

Estimating the Buffer Value of Ground Water:
A Look at California Almond Growers

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Abstract

This paper analyzes the value of groundwater to agriculture as a shock resistor and how this valuation should inform policy makers on the future of California water management. The value of water will be determined under the economic idea of buffer values. The buffer value measures the difference in value between conditions of certainty and uncertainty. This paper will develop a framework for finding the buffer value of groundwater for water intensive crops including one of the most valuable and vulnerable crops grown in California, almonds. This paper found that the buffer value is over half a billion dollars annually and will make recommendations on how to best optimize California water infrastructure to take into account this additional value of water.

Introduction

Agriculture is not the industry most closely associated with California, yet California leads every other state in the nation in agricultural cash receipts of \$42.6 billion and produces more than twice the output of the 2nd largest agricultural state. This agricultural productivity is due to the unique environmental factors affecting California. Including the fertile central valley, a Mediterranean climate, and a large snowpack in the Sierra Nevadas. These factors have contributed to the formation of large agribusinesses that have adapted themselves well to the current system. However, this equilibrium is under threat. California is expected to reach a population of just fewer than 45 million by 2030 while much of the current infrastructure system of dams and aquifers was built over 50 years ago when the state's population was only around 20 million and agriculture was focused on less water intensive crops due to different palettes. Along with the difficulties of growing demand for water, global climate change will increase the variability of rainfall increasing the probability of long intense droughts that would put a larger strain on the state's water storage capacity [4],[8].

Farmers within this environment should account for the more intense shifts in precipitation through additional flexibility within their farms. This is relatively easy for farmers who plant annual crops. Since the plants go through their growing cycle for a single year, farmers can adapt to drought conditions by letting their fields lie fallow and selling their reduced water shares to other farmers who have a much higher marginal valuation of water. However, growers of perennial crops are stuck

in a precarious position, as they have invested significant capital into growing these crops and rely on multiple harvests to recoup this investment. This dilemma is very apparent for Almond farmers.

Almonds have become a very popular crop for California, as a larger focus on healthier diets has drastically increased their value[2]. Due to environmental factors such as climate and soil needs, California produces nearly 80% of the world's almonds. This concentration of production limits the risk of competition for California farmers from other farming regions around the world. The additional value of these crops also carries additional risks. If a drought forced farmers to cut down their almond trees, it would take at least 3 years before a new orchard could be started and yield nuts with an additional 2 to 3 years before those same groves would begin to turn a profit. This fact, and the additional costs of maintaining saplings, means that almond farmers must have an additional value for water beyond the production of almonds, a value placed on its ability to maintain the capital investment in almond trees. Almond farmers value the maintenance of a high groundwater level as a buffer against the risk of future droughts. This value is called the buffer value, and is a shock resistor against droughts. This paper will attempt to create a lower bound on the size of the buffer value for almond farmers based on a sensitivity analysis of their risk of having to cut down their trees within a year.

Background & Literature Review

Tsur and Issar (2008)[12] define the buffer value of water as the difference in the value of groundwater between certain and uncertain environments. In California this uncertainty is related to the idea of the groundwater footprint. The

groundwater footprint implies that the bottom of an aquifer is not flat, and the bathtub model of consumption where every farm has the same depth of water below them is impractical. An aquifer is like an upside down mountain range where farms with access to the same aquifer could have either shallow or deep groundwater reserves below them. In an ideal world, the farmland would be organized such that those with the highest buffer value of groundwater would be above the deepest part of the aquifer. However, many almond farms live in shallow areas of aquifers while farmers of annual crops have access to deeper parts of the aquifer. This is partly due to the types of soils these crops prefer, as almonds do not grow well in the clay rich soil that is associated with high groundwater content. This can complicate the establishment of water markets and creates additional competition for groundwater in almond growing regions. This leads to a common result, the Tragedy of the Commons.

The Tragedy of the Commons is a common behavioral issue that occurs within common pool resource problems. A tragedy of the commons occurs when individual actors sharing a resource necessary for every player's utility, optimize their consumption of the resource on their own utility function and fail to optimize for social well being. This leads to overconsumption of the common resource and the loss of utility for everyone in the long run. A common theory that has been applied to the tragedy of the commons and other externalities relating to natural resources is the Coase Theorem. The Coase Theorem states that when there are complete and efficient markets with no transaction costs there will be an optimal consumption of the resource regardless of who owns the property rights. The Coase Theorem fails here because the property rights of the groundwater are not well defined, as anyone can use the groundwater and the only cost is the cost of pumping the water. This paper will examine a portion of the agricultural yield of California,

and try to create a lower bound for the buffer value of water to show that a water market for these aquifers is viable and well worth the cost of administration and research required for an effective water market with respect to almond farmers.

California water usage is determined through a web of water rights and seniority as well as environmental regulations that has created a complicated system of water usage. California water rights are organized in a system of seniority, where older rights get water before newer water claims. However, seniority is preserved through the continued use of water for the function the water right was originally assigned for (i.e. agriculture, mining, consumption). This is important because if one farmer agreed to sell his water to another farmer for another purpose, the seniority of his water right could be challenged in court. Therefore, these types of water markets have to be agreed to by all parties saying that they will not attempt to litigate the seniority of these water rights if they are sold in a water market.

Another complicating factor is recent environmental regulation designed to maintain the water level of local rivers. This comes into effect during severe droughts. California is divided into different water districts and during severe droughts water cannot be transferred between different water districts [1]. This prevents the current water transfer market from working correctly leading to situations where almond growers are unable to maintain their groves.

Evaluation of the Costs

The source of this data for evaluating the costs of having to regrow almond orchard comes from a UC Davis study on the costs of planting an orchard of almonds to their adult level of production [6]. This study will act as a lower bound looking at the buffer value to farmers on a year-to-year basis. A sensitivity analysis will be done on the production costs based on the risk of not having enough water to

sustain an acre of almonds for the next year. This paper will assume that no additional water shocks will affect the growing trees and they will reach maturity in accordance with the goal of creating a lower bound. Another assumption is that the almond farmers will return to almond farming rather than switching to other less profitable crops based on their revealed preferences as they chose to farm almonds initially. The expected costs of uncertainty will be calculated in terms of present cost with a nominal discount rate of 5%, a common estimate for the cost of capital for infrastructure projects and relates to the rate that government entities can issue debt for public works [7].

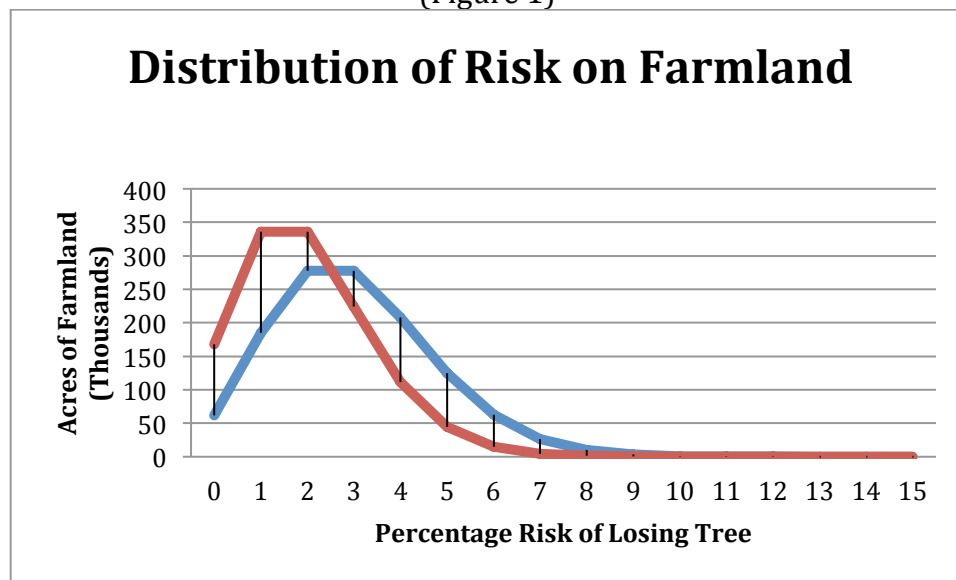
A Poisson distribution will be used to model the distribution of risk towards all almond farmers. This distribution was used because it effectively models the probability of arrival, (the classic example being probability of a customer enter a cashier's line), which is appropriate because the risk to a farmer is tied to the arrival of a drought period. The Poisson distribution fits "drought duration and deficit volumes best ... for the number of droughts" [3, pg. 341]. Because of this, the Poisson distribution is used extensively in other studies to model the arrival of droughts [9]. The placement of farms along the Poisson distribution is determined by the allocation of unique features such as the seniority of water rights and the groundwater level underneath. This would give a sense of risk level a farm faces in a severe drought. These factors are why a significant proportion of these farms do not have any risk of having to cutting down their trees even during a significant multiyear drought. The riskless farms would have senior water rights or access to plentiful groundwater.

Since tree removal would occur only during a multiyear drought, this model will calculate the risk based on the frequency of major droughts in California over the last hundred years. There have been 3 significant droughts (a drought lasting a

half decade or longer) in California over the last hundred years (1929-1934, 1987-1992, and 2012-2016)[11]. This historical data will be used as a baseline for mean risk.

The total acreage of almond farmland in California is 1,200,000 acres [13]. For this set of calculation, the mean single year risk will be 3%. This is done to assume that during a significant drought there will be at least 1 year where a farm is forced to cut down its trees. The three significant droughts in California in the last hundred years imply 3 at risk years for a Californian farm. For comparison, another set of calculations will take place assuming a mean risk of 2%. The distributions are as follows in figure 1, the blue line represents the Poisson distribution with a mean of 3% risk of losing the tree's and the red line represents the Poisson distribution with a mean of 2% risk.

(Figure 1)



This distribution was combined with the cost data to develop a buffer value of water for a year. A major portion of this calculation was applying the distribution seen in Figure 1 to the total amount of farmland within each region. With this distribution, the expected net present cost of the total risk could be determined for

each region. The Expected Net Present Cost for each percentage point (0%, 1%, etc.) was multiplied with the corresponding amount of farm acreage to give the buffer value for all the farms in a region resulting a valuation of total aggregate risk. Then the sum of all of these values will give the total buffer value for a region, or the most these farmers would be willing to pay to eliminate their risk of having to cut down their trees at some point.

The following table has the costs of establishing an almond orchard as well as the opportunity costs that come from lost production from the almond tree's having to mature. To come up with a conservative estimate of the opportunity costs, the almond yield of the trees when they are finally economically viable will be considered as the almond tree's maximum production. This is unrealistic as over a tree's lifespan, which averages 24 years, almond production peaks at 12 years, but this model does not take into account at which point of its lifespan a tree is cut down, so we assume the lowest production possible to allow our estimate to be a lower bound of the true value of this groundwater.

Table 1.

(Net Present Costs Per Acre (\$))

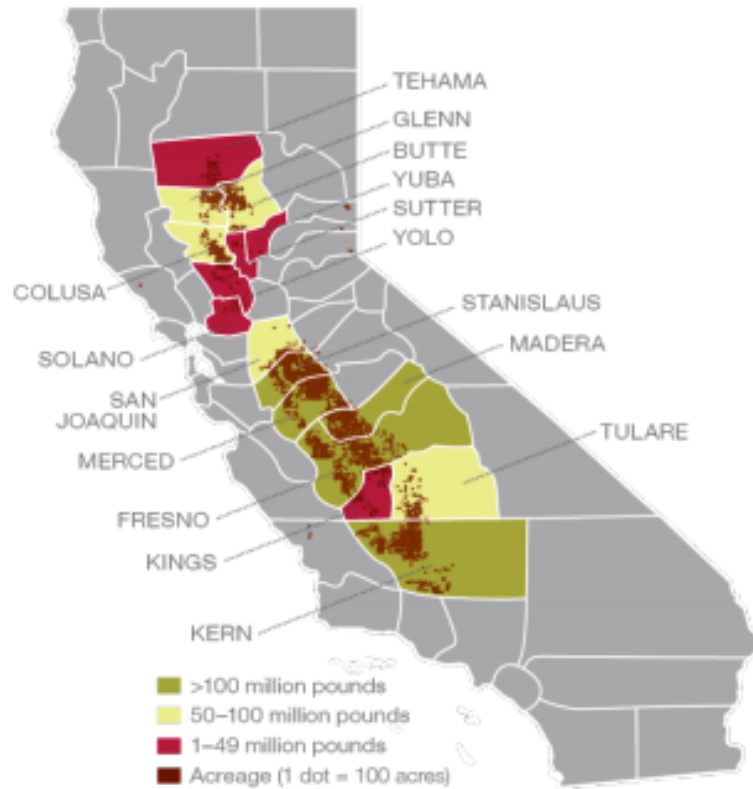
	Southern San Joaquin Valley					
Year	1	2	3	4	5	
Pre-Planting	1,628	0	0	0	0	
Planting	1,370	0	0	0	0	
Cultural	1,109	1,431	2,287	2,976	3,332	
Lost Production	5,400	5,400	4,050	2,700	0	
NPC per-year	9,054	6,196	5,474	4,670	2,611	
	Northern San Joaquin Valley					
Year	1	2	3	4	5	
Pre-Planting	2,347	0	0	0	0	

Planting	1,304	0	0	0	0	
Cultural	621	585	1,109	1,441	1,687	
Lost Production	4,000	4,000	3,000	2,000	0	
NPC per-year	7,878	4,159	3,550	2,831	1,322	
	Sacramento Valley					
Year	1	2	3	4	5	6
Pre-planting	706	0	0	0	0	0
Planting	1,471	0	0	0	0	0
Cultural	545	476	912	1,347	1,550	1,821
Lost Production	5,000	5,000	4000	3,000	1,500	0
NPC per-year	7,354	4,967	4,243	3,576	2,390	1,359

(Source UC DAVIS DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS)

Table 1 shows the large increase in cost of growing almonds within the Southern San Joaquin Valley when compared to the other regions. The conditions are harsher and the precipitation more variable and these facts are represented through a higher cost of establishing an acre of Almonds when compared to the other growing regions. However, the region contains 3 of the 5 most productive counties within the state for almond farming (Madera, Fresno, and Kern counties). This distribution of almond farms will have a large impact on the total buffer value for the state since most of the farms are concentrated in a high-risk area because of the specific demands of almond trees. The Sacramento valley is unique in that it incurs an extra year of opportunity cost, as an acre does not become economically viable until year 6.

Figure 2
(Production of Almonds in California)



Source (Almond Board of California)

The breakdown of the Almond growing regions in figure 2 is as follows; All counties including Solano and everything north of Solano are considered to be in the Sacramento valley, the Southern San Joaquin Valley begins at Madera County and includes all counties south of Madera county, and the Northern San Joaquin Valley is made up of San Joaquin, Stanislaus, and Merced counties.

Model

The model calculates the buffer value as the difference between the value of a good in certain periods and uncertain periods, or the cost of uncertainty. This cost

will be calculated on an annual level to represent the impact that marginally shifting conditions have on a farmer's valuation. This value could jump drastically when a drought starts, however, the point of this calculation is to average out over a longer period of time. This will allow us to look at a scenario of what happens if a drought starts within the next year. The buffer value (BV_R) is essentially the expected cost of having to cut down an orchard in a drought situation. This analysis takes the conservative view that an orchard will be able to be regrown the following year. So there is not opportunity cost associated with letting a field lie fallow for multiple years. Assuming all of this, we can represent the costs facing these almond farmers as follows.

$$BV_R = \sum_{x=1}^{100} (NPC_R * X) * (N_R * P(X))$$

NPC_R =Net Present Costs for a region R

X = a percent risk of having to cut down that acre of almond groves within the next year

$P(X)$ = the Poisson distribution giving the probability that an orchard has the percent risk R for discrete values 0 to 100

N_R = the total acres of almond groves within a region R

Therefore this model can be broken down into two parts, the costs and the distributions. The costs are linear in that the net-present value is constant for a region, then the percent risk maps the net present cost to different risk levels.

The second part of this model deals with the distribution of land between different risk levels, i.e. what is the chance that an acre of land has a 1%, 2%, 3%, ... chance of getting cut down within the next year. This is the probability of incurring the costs of rebuilding. The distribution of risks are based on a Poisson distribution that weights the risk of having to cut down a tree heavily towards the lower end such that there essentially exist no almond groves with a greater than 10% chance of being cut down within the next year. This low probability reflects the observation that it would take multiple years of drought before trees would have to be cut down. This distribution allows us to calculate the number of acres at each specific risk level. Then multiplying the number of farms at a risk level with the costs of being at a certain risk level gives us the buffer value of farms within a region with a specific risk level X. Then by summing from 0 to 100, we get the total buffer value for all the farms within a region.

Results

Table 2.

Total Buffer Value per Region	Total Buffer Value (2%)	Total Buffer Value (3%)	Buffer Value Per Acre (2%)	Buffer Value Per Acre (3%)
SJV-North	\$122,408,374	\$184,133,931	\$395	\$594
SJV-South	\$347,332,736	\$522,478,484	\$560	\$843
Sacramento Valley	\$88,887,029	\$133,709,136	\$477	\$718
Total	\$558,628,139	\$840,321,551	(Average) \$466	(Average) \$700

Table 2 contains the results from the calculations for two different Poisson distributions, one with a mean of 2% risk and the other with a mean of 3% risk (See figure 1).

The total buffer value for almond farmers within the state of California is respectively \$558,628,139 (2%) and \$840,321,551 (3%) annually. This last comparison is important to consider because it is practically impossible for a policy maker to eliminate all risk in agriculture, as so much is dependent upon climate trends. However, we see that reducing average risk by a single percentage point saves farmers around \$280 million annually. This reduction of risk is attainable especially if policy makers took these valuations into account.

Impact on Water Policy

This valuation should serve as a guide for the scale and location of future water products as well as the location of future water projects. California was considering 12 water projects that were competing for a total of \$2.7 billion in state funds [8]. Almond farmers alone could fund these projects if they were designed to maintain the groundwater level and lower the risk of losing their trees.

The biggest issue preventing this is the distribution of this value. This value exists only when consumption of groundwater is treated as a property right. This is where the Coase theorem will be reintroduced. The optimal value of consumption will be reached if the almond farmers can pay other farmers not to pump groundwater with the assurance that it is binding for everyone. There has to be an organization that distributes these property rights to the farmers. It could be public or private.

However, the goal of this organization should be to fund water storage programs, both above and below ground level that directly benefits the water basin in which they are located. This would allow farmers of all types to increase their profits in the long run.

This seems like a win-win for everyone however the current political structure would present numerous issues for trying to get farmers to pay for this water infrastructure. The first issue is the distribution of water rights to individual farmers. This relates to individual payments and the distribution of water rights. Ideally farmers are able to contribute to a water project and buy water rights for themselves individually. However, this would be impractical, as most decisions relating to water infrastructure are done through the individual's water district. However, the value of creating this new water project is concentrated within a minority of junior water right holders. The majority of farmers would receive small marginal benefits. This means that politically even though this project could be economically viable, the individual water districts might not undertake it because it does not benefit the majority of farmers in their district.

The second major issue is dealing with environmental regulations. This water projects will have to use public land due to the scale and location of possible water infrastructure locations setting up the need to deal with public entities either at the state or federal level and the requisite political support. Furthermore, any infrastructure that integrates into the natural river ecosystem would also be subject to environmental regulations during extreme droughts. This means that farmers would still face the issue of being unable to attain water during extreme drought situations and not receiving the buffer value estimated within this paper. These factors have limited water infrastructure investments from private sectors, but that doesn't mean that the current spending on water infrastructure can't be improved.

The integration of rules from natural resource economics could improve overall efficiency of groundwater usage if they are implemented in deciding what infrastructure should be built. The Hartwick rule for sustainability states that any excess benefit from the consumption of a non-renewable resource should be reinvested in produced capital that offsets the loss in value from the resource [10]. Groundwater is a renewable resource, based on the definition of renewable resources. The extent of groundwater mining currently taking place in California is reducing the ability of these aquifers to recharge as the water table falls lower and lower. As groundwater continued to be pumped groundwater behaves less and less like a renewable resource. So, in practical terms, groundwater will behave like a non-renewable within our lifetimes.

In recognition of groundwater's changing nature, the optimal reinvestment would go towards maintaining the specific benefits of groundwater. To do this for groundwater this capital would have to develop a source of water that was always available. The most likely candidate for investment would be desalination technologies. Desalination plants are a very good example of the Hartwick rule's intention. Offsetting the loss of utility from depleting natural resources with human technology paid for by the benefits of using that resource. Desalination is not dependent upon the climate for any of the water it produces. Therefore, desalination could act as a perfect substitute for ground water in its capacity of providing an assured source of water to the state of California, in other words reducing the costs of uncertainty, and providing a buffer value. However, desalinization would be capital intensive, as it requires a constant energy source and machinery to

desalinate the water as well as a new infrastructure network to transport water inland from the coast. This would be uphill and require an enormous amount of energy. So the buffer value would come from coastal centers using desalinated water in drought years and allowing more of the remaining surface water to be used by farmers in drought years.

In the end, politics will play a huge role in the ability of this water economy to develop. Whether it is in the water markets and their effectiveness or who has to bear the risks of droughts. Improvement will only really be possible when technologies exist that make everyone better off.

Future Research

The main issue that develops with the study of water is that climate change is altering the levels of precipitation but the specific scale of these changes is currently unknown. Given this fact, a future study of the dynamics of the risk level would be effective in developing an optimal water policy. This future study should be conducted using Markov chains, a stochastic process that models the movement of an entity between different states based on the probability of moving between individual states. The main issue with this study would be determining the different probabilities of movement between the individual states. However, if this study was conducted, it can model a dynamical system that would give policy makers a better understanding on the steady state of the water systems their policies create and whether or not they were sustainable in the long run.

Conclusion

The possible benefits from the proper valuation include better long run profits for almond farmers, improved water infrastructure quality, and the minimization of risk to droughts. This all comes from the persistent presence of groundwater and its ability to make up for the loss of surface water during drought years, and its ability to act as insurance for these crops. The results of this model suggest that almond farmers could, by themselves, contribute more than \$500 million annually to water infrastructure projects if these projects provide a buffer value. The inclusion of other types of orchards would only push the value of this conclusion higher. This value has to be taken into consideration and projects that focus providing water directly to these farmers. For policy makers rewarding farmers who contribute money towards ground water infrastructure could lead to a pareto-optimal solution. Better flood control that instead of pushing water down stream captures it and allows it to sink into the aquifer. Policy makers should take advantage of this new value to pursue new types of: water projects, economic structures, and technology.

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