Defining the ‘Saving’ in Agriculture Water when Irrigation Technology is a Choice Variable: The Case of the Klamath Basin

By

Susan M. Burke
Ph.D candidate
Department of Agricultural and Resource Economics
Oregon State University
Corvallis, OR 97331

Richard M. Adams
Professor
Department of Agricultural and Resource Economics
Oregon State University
Corvallis, OR 97331

Presented at Western Agricultural Economics Association Annual Meeting
July 11-14, 1999
Fargo, ND

Title: *Defining the 'Saving' in Agriculture Water when Irrigation Technology is a Choice Variable: The Case of the Klamath Basin*

Abstract:

Increasing demand for water in the environment has increased the cost of irrigation water in agriculture leading to the adoption of water saving irrigation technologies, reducing agricultural return flows. However, when agricultural return flows are a source of environmental supply 'savings' soon disappear *because* of the reduced agricultural return flows.

Introduction

Increasing demand for water in the environment has increased the cost of water for use in agricultural production and led to the adoption of water saving irrigation technologies. However, it may be a misnomer, to say that saving water at the farm level translates into a basin wide saving. The quantity of water saved is dependent the reuse of agricultural return flow.

The on-farm benefits of improving irrigation efficiency to maintain agricultural production in the face of decreasing agricultural water endowments is commonly researched by economists. Where, irrigation efficiency (IE) is defined as the ratio of evapotransporation (ETc)to inflow[1]. The higher the IE rate the less the return flow. However from a basin wide perspective, to translate the decrease of agricultural water endowments into a 'savings of water' is incorrect when agricultural return flow is used to supply non-agriculture demand. This is because all or part of the quantity of water 'saved' by reducing agricultural deliveries must be used to meet the shortfall in non-agricultural demands driven by the reduction in agricultural return flow.

This paper nests an on-farm decision making model, used to predict irrigation technology adoption rates, with a simplified basin wide hydrologic model of water use to quantify changes in water use. The goal of the model is to provide the policy maker with a tool to determine the amount of water available to agriculture conditioned by the expected technology response of individual farmers and the subsequent change in basin wide water use. The empirical backdrop is the Upper Klamath Basin, straddling the California and Oregon border.

---

[1] Evapotranspiration is the quantity of water that is removed from the system by crop consumption, evaporation and deep percolation.

Literature Review

The allocation of scarce water resources to agriculture in the American West has received increasing attention as the cost to the environment of diverting and consuming water in agricultural increases. The chronology of economic research on the subject began with quantifying increases in allocative efficiency (Burness and Quirk; Hartman and Seastone, Vaux and Howitt; Booker and Young) by increasing the price of water through such means as increasing block rate pricing structures or creating water markets.

More recent research focuses on the trade-offs between agricultural production and the environment from changes to existing allocation methods and to various efficiency control policies. The environmental effects examined have included changes in stream flow, water quality, application of agro-chemicals and quantity and quality of deep percolation. (Weinberg et. al.; Dinar and Letey; Colby; Caswell et.al (1990)., Helfand and House and Fleming and Adams). However none of this work has examined the re-use of water on a basin wide scale.[2]

The Model

The economic and hydrologic models are linked by irrigation efficiency. A simplified hydrologic model of return flow in a basin is:

$$\mathrm{RF} = \mathrm{I} * (1 - \mathrm{IE}) \qquad (1)$$

Where RF is return flow, I is inflow and IE is the irrigation efficiency rate.

The farmer allocates resources; land, applied water, labor and capital dollars, across crops, in order to maximize profits. Farmers choose IE rates indirectly by determining the

---

[2] Griffin and Hsu, Burness and Quirk and Bockstael have done research regarding the importance of relative spatial location in economic modeling

optimal combination of water and technology or labor costs required to deliver ETc to the crop. In addition to the standard requirement of quasi-concavity, the production function should possess two properties to accurately model agricultural production: 1) input substitution and 2) the ability to account for land heterogeneity. Each of these properties is discussed below in turn.

Substitution between labor/capital and water is made through the farmer's choice of irrigation technology and management. For example, flood irrigation requires less capital than drip irrigation, however flood irrigation requires significantly more applied water than drip irrigation, yet both technologies can supply the yield maximizing quantity of ETc[3]. For simplicity the inputs, labor and capital, will be combined into one composite good called technology[4]. This simplification defines ETc is a function of water and technology dollars, in either labor or capital. Nothing is lost by making this simplification because the focus of this research is on how much farmers improve efficiency not how IE rates are improved.

Land heterogeneity, described as the difference in the quality of land as measured by crop yield per acre, is the second property sought after in the model. The underlying assumption is that farmers introduce land into production in the order of the land's quality. The best land comes into production first followed by continually decreasing quality until the last unit

---

[3] The practice of delivering less ETc than is yield maximizing is referred to as stress irrigation. Whether farm managers practice stress irrigation seems dependent on the geography and type of crop. In some agricultural areas, with relatively high valued crops and constraints on land farm managers choose to deliver yield maximizing quantities of ETc to their crops. In other agricultural areas, without land constraints, keeping more land in production and reducing the yield of each acre of land, may be the profit maximizing behavior. This model assumes the former condition, extensions of this research would include stress irrigation as a choice in the set of on-farm management options.

[4] Technology is denominated in dollars representing increases in labor (as per hour labor dollars) and capital (as annual depreciation costs of capital investment.)

of land placed into production has a marginal return of zero. Conversely, as land is forced from production by a reduction in other inputs, here applied irrigation water, the marginal land is the first to exit. The result of this decrease (increase) in land in production is increasing (decreasing) average crop yields per acre.

The general functional form that posses the above properties for average yield per acre of crop i is:

$$Y_i = f_i\left(x_{il}, ETc_i\left(x_{it}, x_{iw}\right)\right) \tag{2a}$$

$$\text{and } \frac{\partial Y_i}{\partial x_{il}} > 0 \tag{2b}$$

$$MRS = \frac{ETc_{it}}{ETc_{iw}} = -\frac{dx_{iw}}{dx_{it}}\Big|_{ETc=\text{constant}} > 0 \qquad \frac{dMRS}{dx_{it}} < 0 \tag{2c-d}$$

Where x_j is the input of the j resources, l, t, w, referring to land, technology and water, respectively. This general form of the production function defines the average yield of crop i as a function of land and ETc; and ETc as a function of technology and applied irrigation water. Equation (2b) is a curvature restriction that accounts for land heterogeneity, where average yield per acre increases as total land in production falls. Equations (2c-d) define diminishing marginal rate of technical substitution between applied water and technology in the production of ETc.

Specifically, the functional form of the profit maximization problem which possesses the two properties of the production function, input substitution and land heterogeneity, can be modeled by combining a quadratic yield expression for land with a constant elasticity of substitution (CES) function which produces ETc. Assuming the costs are linear, the functional form of the model for one crop and one region is :

$$\underset{x_j}{\mathrm{Max}}\,\boldsymbol{p} = P(\boldsymbol{a} - \boldsymbol{d}x_l)x_l - \sum_k R_k \boldsymbol{w}_k x_k - \boldsymbol{v}_w x_w - \boldsymbol{w}_w (b - s) \tag{3a}$$

subject to:

$$ETc \geq R_e x_l \tag{3b}$$

$$ETc = \boldsymbol{y}\left(\sum_k \boldsymbol{j}_k \left(x_k{}^{\boldsymbol{h}}\right)\right)^{\frac{1}{\boldsymbol{h}}} \qquad k = t \text{ and } w \tag{3c}$$

$$\frac{ETc_i\left(x_{iv}, x_{iw}\right)}{x_{iw}} \geq \overline{IE}_i \tag{3d}$$

$$R_j x_l \leq X_j \tag{3e}$$

$$\sum_k \boldsymbol{j}_k = 1 \tag{3f}$$

where: e is the subscript referring to ETc

P = output price

a = average yield intercept parameter

d = average yield slope parameter

w_j = input cost

x_j = input of the j resources

R_j = coefficient of per acre input requirement for j resources

R_e = coefficient of minimum per acre ETc

y = CES technology parameter

j_k = CES share parameter

h =function of the elasticity of substitution, σ ($s = \frac{1}{1-h}$)

X_j = total endowment of resource j, note: R_l= 1

$\overline{IE}$ = The initial IE rate

The quantity of applied water and technology are incorporated into the production function through constraints (3b) and (3c), which account for the fixed proportions relationship of ETc and land and, which defines ETc in terms of applied water and technology, respectively. Through the use of a CES function for ETc, the model returns information regarding the substitutability of technology for applied water thereby estimating the increases in the (IE) rate. The IE rate is initialized at the observed rate, $\overline{IE}$. Equation (3d) limits the IE rate to be greater than or equal to the initial rate.

Examination of the first order conditions reveals intuitive marginal relationships. Consider a simplified Lagrangian that assumes the constraints (3b) and (3e) bind. Let μ_1 be the Lagrange multiplier on ETc.

$$L = P(\alpha - \delta x_l)x_l - \sum_j R_j \omega_j x_j - \mu_1\left(x_l R_e - \phi\left(\sum_k \varphi_k (x_k)^{\eta}\right)^{\frac{1}{\eta}}\right) \qquad (4)$$

First order conditions of the Lagrangian are:

$$\frac{\partial L}{\partial x_l} = P(\alpha - 2\delta)x_l = \mu_1 R_e + \omega_l \qquad \text{note: } R_l = 1 \qquad (5a)$$

$$\frac{\partial L}{\partial x_k} = \mu_1 MP_k = \omega_k \qquad \forall\, k \qquad (5b\text{-}d)$$

$$\text{where: } MP_k = \phi\left(\sum_k \varphi_k (x_k)^{\eta}\right)^{\frac{1-\eta}{\eta}} \varphi_k (x_k)^{\eta - 1} \quad \forall\, k \qquad (6)$$

Examination of the first order conditions shows the connectivity of land, applied water and technology to ETc. In equation (5a), the equilibrium quantity of land in production is determined by equating the value of the marginal product of land, (VMP_l), to the price of land *plus* the per acre requirement of ETc, R_e, times the shadow value of the marginal product of ETc, μ_1. Consider $R_e \mu_1$ to be the value marginal product of ETc, VMP_e. Similarly, the first order conditions generated by differentiating the objective function with respect to applied water and technology (equations 4b-d) equate the respective input price to the shadow value of ETc times the respective input's marginal product. Where μ_1 is the 'price' of ETc (the shadow value), the first order conditions of applied water and technology can best be described as an analog to the familiar first order condition, where value of the marginal product of an input is equated to its price, as equating the *shadow*-value of the marginal product inputs to their prices.

The parameters of the model are developed using positive mathematical programming (PMP) (Howitt 1995) and a cross section of data. The cross section, or baseline year is chosen based on whether there were full agricultural water deliveries. Multiple model scenarios are run assuming various reductions to agricultural water endowments as a percent of the baseline year endowments. Predicted changes in IE rates are then used in the hydrologic model to calculate changes in return flow and consequential shortages of water supply to non-agricultural users.

Analyzing the change in return flow is helped by taking the total differential of the return flow equation (equation 1). The differential is:

$$\Delta RF = \Delta I(1 - IE) - I\Delta IE \qquad (7)$$

The first expression on the right hand side of equation (7) is the planned reduction in agricultural diversions, or inflow, I, times the portion of inflow that becomes return flow, (1-IE). This expression represents the policy makers choice on the reduction in return flow. The second expression on the right hand side of equation (7) is the change in return flow that results from a change in the on farm IE rate. This expression is more difficult for a policy maker to plan as it is generated from the profit maximizing irrigation technology choices of the farmers, conditioned on the reduction of agricultural diversion. The model presented here estimates the unplanned change.

Empirical Backdrop

The Upper Klamath River Basin (the Upper Basin) is situated on the California-Oregon border to the east of the Cascade mountains. It covers approximately 5,155,000 acres and is home to a national park, a national monument, two national forests and six wildlife refuges. The wetlands of the Upper Basin are a pinch point of the Pacific Flyway, therefore they are essential for migratory waterfowl. In addition to the natural resources within the Upper Basin, the Klamath River itself is one of the Pacific Coasts most important salmon and steelhead trout rivers.

The Klamath Project, located in the south central Upper Basin was initiated in 1905 as one of the first federal irrigation projects to be constructed by U.S. Bureau of Reclamation (USBR). The project encompasses 234,000 acres of land. Upper Klamath Lake, the source of the Klamath River provides ninety percent of the off-stream diversions used to irrigated lands within the Klamath Project.

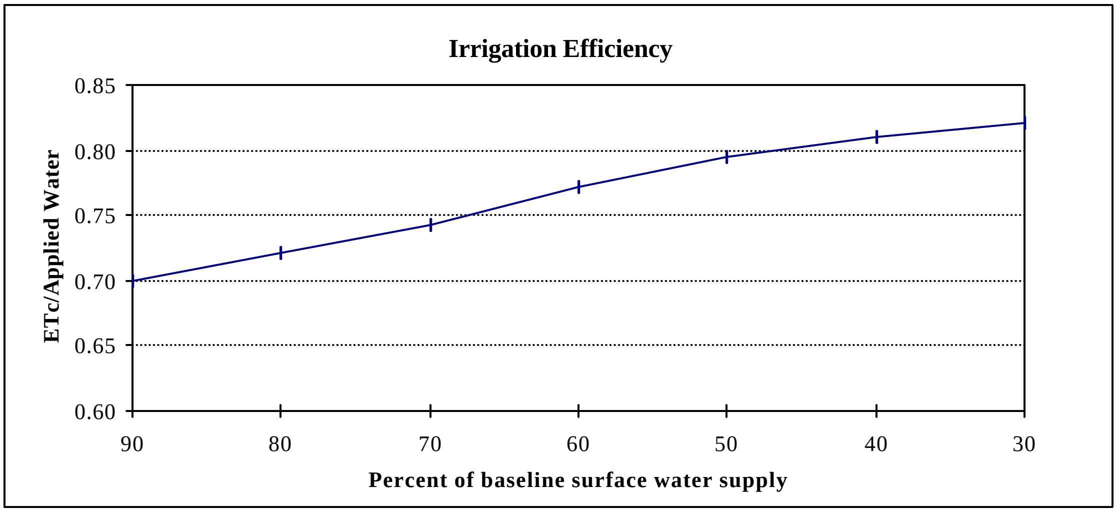
Within the Klamath Project the proximity of farming and wildlife is striking. Farm fields border on or are located within the Tule Lake National Wildlife Refuge (TLNWR) and the Lower Klamath Lake National Wildlife Refuge (LKLNWR) and water flows directly into the marshes from irrigation drainage channels. Within the Klamath Project, the distinction between canal and drain water becomes blurred as conveyance channels carry a mixture of source water and irrigation return flows. Legally the LKLNWR and TLNWR hold junior water rights to agriculture and are dependent on these agriculture return flows for a majority of water used to flood the marshes.

Salmon are threatened and endangered species in the Klamath River. Additionally the shortnose sucker fish whose habitat is Upper Klamath lake is listed as endangered. Situated at the source of the Klamath River, and as the largest diverter of Klamath system water, the Klamath Project is currently the target for reductions in diversions. When these reductions occur, they cause reductions in return flow and therefore shortages in the water required to maintain LKLNWR and TLNWR.

In short, between Upper Klamath Lake and the river, both geographically and politically, lies the Bureau of Reclamation's Klamath Project. The Bureau must balance water level requirements in the Upper Klamath Lake with stream flow requirements in the Klamath River and Wildlife requirements to the south.

Results

Figure 1 shows the relationship of IE rates to the percent of available agricultural water deliveries. Beginning at a basin wide average IE rate of 70 percent increasing to 82 percent when agricultural water deliveries are 30 percent of baseline. The curve demonstrates a cubic relationship whereby the change in the IE rate increases at an increasing rate until the 60 percent availability and then increases at a decreasing rate. The curve asymptotes after a 30 percent availability. This range of IE rates is consistent with irrigation technology methods in the Klamath Project.



The total differential of the percent change in return flow is shown in Table 2. The two effects discussed above, are the planned effect, resulting from a reduction in agricultural deliveries and the unplanned effect, resulting from the change in IE rate. In the case of 90 percent baseline water deliveries the planned reduction in return flow is 10 percent and the unplanned reduction is 5.9 percent, making the total reduction 15.9 percent. The contribution of the unplanned reduction more than doubles the shortage in return flows. In the Klamath Basin the unplanned effect reduces the amount of water that was expected to be available to flood marshlands for wildlife habitat by half.

Percent of Baseline Applied Water	100.0	90.0	80.0	70.0	60.0	50.0	40.0	30.0
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Percent reduction in agricultural return flow								
Planned	0.0	-10.0	-20.0	-30.0	-40.0	-50.0	-60.0	-70.0
Unplanned	0.0	-5.9	-5.6	-5.1	-5.8	-3.8	-2.0	-1.1
Total	0.0	-15.9	-25.6	-35.1	-45.8	-53.8	-62.0	-71.1

The unplanned reductions fall as the percent of baseline applied water falls. The reason for this is twofold. First the rate of change in the IE ratio is falling and secondly as the amount of water diverted to agriculture decreases, the effect of a change in IE rates becomes less significant.

Assuming the National Wildlife Refuges preserve habitat, the unplanned reduction in agricultural return flow must be replaced with water from Upper Klamath Lake. In the above example the 'savings' of 10 percent of water to agriculture (90 percent of baseline applied water) is reduced by the shortfall of 5.9 percent of water to the National Wildlife Refuge. Therefore the savings of water generated by an increase in IE rates, is only 4.1 percent. This result holds anytime there is reuse of agricultural return flows within a basin.

Conclusion

To understand the basin wide savings of water requires an understanding of the change in IE rates and ultimately the change in basin wide ETc. Agricultural economic models that focus on the change in applied water as a reaction to reductions in water available to agricultural, without regard to the change in technology that occurs may be misleading policy makers on potential water savings. The overstatement will be largest the smaller the reduction of agricultural water deliveries. Models that focus only on changes in ETc, without regard to the substitution of technology for water may be mis-stating either the costs of technology required to produce ETc, or water costs, or both, thereby mis-stating the economic consequences to agriculture from reductions in irrigation water deliveries. To affect a true basin wide savings the model must condition the choice of water available to agriculture on changes in IE rates.

Bibliography

Booker, J.F., R.A. Young. "Modeling Intrastate and Interstate Markets for Colorado River Water Resources." *Journal of Environmental Economics and Management* V26 N1 January 1994: 66-87.

Bockstael, N.E. "Modeling Economics and Ecology: The Importance of a Spatial Perspective." WP96-23, Department of AREC, University of Maryland at College Park.

Burness, S.H. and J.P Quirk. "Water Law, Water Transfers, and Economic Efficiency: The Colorado River." *The Journal of Law and Economics* V23 N1 April 1980: 111-34.

Caswell, M. and D. Zilberman. "The Choices of Irrigation Technologies in California." *American Journal of Agricultural Economics* 1985: 224-234.

Colby, B.G. "Enhancing Instream Flow Benefits in an Era of Water Marketing." *Water Resources Research* Vol. 26 N 6 June 1990: 1113-20.

Dinar, A. and J. Letey. "Agricultural water marketing, allocative efficiency, and drainage reduction." *Journal of Environmental Economics and Management* V20 1991: 210-23.

Fleming, R.A. and R.M. Adams. "The Importance of Site-Specific Information in the Design of Policies to Control Pollution." *Journal of Environmental Economics and Management* Vol. 33, 1997: 347-358.

Griffin, R.C. and S. Hsu. "The Potential for Water Market Efficiency when Instream Flows Have Value." *American Journal of Agricultural Economics* V75 May 1993: 292-303.

Hartman L.M. and D.A. Seastone, "*Water Transfers: Economic Efficiency and Alternative Institutions*" Johns Hopkins Univ. Press, Baltimore, 1970.

Helfand, G.E. and B.W. House. "Regulating Nonpoint Source Pollution Under Heterogeneous Conditions." *American Journal of Agricultural Economics* V77 November 1995: 1024-32.

Vaux, H.J. and R.E. Howitt. "Managing water scarcity: An evaluation of interregional transfers." *Water Resources Research* V20 1984: 785-92.

Weinberg, M., C.L. Kling and J.E. Wilen. "Water Markets and Quality." *American Journal of Agricultural Economics* V75 N2 May 1993: 278-91.