Analysis of a Spatial Rotation Plan
For the Tule Lake National Wildlife Refuge

By

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Abstract: This paper examines the joint agro-wildfowl regulation of the Tule Lake National Wildlife Refuge in California. The area is jointly managed by the Bureau of Reclamation for both farming and wildfowl benefits. Production in both sectors has been declining recently, in farming due to nematode and soil pathogen buildup and in wildfowl production due to climax vegetation choking the lake. A novel spatial rotation plan has surfaced to solve both problems. We develop a simple model of the rotation option to identify critical variables and then we estimate some of these using data on lease bids.

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I. Introduction

The Klamath Basin, which straddles the border between Oregon and California, was once an extensive wetland area of about 185,000 acres. The shallow lakes and freshwater marshes of the wetlands attracted concentrations of over 6 million waterfowl during the peak fall periods. But in 1905, the U.S. Bureau of Reclamation implemented a large reclamation project aimed at draining the wetlands and opening the rich lakebeds to farming. Today, less than a quarter of the original wetlands remain, largely in six national Wildlife Refuges.[1] These are now the migratory stopover for a reduced but still significant population of up to a million waterfowl, as well as home to resident populations of about 40,000 birds.

The conversion of this large area was not accomplished without conflict and ultimately, compromise, between agricultural and waterfowl interests. As a result, the entire Klamath Basin is operated as a patchwork of wildfowl refuge and compatible agriculture, regulated in a manner designed to preserve the delicate balance between both sectors. Among the more important proponents of integrated development and management was Theodore Roosevelt, who signed into law a bill in 1908 establishing the Lower Klamath Refuge as the first national waterfowl refuge. The Lower Klamath was the first of several refuges developed within the Klamath Basin, within a regulatory structure that promoted both agricultural development and preservation of wildlife.

[1] These are: Lower Klamath, Tule Lake, Clear Lake (all in California), and Bear Valley, Upper Klamath, and Klamath Marsh (all in Oregon).

The focus of this study, the Tule Lake National Wildlife Refuge was established as a part of the Klamath Basin refuge system 1928. The Tule Lake National Wildlife Refuge consists of about 40,000 acres in total located in the extreme northeast corner of California. The Refuge consists of about 10,000 acres of shallow water, an additional 3,000 acres of marshland, about 8,500 acres of upland, and about 17,000 acres of farmland. The farmland is managed by the U.S. Bureau of Reclamation via a system of competitive bidding. The Bureau also regulates farming by limiting the application of pesticides and herbicides, determining the allocation of water to the refuge and the farming system in draught conditions, and restricting crop decisions in order to provide feed and stubble for waterfowl. This integrated agriculture/refuge management is consistent with the enabling legislation for Tule Lake, the Kuchel Act of 1964, which mandated that the area would be ". . .dedicated to wildlife conservation . . .for the major purpose of waterfowl management, but with full consideration to optimum agricultural use that is consistent therewith".

The joint use of the Tule Lake area has generated conflict almost since the Refuge was established in 1928. Over the past decade or so, the conflict has escalated as wildfowl populations along the entire Pacific Flyway have continued a secular decline. Environmentalists have sued the Fish and Wildlife Service (FWS), claiming that agricultural practices in the refuge are a major cause of reduced bird populations. Environmentalists have been particularly critical of water diversions into the agricultural system, pesticide, herbicide and fertilizer runoff, and allowance of high valued row crop (potatoes, onions, and sugar beets) rather than grain crop production. The FWS denies these claims, citing instead declining habitat along the entire flyway, and declining conditions in Tule Lake itself, including siltation, eutrophication, and grassland biodiversity loss from the process of maturation.

Out of this conflict over a public resource has come an interesting compromise policy suggestion that has the promise to be a rather rare “win-win” situation. This is the so-called “sump rotation” plan, a plan to actually move the wildlife refuge around the Tule Lake Refuge area in order to generate spatial rotation of farming and wildfowl habitat provision. The replacement of formerly farmed areas with wetlands would set up ideal initial conditions for high waterfowl production, since grasses and waterplants in the early successional stages are believed to be most productive. Conversely, planting crops in previously flooded areas would give some relief from nematodes and soil pathogens that plague lands devoted to row crops over long periods. This paper describes the rotation plan and is a first attempt at calculating the costs and benefits.

II. A Model of the Sump Rotation Option

Consider a joint use refuge area fixed in size at A acres, with A_f devoted to farming and A_w devoted to waterfowl habitat. Suppose that there is an aggregate benefit function B(t) for the entire refuge associated with joint farming and wildfowl use. Assume that aggregate net benefits from joint farming and wildfowl production degrade over time at some rate d. On the wildfowl side, benefits decline because the waterfowl habitat loses productivity as the lake and marshes become silted, choked with weeds, and populated with climax grasses of lower productivity. On the farming side, productivity declines because of buildup of soil pathogens and nematodes associated with cumulative production of row crops. Thus if initial year (or maximum) benefits are B_0 , we would expect:

$$B(t) = B_0 e^{-dt} \qquad (1)$$

after t years of refuge use. Now suppose that a sump rotation can restore the degraded system benefits to the original level, but with a one time cost of c dollars. Then we can write the present value of a single rotation cycle of length T years, from the vantage point of year zero, as:

$$PV = \int_0^T B_0 e^{-(r+d)t} dt - c = B_0 (r+d)[1 - e^{-(r+d)T}] - c \qquad (2)$$

Suppose we consider a sequence of n such cycles, each of length T, starting at date zero. Then the present value of the entire string of rotation cyles will be:

$$V = [PV_0 + PV_1 e^{-rT} + PV_2 e^{-r2T} + PV_3 e^{-r3T} + ... + PV_n e^{-rnT}] \qquad (3)$$

where PV_i gives the value of the ith individual cycle rotation. Noting that with T constant, each PV_i is also constant, and noting that the sum of a series $[1 + k + k^2 + k^3 + ...k^n] = 1/(1-k) = 1/(1-e^{-rT})$, we can write the present value of an infinite sequence of rotations as:

$$V = [\int_0^T B_{0]} e^{-(r+d)t} dt - c][1/(1-e^{-rT})] = [B_0 /(r+d)][1 - e^{-(r+d)T}][1 - e^{-rT}]^{-1} \qquad (4)$$

If we are interested in finding the rotation length that maximizes (4), we can differentiate and set equal to zero. The resulting equation is non-linear and cannot be solved in closed form, but the first order condition satisfies:

$$e^{-dT}[1-(d/(r+d))e^{-rT}]=[(r/(r+d))-(rc/B_0)] \qquad (5)$$

The LHS has a maximum of $r/(r+d)$ at T=0, and declines in an inverse logistic shape as T gets larger. The RHS is a constant less that the LHS, and hence there is a solution characterized by the intersection of a horizontal line and a decreasing function. The existence of a solution to the rotation problem is guaranteed as long as $[B_0/(r+d)] \succ c$, and this condition is satisfied as long as the farming/wildlife system is profitable without rotation. Comparative statics for the cost/value parameters are straightforward: the rotation length increases when (c/B_0) increases. Comparative statics for the discount rate and the deterioration rate are ambiguous.

III. Empirical Analysis

The possibility that spatial rotation of the farming/wildlife refuge might mitigate both the nematode problem in farming and the productivity loss in wildfowl production raises interesting cost/benefit questions. The economic feasibility of rotation hinges on two important rates (the discount and deterioration rates), the fixed cost of rotation, and the initial or post-rotation benefit level. As (5) shows, the larger the fixed costs of rotating the system (establishing new dikes, altering the irrigation and infrastructure system) the more it pays to extend the rotation length, and in the limit, choose not to rotate. The size of the initial benefits works in the opposite direction and the rate constants have complicated effects.

We are in the process of gathering data to conduct a cost benefit analysis of the Tule Lake rotation policy option. In principle, this is a complicated modeling problem, since one would want information on both farming productivity and wildfowl production over time, information on the value of wildlife production, information on the possible post-rotation levels of these, and detailed information about the rotation costs. We have some of the information and are working on putting together the remaining data.

In the interim, it is worth doing a sort of back of the envelope calculation with easily available data. Interestingly, in this case the fact that the entire area is operated as a joint system under Bureau of Reclamation direction gives us access to some data not usually available. In particular, we have information on the winning bids for each plot of land leased by the Bureau over a long time period. This turns out to be a large amount of data, since there are over 160 leases. Generally, a successful bidder may farm each plot for up to five years, but each bidder also has the option to drop the lease and rebid on the plot in question or any other plots when prices and productivity do not meet expectations. Hence we have a cross-section time series of bids that has gaps for plots held more than one year. We also have some plot-specific information, but not as much as desirable. In particular, we have acreage planted to each crop on each plot each year, but no information on plot-specific productivity or prices. We do have region-wide data on yields and prices for the Tule Lake Refuge as a whole, however.

Our preliminary analysis is somewhat hampered by some holes in the series that we are intending to fill ultimately. We currently have individual plot bids for all plots over the 1980-1992 period, complete price and yield data for the region over that period, and plot-specific acreage, but with missing data in 1982,1983 and 1985. This necessitates some creative specification, and we settled on variants of specifications beginning with the following equation for the bid:

$$B_{it} = E_{it}[\overrightarrow{R_{it}}]\exp[-d_i N_{it}]\exp[\varepsilon_{it}] \qquad (6)$$

This equation posits that winning competitive bids for each plot (expressed as a bid price per acre per year) are equal to a forward-looking vector of expected rents (where expectations for plot i are formulated at the bid date t), a plot-specific productivity degradation term associated with the nematode population in plot i, and an error.

We parameterize (6) by assuming a simple extrapolative expectations process whereby the vector of expected rents is simply proportional to the region-wide mean weighted crop revenues in the period prior to the bid, so that $E[\overrightarrow{R_{it}}] = \theta REVS_{t-1}$.

Next, since the nematode population in unobservable, we make some assumptions about how nematode infestations may be related to past plantings of row crops. There are various ways to do this. One is to assume that the current population is proportional to a weighted sum of recent shares of acreage planted in row crops in excess of some threshold level (below which no degradation occurs). In particular, assume that:

$$N_{it} = \sum_{j=1}^{j=n_{it}} [RCS_{i,t-j} - \overline{RCS}]\lambda^j \qquad (7)$$

where RCS_{it} and $\overline{RCS}$ are the shares of acres of row crops planted in the previous n years and the threshold level, respectively. In the special case where λ is one, the nematode population is assumed to be related to the simple sum of past deviations; when λ is less than one, the current population is presumed to be related more strongly to recent plantings, etc. We might also hypothesize nematode populations as related to the average of past deviations so that the above sum would be divided by n_{it}.

Since we are currently missing some plot-specific planting data, we have different numbers of observations on past planting of row crops in different years. In the end this made it difficult to deal simultaneously with missing data and the estimation of $\overline{RCS}$ as a free parameter and hence we abandoned the hope of estimating a threshold row crop planting share. The models reported here thus assume that the current nematode population is proportional to cumulative row crop planting $CUMROW_{it}$. Our preliminary empirical specification can be written as:

$$\ln B_{it} = \alpha + \beta \ln \overline{R}_t + \delta \sum_{j=1}^{n_{it}} CUMROW_{i,t-j} + \eta GRAIN + \varepsilon_{i,t} \tag{8}$$

The coefficient on expected rents (or revenues $\overline{R}_t$) should be positive, the coefficient on cumulative row crop shares negative, and the coefficients on the dummy variable $GRAIN$ (equal to one for those plots on which row crops are prohibited.[2]

Table 1 gives estimated parameters for the specification in (8). We estimated (8) using OLS with fixed effects. The dependent variable is the log of the plot-specific bid, expressed as a price per acre per year (mean=4.6). The number of observations over the period investigated is 1001. We do not report the 107 fixed effects because panel lengths are up to 12 observations, with several panels containing missing data.

Table 1

Fixed Effect Bid Price Regression

Dependent Variable is Log of Rent Bid Per Acre

variable	**coefficient**	**standard error**	**t-statistic**
ln R	0.272	0.063	4.31
GRAIN	-0.236	0.111	-2.12
CUMROW	-0.223	0.013	-16.63
Observations	1001		
Adjusted R-square	0.92		
Dependent Variable Mean	4.6		

IV. Discussion

Despite the data difficulties we are currently working with, the econometric results are encouraging. We find evidence of plot-specific productivity degradation associated with cumulative plantings of row crops (CUMROW). We also find that the simple extrapolative forecasting assumption, in which we assume that future expected plot rents are proportional to the regional weighted average revenues ($\ln \vec{R}$) in the year prior to the bid, works satisfactorily. Crop prices and yields of some crops vary considerably over our data period and adding longer lags does not improve fit. The GRAIN dummy has the expected sign, indicating that the Bureau of Reclamation restrictions against row crop production reduce bids an average of 23.6% per

[2] Certain plots around the lakebed are designated as grain-only areas in order to provide stubble and crop residues

acre per year. This raises the interesting question of whether the wildfowl habitat and feed value is worth the bid reduction.

We have several future directions in mind with this project. First, we need to refine our estimates of the bid functions after filling in missing data. The estimates presented here are a good start, and there are various other directions suggested by these preliminary results. Ultimately we would like to parameterize a model like the one presented in Section II above. This would require further work understanding how much crop productivity would increase on nematode free soil, and work estimating the value of the wildfowl productivity increase. Second, we intend to develop and estimate a panel data model of crop share choices. The Tule Lake setting has institutional features that will make this interesting. For example, the Bureau imposes maximum levels of row crop production on plots for which row crop production is allowed. This is done to manage the nematode externality that exists because farmers only lease for short term rather than owning the plots. As discussed above, the Bureau also prohibits row crop production in plots near the lake and imposes minimum planting shares of wheat. Thus farmers are faced with constrained share choices, with maximum shares on some plots and minimums on others. A model which jointly estimated constrained share choices, along with the bid functions, would present interesting modeling and estimation issues to tackle.

We also intend to explore some of the mechanisms associated with the bidding process itself. We have some information on the specific persons who were high bidders, some on second and third runners up, and panel data over the recent past across all plots. Several issues relating to the workings of the bid process are worthy of investigation. One is the nature of the value of having asymmetric risk embodied in a bid process that lets farmers bid for five year durations and then drop the contract if prices fall. We would expect that this bail out option has

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for the wildfowl. These will yield lower bids since row crops are much more profitable than grain crops.

some value and an interesting empirical question is whether the value of that flexibility option can be uncovered from patterns in the bids. Another issue is whether the decline in numbers of bidders and the consolidation of operations within families affects bidding behavior. A third issue is what kinds of spatial patterns we might see in the bidding. It is of some value, for example, to have adjacent plots, so that we might see farmers bidding more when they hold contracts on contiguous pieces. It may also be the case that the nematode problem has some spatial structural character, in which case we might attempt some spatial econometric modeling.

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