.5. The classification is the same for men and women.

Micro vs. Macro Studies of the Impact of Obesity

Most of the literature on obesity consists of "micro" studies that look at individual-level data to estimate the impacts

Table 1. Overweight and Obesity Prevalence (in Percentage) for the Years 2005 and 2015

Country	Percentage Overweight or Obese (2005)	Percentage Overweight or Obese (2015)	Percent Increase in Overweight or Obesity	Projected Values for Year 2025
L&M Income Countries				
Bangladesh	13.8	19.4	40.6	27.3
India	14.2	19.1	34.5	25.7
Nepal	15.0	20.4	36.0	27.7
Sri Lanka	16.8	22.6	34.5	30.4
Myanmar	17.5	24.0	37.1	32.9
Bhutan	19.1	26.4	38.2	36.5
Pakistan	21.1	27.7	31.3	36.4
China	24.1	31.6	31.1	41.4
High-Income Countries				
Hungary	55.8	61.1	9.5	66.9
UK	57.8	63.2	9.3	69.1
Canada	58.6	63.7	8.7	69.2
Mexico	58.9	64.4	9.3	70.4
Australia	59.2	64.0	8.1	69.2
United States	61.9	67.4	8.9	73.4

of various factors, including BMI, on indicators of health, including longevity. Some studies have found that severe obesity in the U.S. may reduce the life expectancy of males by 0.6 and females by 0.9 years. Broader surveys of the literature that include findings from developing countries also suggest that obesity and even overweight increase mortality risk. There is evidence that increases in obesity result in direct health care costs and indirect costs of lost productivity due to illness. It is estimated that 27% of the rise in inflation-adjusted medical expenditures in the U.S. between 1987 and 2001 was due to the rising prevalence and costs of obesity. A recent study predicts that a one-unit increase in BMI for every adult would increase annual public medical expenditures by $6.0 billion.

Micro studies provide the background for developing guidelines for individual behavior and are essential for the work of medical doctors and nutritionists. But policymakers are also interested in macro findings from analyses of aggregate data, which can assist in identifying factors associated with higher life expectancies across communities, and investigating the relationship between obesity and life expectancy in different communities.

Aggregate analysis is also useful for comparison among regions and nations and for assessing broad policy proposals. For example, there are recent proposals to reduce obesity across the board (by sugar or soda taxes), based on micro analyses that emphasize the negative effects of obesity. An important question is: to what extent will such policies that aim to reduce obesity prevalence improve average measures of health of different populations?

This question led us to conduct a macro analysis of the impact of an aggregate measure of obesity (percentage obese in a region), as well as other factors, on aggregate life expectancy. Because the population is comprised of several groups of individuals—underweight, healthy, and obese—and the sum of probabilities is equal to 1, populations with higher shares of obesity are likely to have a relatively smaller underweight population.

Thus, the impact of aggregate obesity on average life expectancy may include both the direct effect of the increase in obesity prevalence and the indirect effect of the decrease in underweight prevalence. Populations with a higher rate of obesity may have a longer average life expectancy if the impacts of the reduced prevalence of underweight individuals on average life expectancy dominate the impacts of the higher obesity rate.

While micro studies clearly suggest that obesity reduces life expectancy (all else equal), the macro relation between average obesity and average life expectancy is not obvious theoretically and needs to be examined with data. Another difference between micro and macro approaches is that micro studies allow one to identify the impacts of individual traits (biological, socioeconomic, habits, etc.) on life expectancy, while macro studies allow one to detect the impacts of variables common to individuals within a community but different between communities (access to education, average medical expenditure, weather, etc.). The fixed factors that affect all or nearly all individuals of a country can be controlled for in a macro study but are not likely to be included in a micro study conducted in a single country. Macro studies provide added perspective on community well-being and impacts of broad policies.

The Econometrics Analysis

Our empirical analysis used data from the WHO and other sources for 183 countries during the period 2007–2014, with information about life expectancy at birth, adult obesity rates, mortality rates for men and women, per capita health expenditures, and GDP at constant prices. Also included were several other indicators, such as school enrollment and climatic conditions in different countries.

Our econometric analysis has several key findings. First, increasing prevalence of obesity is associated with increased average life expectancy for men in countries where obesity rates are below 25% and for women in countries where obesity prevalence is below 30%. Above these threshold levels, average life expectancy declines with increases in the rate of obesity. The macro results suggest that for many countries—mostly developing ones—underweight has a greater impact than overweight, in the sense that a marginal increase in obesity prevalence will increase average life expectancy of the country.

One implication is that enhancing food intake in developing countries will improve average life expectancy. Of course, obese individuals should take measures to reduce their own weight, and optimal food intake is an individual choice. The analysis suggests establishing bifurcated food policies: expanding nutritional availability and intake for low BMI individuals and, at the same time, promoting habits and incentives that will reduce obesity among high BMI individuals.

A second conclusion is that health expenditure has a positive effect on longevity. In particular, the incremental contribution of increased health expenditures to life expectancy per capita is higher for women, possibly suggesting biased allocations of health expenditures toward men. Thus, health expenditures targeted at women result in greater life expectancy gains.

In high-average obesity countries (e.g., the U.S.), high medical expenditures may counter some of the negative effects of obesity on life expectancy. In developed countries, high medical expenditures may also may offset some of the negative effects of underweight. The incremental effect of an increase in health expenditure is higher in less-obese countries, which tend to be developing countries. Our analysis also suggests an opportunity for economic gains from reducing obesity rates in high-obesity countries since significant expenditures are used to counter the adverse effects of obesity on life expectancy in these countries.

A third conclusion is that global average life expectancy tends to increase over time, by 1 year around every 5 years globally during our study period, 2007–2014. Further, women have a higher life expectancy than men ranging from 3.42 year to 4.84 years on average. Obesity prevalence is higher among women, and they are less adversely affected by obesity. About 1.4 years of difference in life expectancy between females and males is explained by higher average obesity, which tends to increase life expectancy, especially in developing countries.

Our fourth conclusion is that average obesity has increased significantly between 2007–2014. The global average of national rates of obesity among men increased from 11.5% to 14.3%, and for women it increased from 16% to 21.3%. This seems to increase life expectancy, as for most countries it has been associated with a reduction in underweight. Japan, Singapore, and Korea have obesity prevalence lower than 10%; these countries have high life expectancy and relatively low per capita health expenditure. The variance of BMI in these countries is smaller than in other countries, with the lion's share of the population in the "normal BMI region," which contributes to high life expectancy and low medical costs.

Table 2. Average Life Expectancy, Obesity Prevalence, Health Expenditure per Capita for Selected Countries According to Life Expectancy Among Women

Country	Life Expectancy (2016)		Percent Obese (2016)		Expenditure/Capita (2014)
	Women	Men	Women	Men	$
Japan	87.2	81.1	4.1	4.6	3,727
France	85.7	80.1	23	23.5	4,508
Italy	84.9	80.5	23.3	22.5	3,239
UK	83.2	79.7	30.4	28.6	3,377
USA	81.0	76.0	38.2	36.5	9,403
Mexico	79.2	74.0	32.6	23.7	1,122
Brazil	78.9	71.4	25.9	18.5	1,318
China	77.9	75.0	7.1	6.2	731
Russia	77.2	66.4	30.8	19.4	1,836
Saudi Arabia	76.5	73.5	41.2	31	2,466
Egypt	73.0	68.2	40	22	594
Indonesia	71.4	67.3	9	4.9	299
India	70.3	67.4	4.9	2.7	267
Kenya	68.9	64.4	9.4	2.5	169
Ethiopia	67.3	63.7	5.6	1.6	73
South Africa	67.0	60.2	38.5	14.5	1,148
Afghanistan	64.5	61.0	6.2	2.7	167
Ghana	64.4	62.5	15	4.1	145
Nigeria	55.7	54.7	11.5	4.1	217
Cote d'Ivoire	55.7	53.6	13.1	5.2	187

Global and U.S. Cases

Tables 2 and 3 present data for 20 countries and for 20 U.S. states, selected to represent the major patterns that we report here. For each region, we present the 2016 life expectancy and average obesity rates, for men and women, and medical expenditure per capita (based on 2014).

The three countries with the highest life expectancy (1–3 in table 2) have average obesity rates that are smaller than those of the second eight countries (4–11), while the nine countries with the lowest life expectancy (12–20) have the lower average obesity rates. Western European countries, Japan, and Korea have lower obesity rates and higher life expectancy than the U.S., which also has the highest

Table 3. Life Expectancy, Obesity Prevalence, and Per Capita Health Expenditure for U.S. States in 2014

State	Life Expectancy in Years		Obesity Prevalence (%)		Expenditure/ Capita
	Women	Men	Women	Men	$
Hawaii	83.9	78.4	21.0	23.1	13,951
California	83.0	78.6	25.4	24.0	14,553
Minnesota	82.9	78.9	25.4	29.7	17,124
Connecticut	82.6	78.4	26.0	26.5	18,816
New York	82.5	78.1	26.2	27.8	18,466
Colorado	82.2	78.2	20.7	21.9	13,105
Florida	82.0	76.9	26.6	25.8	15,471
Washington	82.0	78.0	26.0	28.5	15,214
Idaho	81.4	77.6	29.2	28.7	13,363
Illinois	81.3	76.7	30.7	27.9	15,838
Virginia	81.2	77.1	29.3	27.7	14,518
Texas	80.8	76.2	30.7	33.2	13,522
Wyoming	80.7	76.7	29.2	29.7	16,298
Michigan	80.5	76.0	30.6	30.9	15,448
North Carolina	80.2	75.4	31.1	28.3	13,868
Georgia	79.7	75.0	32.4	28.6	12,607
Kentucky	78.8	73.7	29.9	33.3	15,413
Louisiana	78.6	73.1	35.7	34.0	15,234
Oklahoma	78.5	73.7	32.5	33.5	14,661
Mississippi	77.9	71.9	37.9	32.9	14,669

medical cost per capita. Developed countries, with a higher life expectancy (the first five countries) are mostly in the post-industrial stage, where the gap in obesity rate between males and females is small. In most of other countries (the bottom 15 countries), which have a relatively smaller service sector and larger agricultural and industrial sectors, women tend to have a much higher rate of obesity than men.

In Table 3, we see significant heterogeneity among states. Some of the coastal states tend to have a higher life expectancy and lower obesity rates than the Midwestern states and especially states in the South. The top states in terms of life expectancy have profiles that are close to Western Europe: 20–25% obesity rates and life expectancy above 80 for women and close to 80 for men. States with the lowest life expectancy, mostly southern states, have obesity rates well above 30% and male life expectancies closer to 70 than 80. The states with the lowest life expectancy spend less per capita on healthcare than the states with higher life expectancy.

Conclusions

This paper illustrates the value of examining issues from both a micro perspective, using individual-level data, and a macro perspective, using aggregated data. Micro-level results suggest that life expectancy and health are improved when BMI is in the range designated normal, and that individuals should modify their behavior to reach this range. Aggregate data, however, suggest that differences between communities exist, and policies like sugar or fat taxes, which may be appropriate in certain areas, may not be appropriate in developing countries where underweight is a major problem. Thus, nutrition policies need to be tailored to local circumstances and likely should change over time.

There are still regions that suffer from chronic undernutrition. Medical expenditure can compensate for nutritional deficiencies, but it may be preferable to modify nutritional choices to improve health and reduce medical expenses. The paper suggests that, overall, there is still insufficient consumption of calories in many regions, and reduction of caloric intake is not appropriate everywhere. In many developing countries, there is a need to enhance caloric consumption and diversify the diet.

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Authors' Bios

Sangeeta Bansal is a professor and Shivani Gupta is a research scholar in the Centre for International Trade and Development at Jawaharlal Nehru University. Jacob Lefler is a Ph.D. candidate in the ARE department at UC Berkeley. David Zilberman is a professor, holding the Robinson Chair of Agriculture and Resource Economics at UC Berkeley, and a Wolf Prize Laureate. They can be reached by email at sangeeta.bansal7@gmail.com, shivanisuccess22@yahoo.com, jacob_lefler@berkeley.edu, and zilber11@berkeley.edu, respectively.

For additional information, the authors recommend:

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Preparing for a Drier Future: Welfare Consequences on the Salton Sea Region of Re-allocating Colorado River Flow Deficit

Jacob Rightnar and Ariel Dinar

Colorado River water flow is running short of its 1922 allocation to users. We assess effects of reallocation of Colorado River water deficit on sectoral and regional welfare in the Salton Sea Region. We use several allocation schemes from previous regional studies, including an allocation based on priority to greatest regional benefit, and allocations based on proportional water quantity reductions with and without social preferences to certain users. We derive water allocations that are most beneficial and feasible for the region as less water becomes available.

The allocation of common pool water resources under supply uncertainty introduces challenges to regional economic performance and stability. This is likely when such allocations are based on fixed quantities of the available water, assigned as property rights to each user, but rarely realized. This is the case with Colorado River basin water, which is shared by seven western U.S. states and Mexico. Sharing is based on the 1922 Compact using the 1922 level of the annual Colorado River flow of 16.46 million acre-feet (MAF). But due to long-term reductions in water flow of the Colorado River, the 1922 Compact failed to fulfill the agreed-upon allocations (in 56 out of the 95 years between 1922–2017) to users, resulting in shortages and disputes that will be further exacerbated by climate change.

A situation in which a commitment of a common pool resource, such as water, to users cannot be fulfilled is defined as a bankruptcy of the resource. Generally speaking, a bankruptcy situation exists when participating agents submit claims that are larger than what is available for distribution (either monetary or physical quantity). That deficit has to be allocated among the claimants such that each will receive a non-negative amount that cannot exceed the claim.

California has a fixed annual quantity of 4.4 MAF from the Colorado River flow that has been rarely fulfilled. We focus on the Colorado River water bankruptcy situation that affects Southern California and, in particular, the Salton Sea region, including several major water-consuming sectors.

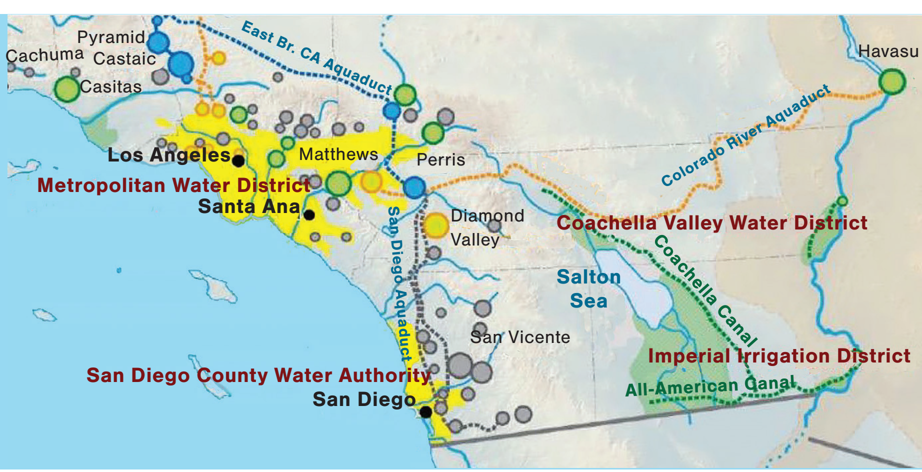
In this paper, we apply a methodology to estimate water demand functions for the agricultural and urban sectors and recreation in the Salton Sea region. In addition, we apply optimization principles to the allocation of the water deficit such that the regional welfare is maximized (Social Planner Allocation--SPA). We then apply a couple of (more practical) bankruptcy allocation methods to calculate the resulting sectoral and regional welfare and compare the total regional welfare and the sectoral distribution of the welfare between the SPA and the bankruptcy allocations.

The Colorado River Service Area of California and Stakeholders

The Colorado River service area (Figure 1) of California includes major agricultural operations, urban centers, and the Salton Sea. The Imperial Irrigation District (IID) presides over the majority of the area in which the Salton Sea resides. IID services a population of over 150,000 and an agriculture industry that nets over $1 billion in annual sales. Currently, IID has an allocation of 2.6 MAF of Colorado River water as a "perfected right," meaning that on occasions when shortfall exists in the river's flow the IID's water allocation must be satisfied first.

The Coachella Valley Water District (CVWD) includes both major agricultural operations and urban centers. CVWD has been afforded 0.45 MAF of water per year from the Colorado River, which supplies the agricultural industry, as well as 373,000 permanent

Figure 1. The Colorado River Basin Water Service Region



Source: Wikipedia, Water in California: https://en.wikipedia.org/wiki/Water_in_California#/media/File:Water_in_California_new.png
Note: Colored circles represent state and federal water reservoirs.

residents, and up to 3.5 million seasonal residents and tourists (tourism industry linked to the Salton Sea). The agriculture industry in the Coachella Valley sells over $500 million per year.

The Metropolitan Water District of Southern California (MWD), an exclusively urban stakeholder (in our analysis), charged with managing and delivering water from the Colorado River to southern coast urban centers, has an allocation of 1 MAF (not including San Diego County). And finally San Diego County Water Authority (SDCWA), which is legally a part of the MWD but due to its history of acting as an autonomous stakeholder in Salton Sea negotiations, will be considered as an individual stakeholder for the purposes of this analysis. SDCWA supplies over 3 million residents within the County of San Diego. It has an annual entitlement of 0.33 MAF per year, of which 0.18 MAF is delivered from the Colorado River.

Methodology and Data

Determining Value of Water

The value of water can be represented by the demand of consuming sectors, indicating the willingness to pay for an additional unit of water in the case of urban consumers. In irrigated agriculture, value of water is represented by derived demand, indicating the value of an additional unit of water in production. The value of water in the Salton Sea is based on the water-dependent recreational activities that are a function of the water level in the sea (ignoring the health implications of low water levels).

The value of water in irrigated agriculture was determined using the 'residual approach,' which calculates the net revenue that is attributed solely to a unit of applied water. We used data from the University of California Cooperative Extension crop budgets in the three counties of the Salton Sea region (Imperial, Riverside, San Diego). The value of water for urban uses was derived from a demand curve estimated for the entire region. To determine the recreational value of water to the Salton Sea itself and compare it to agricultural or urban uses, we estimate the relationship between inflow of water into the Salton Sea and the number of tourist visits and dollars spent by tourists in the region.

Determining Welfare Effects

Based on the distribution of flows over the past 100 years in the Colorado River, we calculated the flow deficit between the 1922 flow and actual annual flow levels. We determined the three deficit ranges for the analysis as: small deficit 0–0.5 MAF, with a mean of 0.250 MAF; medium deficit 0.5–2.0 MAF, with a mean of 1.25 MAF; and high deficit 2.0–2.5 MAF, with a mean of 2.25 MAF. We then evaluated, using the demand functions and the recreational value, the impact of several allocation methods on the sectoral and regional welfare by calculating the welfare changes from the reduced water allocation due to the deficit.

The Allocation Mechanisms

Below are the six simulations of allocation mechanisms we applied, each with the three levels of deficit that represent the range of deficit experienced in the past 100 years.

(1) In the case of SPA, the planner's goal is to minimize losses incurred through water restrictions. The regional welfare is determined through the dollar value produced in the region by the application of water to the different economic activities. Allocated water to each stakeholder ranged from no volume allocated at all to the maximum volume of water that a given stakeholder-sector could utilize. We used this model to assess the highest proportion each stakeholder-sector could receive until an additional allocation of water would produce greater social welfare when placed elsewhere. Thus, the maximum welfare a single stakeholder-sector could produce relative to the other stakeholder-sectors is derived.

(2) The Proportional Use Bankruptcy allocation is dependent on both the agreed water entitlement and the total water use for each stakeholder. As such it takes each stakeholder's proportion of the actual annual withdrawal and scales it down proportionally to the sustainable withdrawal for the state of California.

(3) The Proportional Claim Bankruptcy allocation is applied to the allocations that each stakeholder has been promised (on paper, with likely incredibility) by the regulator or in the water-transfer agreement.

(4) A Bankruptcy allocation based on priority to the Salton Sea is derived from the proportion of existing use but with the addition of an allocation set aside for the Salton Sea, and is designed to close the gap between current inflow and a historically sustainable flow.

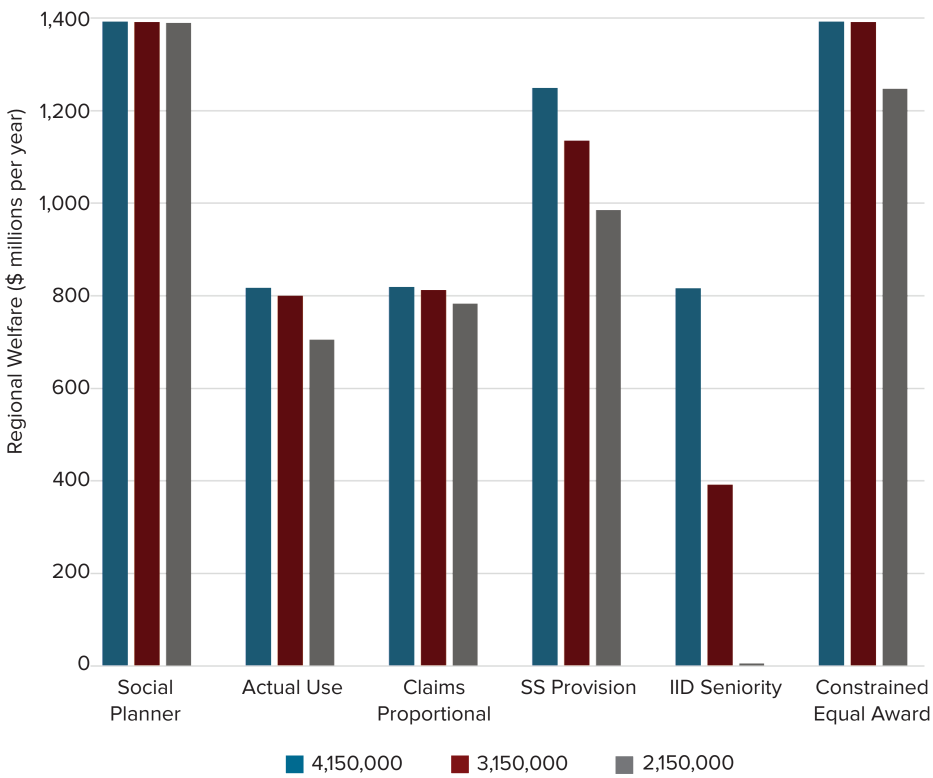
(5) A Bankruptcy allocation based on priority to IID water rights; this allocation addresses the IID's present perfected rights.

(6) The Constrained Equal Awards allocation is one in which the deficits are distributed equally among all stakeholders, with some form of constraint or weighted preference set by the regulator. The constraint is that no stakeholder receives more than its maximum historic entitlement. This should produce a model that favors stakeholders who have historically used less water.

Results

Figure 2 presents the main aggregate regional results (for detailed results see Rightnar and Dinar, 2020). The social planner allocation does not weigh the water needs of agricultural stakeholders as highly as that of urban stakeholders. All simulations produced under this framework result in major losses to the agricultural industry, which has historically utilized an

Figure 2. Total Regional Welfare Produced by All Models Under Three Water Reduction Scenarios



average of 2.5 MAF a year, particularly the IID. The SDCWA agricultural sector fares the best of all agricultural sectors, possibly due to the high-value crops produced on a relatively small acreage and with relatively smaller amounts of water per acre. The urban sectors have higher willingness to pay, and thus are insulated from losses incurred by a reduction. The Salton Sea fares well in these models, due to the high value produced by the tourist economy. Thus, the social planner model provides a sustainable allocation for the Salton Sea while shielding urban centers from major water cutbacks yet severely damaging the agricultural sector.

The simulations that provide stakeholders with water, in proportion to their existing usage and claims, produce a lower regional welfare versus the social planer model. Because agricultural water uses already account for most regional water use, these models protect agricultural interests by affording them the same proportion as supplies dwindle. Urban water centers would not contribute to the regional welfare to the degree that they are able, considering their high consumer surplus. The low quantity of water dedicated towards the Salton Sea does not afford it a sustainable inflow. Yet by developing a model that supports a sustainable ecosystem, we can project the regional welfare higher than that produced by a model using only existing uses and entitlements, although lower than produced in social planner models. Therefore, the proportional allocation model is beneficial to the interests of the agricultural sector and may result in urban water price increases, while not sustainably providing water to the Salton Sea unless water is legally committed to the environment.

The models in which the IID's senior rights are upheld are the most damaging to regional welfare. Simply reducing the regional water use to 4.15 MAF results in the IID being allocated at a minimum of 65% of the region's water. Once we consider scenarios in which the bankruptcy increases, we see massive reductions in the regional welfare. In major drought periods where the bankruptcy reaches 2.0 MAF, the IID would be entitled to all water California draws from the Colorado River. This leads to a devastating situation for other agricultural sectors, and water shortages in urban sectors.

At the lowest levels of deficit, the constrained equal award model produces a welfare level that is indistinguishable from the social planner approach at similar levels. As deficit increases, the welfare resulting from this model is reduced to a greater degree than in the social planner approach, although it remains greater than that of any other framework. This framework provides a near-optimal welfare level while affording more water to agricultural districts while still impacting agriculture. Additionally, this method asks stakeholders with a lower historic use to make fewer reductions.

The reason for the seemingly small welfare changes from major water reductions, is the result of the shape of the demand function, which represents the fact that major amounts of water are used to irrigate relatively low-value crops (alfalfa), and relatively small quantities of water are allocated to irrigation of high-value crops (vegetables), such as is the case in the IID and in the Coachella Irrigation District. More information can be found in Rightnar and Dinar, 2020 (Supplementary Material).

Regarding the valuations that favor urban sectors, we assume this tendency arises due to urban users paying full market rate for water, whereas agricultural water is subsidized, inflating urban willingness to pay for water. Additionally, the models that do not consider IID's status as a senior water rights holder indicate that these are not conducive to the general welfare, and produce systemic inefficiencies.

Regardless of the status of IID's present perfected rights, it is not reasonable that it would accept drastic deficits in its entitlement. This does not mean that they would never accept reductions in their entitlement, as they have agreed to such reductions previously. The IID is invested in maintaining the Salton Sea, due to the air pollution hazards it poses within its jurisdiction. This implies that it is politically feasible to persuade IID to follow a bankruptcy allocation model that sacrifices a portion of its allotment to sustain the Salton Sea, despite the welfare loss from the agricultural industry.

We should note that while urban districts produce a greater regional consumer surplus than agricultural users, they also can mitigate the loss of water through utilizing alternative sources such as groundwater and recycled wastewater. In particular, MWD and SDCWA have a robust range of water sources (desalination, managed aquifer recharge) to replace Colorado River water (MWD 2018).

Meanwhile, the stakeholders in the eastern half of the region (CVWD and IID) lack access to the ocean, receive less rainfall, and lack the capital to import water. Imperial Valley, the region's largest user, lacks alternatives to water drawn from the Colorado River. Groundwater in the Imperial Valley is of poor quality and is generally unsuitable for domestic or irrigation purposes. In response, IID has built a series of programs and initiatives aimed at improving conservation practices and infrastructure to better utilize existing water supplies. One example includes the On-Farm Efficiency Program, which has led to the conservation of over 44,371 AF annually.

The Coachella Valley takes advantage of its available groundwater resources. While the aquifer has an estimated capacity of 39 million AF, the Coachella Valley currently finds itself in an overdraft situation (very low precipitation and snowmelt) and deteriorated quality (due to recharge and deep percolation of salinity-elevated Colorado River water, which is also used at groundwater replenishment facilities. In the future, Colorado River water may provide a potential source of water for CVWD to treat to drinking standards and deliver to urban customers. Although, while CVWD is limited in its water sources, it can replace the economic use of that water. If a loss in allocation will affect the agricultural industry negatively, it is possible to mitigate this loss through strengthening its tourism sector. We assumed in our analysis (CVWD, 2002; 2018) that in certain years a relatively small portion of the water consumption in the CVWD originates from the natural aquifer, no more groundwater will be pumped than the current level, and that the region would be unable to maintain the current economic or population base without entitlements from the Colorado River as current consumption is unsustainable.

Due to these factors, an allocation scheme that favors the IID may be justified even without considering their senior rights. This does not mean that the regulator should allocate water to a stakeholder producing suboptimal welfare simply because of its inadaptability. It is merely a consideration when predicting regional welfare after implementation. The ability of most stakeholders to manage the loss of water in comparison to the IID mitigates the suboptimal regional welfare that these models produce.

Conclusion

It is possible to minimize regional welfare loss as we move to establish a new normal in light of decreasing Colorado River flows. This can be fulfilled by treating the water system as a bankrupt entity. How to distribute these limited resources is answered by the benefits to the public derived from the new allocation. We can determine the welfare for the region by allocating water to a given stakeholder and establishing the allocations that are most beneficial for the region as less water becomes available. We must operate within the existing legal framework and stakeholder characteristics. Relating the value of water to a dollar amount helps provide initial estimates on regional welfare losses, but multiple factors affect the region once our allocation framework is implemented.

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Authors' Bios

Jacob Rightnar is a Transportation Planner with Caltrans District 1 Eureka Office and Ariel Dinar is a Distinguished Professor in the School of Public Policy at UC Riverside. They can be reached by email at jrigh001@ucr.edu and adinar@ucr.edu, respectively.

For additional information, the authors recommend:

Rightnar, J., and A. Dinar. 2020. "The Welfare Implications of Bankruptcy Allocation of the Colorado River Water: The Case of the Salton Sea Region." *Water Resources Management*, 34:2353–2370. https://doi.org/10.1007/s11269-020-02552-1.

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Assessing the Costs and Benefits of Winter Cover Cropping in California

Ellen Bruno, Alyssa DeVincentis, Samuel Sandoval Solis, and Daniele Zaccaria

Winter cover cropping is a promising agricultural management practice that boosts soil health. This article discusses a benefit-cost analysis of winter cover crop adoption and introduces a web-based interactive calculator for farmers to assess changes to baseline farm profits.

Winter cover cropping is an agricultural management practice that can enhance soil health while protecting fields from soil erosion and compaction. Cover crops are typically grown on farmland that would otherwise be left fallow in the wintertime, such as fields used for annual spring-summer crops, or in between rows of trees or vines, and thus do not replace a cash crop. Despite its well-known soil health and ecological benefits, and popularity in other parts of the U.S., winter cover crop adoption rates are low across California's specialty crops. To better understand drivers and incentives for adoption, we created a benefit-cost calculator that estimates how baseline profits change as a farmer integrates winter cover cropping.

This tool was designed for specialty-crop farmers who are interested in growing winter cover crops and want to understand how long it will take for that investment to break even. However, the tool is useful for anyone interested in better understanding the financial implications of cover cropping. In this article, we explain the methodology behind the tool and how to use it.

Methodology

We developed a calculator that estimates the expected changes in expenses and revenues associated with the introduction of winter cover cropping for a given farming operation. We started by modeling the implications of winter cover crops to average farms that grow processing tomatoes and almonds, two of California's most important agricultural commodities. The model estimates a benefit-cost ratio in present value terms, i.e., the ratio of the sum of benefits over the sum of costs accumulated over time and discounted to the present.

In our baseline analysis, we considered cover crop seed mixes that are commonly used for winter cover cropping in California's Central Valley. For tomato operations, this was assumed to be a small grain forage mix (e.g., bell beans, winter peas, common vetch) and for almonds, this was assumed to be a more expensive clover mix.

Table 1 lists potential benefits and costs of winter cover cropping. Benefits and costs are not the same every year. The monetary values for each of these components are incorporated into the model at the specific time when that benefit or cost is likely to be experienced.

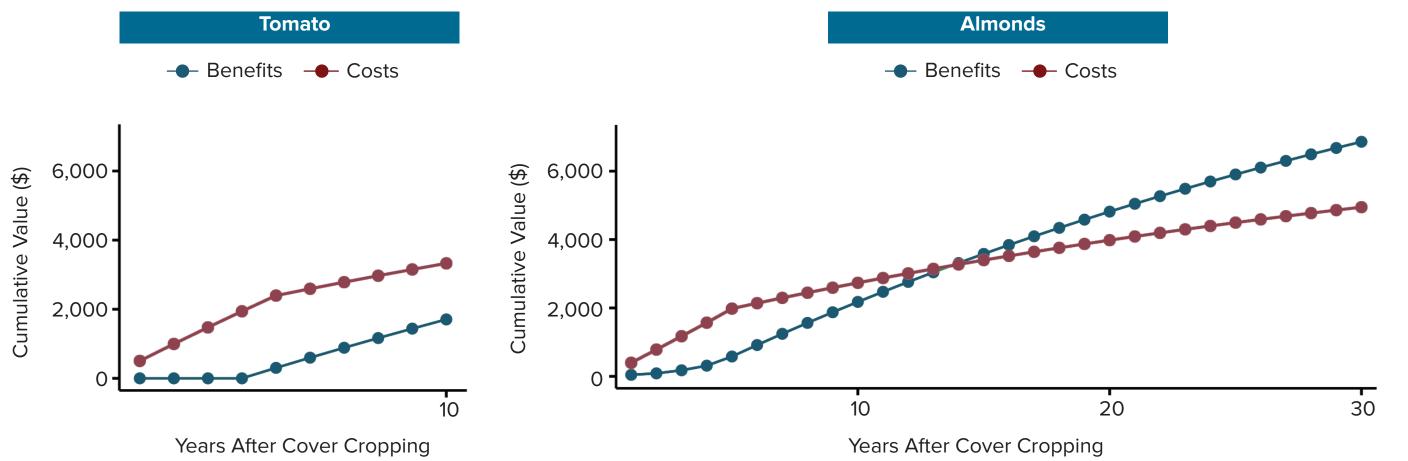
Benefits include increased income from greater yields, which results from improvements in soil quality, fertility, and soil-water relations due to cover cropping. Benefits also include reductions in expenses associated with soil erosion control, nutrient cycling, weed control, mycorrhizal fungi colonization, and reduced tillage operations. Almond growers may also benefit from lower beehive prices.

The potential for cover crops to affect the irrigation requirements of cash crops is debated in the scientific literature. Cover crops may lead to higher water infiltration (resulting from improved porosity of the top soil), which can lead to increased capture of winter and spring rainfall, increased soil-water storage, which in turn can delay irrigation start and eventually reduce spring/summer irrigation requirements slightly; however, these effects are soil-specific and difficult to quantify and generalize and, thus, are not included in the baseline model. Other potentially valuable aspects of cover cropping that were not explicitly accounted for in the analysis include reduced soil sealing and compaction, better soil oxygen concentration and diffusion rates, as well as increased effectiveness of salt-leaching practices.

Table 1. The Potential Benefits and Costs of Winter Cover Cropping in California's Specialty Crop Systems

Benefits	Costs
• Increase in yields (from improved soil quality, fertility, and soil water relations)	• Seeds
• Reductions in expenses associated with soil erosion control, nutrient cycling, weed control, and mycorrhizal fungi colonization	• Labor associated with planting & termination
• Improved ecosystem services (soil organic matter, runoff, soil-carbon storage)	• Potential cash crop harvest complications
• Reduced tillage needs	• Depreciation of machinery
• Lower beehive prices (almonds only)	• Time spent learning about cover cropping and disseminating instructions to crew
• Reduced spring/summer irrigation requirements	• Irrigation for germination, if needed during dry fall-winter period

Figure 1. Benefit and Costs of Cover Cropping in Tomato and Almond Production Systems



Note: These results use average values for each component of the cost-benefit analysis. For a given time horizon, a present value is estimated using a discount rate of 2.6%. At each time step, cumulative costs and benefits are discounted to the present and summed.

Furthermore, while cover cropping has been shown to improve ecosystem services and downstream user benefits, these are not included in the baseline benefit-cost calculations. These societal benefits, which include increased soil organic matter, the protection of downstream surface water quality via reduced runoff, and carbon sequestration through enhanced soil-carbon storage, were not included because they would not accrue as a revenue flow to the farmer choosing to adopt.

Costs include the initial expenses associated with cover crop seeds, planting, and termination, depreciation of machinery used for this management practice, and time spent learning how to incorporate cover crops into an operation, as well as disseminating new instructions to crew members. The model accounts for financial losses due to potential harvest complications with cash crops. For example, a heavy rain at the end of March could delay termination of cover crops, and thus delay the planting of tomato seedlings, which can postpone the timing of tomato harvest. This poses a potential complication for farmers who contract with tomato canneries, resulting in penalties.

To quantify these benefits and costs, we collected data from UC Ag Issues Center's Cost and Return Studies, scientific publications, semi-structured farmer interviews, and field experiments to establish an average value of each benefit and cost component. We then aggregated these components to estimate benefit-cost ratios for tomato and almond production systems, where a value of the ratio greater than 1 indicates a net positive change in profits. The interactive calculator is seeded with the average value for each benefit and cost component, but can be adjusted by the user to reflect a specific farming operation. While our model attempts to be as comprehensive as possible, some potential benefits or costs are not included, such as interactions with pruning or other practices.

Results

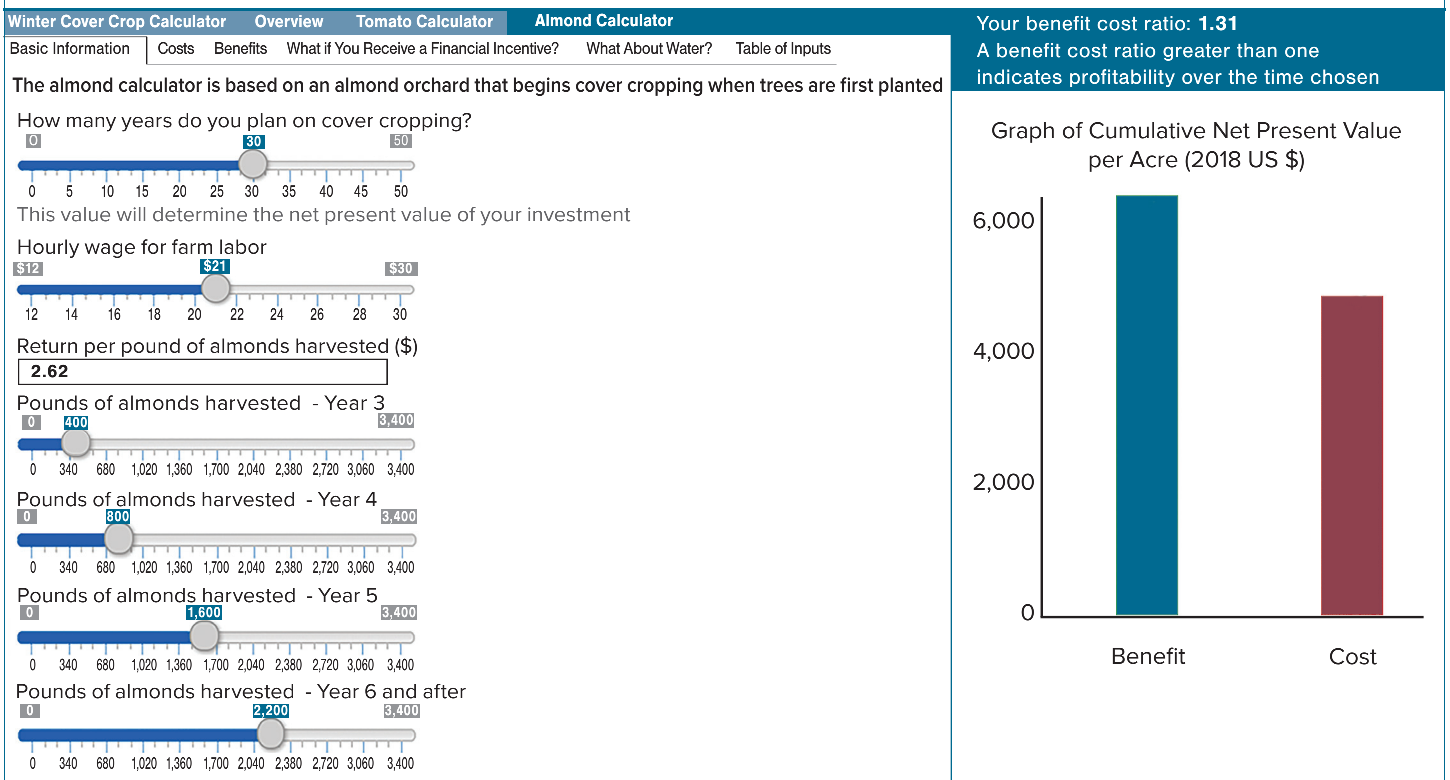
When using average values for all the benefit and cost components, we find that almond systems have a benefit-cost ratio greater than 1 when considering a 30-year time horizon, meaning that benefits are likely to exceed costs on average. When using average values for the tomato system, we find the benefit-cost ratio to be less than 1, given their assumed 10-year time horizon. The time horizons of 10 and 30 years were chosen for tomato and almond operations, respectively, to reflect typical rotation patterns and crop life cycles. Figure 1 displays these results year-over-year. At the 10-year mark for tomatoes and the 30-year mark for almonds, the average benefit-cost ratios are 0.5 and 1.3, respectively, indicating that total benefits eventually outweigh total costs for almond operations, but not tomatoes.

Winter cover cropping is an investment in the long-term viability of agricultural operations. The benefits and costs accrue differently over time and may vary from year to year. Harvest complications with a cash crop reduce profitability but can be avoided with flexible contractual obligations or by growing a cover crop with predictable senescence. Overall, our results show the value of this soil management practice is greatest for California farmers with a longer time horizon and willingness to manage a cover crop as carefully as their cash crop.

Interactive Web-based Calculator

The web-based cover crop calculator, partially shown in Figure 2 and available here, is an interactive decision-support tool that calculates the benefits and costs of winter cover cropping in almond and processing tomato operations. The tool estimates how much farmers can expect their profits to change after growing winter

Figure 2. Snapshot of Almond Calculator



Source: https://shiny.lawr.ucdavis.edu/shiny/cc_calculator/app.Rmd#section-almond-calculator

cover crops for a certain number of years. All values used in the calculator are flexible and can be adjusted to match the reality on any commercial farm. The calculator is seeded with the average values for each cost and benefit component that we considered, but the user can easily adjust or remove any component.

The calculator assumes continuous cover cropping after the year of adoption (first year), and that all benefits of cover crops begin accruing within the first five years. Importantly, the tool may not capture every potential benefit and cost from introducing cover crops into a farming operation. It simply serves as a guide to when a farm can expect to experience economic returns, based on the monetized benefits and costs.

As mentioned previously, cover crops could either increase or decrease spring-summer irrigation requirements. Although this component is not included in the baseline net present value model, the calculator is flexible in this variable. The user can specify the extent to which cover crops increase or decrease irrigation requirements in the growing season and can add irrigation costs to germinate the crop if needed, and then observe how their baseline profits shift accordingly. Users can also explore how a financial incentive, in the form of an annual subsidy payment per acre of cover-cropped farmland, will affect their outcomes. The calculator allows one to value the social benefits of cover cropping (ecosystem services, carbon sequestration, and downstream water quality) via this subsidy component.

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Authors' Bios

Ellen Bruno is an assistant Cooperative Extension specialist in the ARE department at UC Berkeley. Alyssa DeVincentis is a Ph.D graduate from UC Davis in Hydrologic Sciences. Samuel Sandoval Solis is an associate professor and Cooperative Extension specialist and Daniele Zaccaria is an associate Cooperative Extension specialist, both in the Department of Land, Air and Water Resources at UC Davis. They can be reached at ebruno@berkeley.edu, ajdevincentis@ucdavis.edu, samsandoval@ucdavis.edu, and dzaccaria@ucdavis.edu, respectively.

For additional information, the authors recommend:

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UC Davis
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Julie McNamara, Communications Director
Giannini Foundation of Agricultural Economics
Department of Agricultural and Resource Economics
University of California
One Shields Avenue, Davis, CA 95616
E-mail: julie@primal.ucdavis.edu
Phone: 530-752-5346

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