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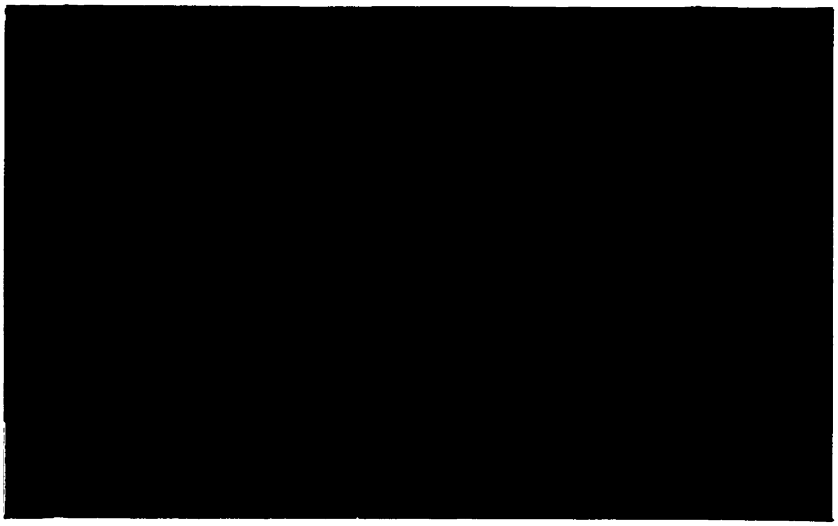

THE EFFECTS OF THE FEED GRAIN AND WHEAT PROGRAMS ON IRRIGATION AND GROUNDWATER DEPLETION IN NEBRASKA

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Introduction

During the past 40 years, U.S. agriculture has been revolutionized by rapid and profound technological change. The introduction and spread of new technologies such as high-yielding hybrid crop varieties, synthetic agricultural chemicals such as fertilizers and pesticides, and new irrigation methods have enhanced agricultural productivity tremendously. Moreover, in many cases (fertilizers, pesticides, irrigation), they have reduced agriculture's dependence on natural resources such as soil fertility and precipitation.

At the same time, however, use of these technologies has contributed to a deterioration in the natural resource base of agriculture and in environmental quality, especially in marginal growing areas where these technologies have fostered intensification of cultivation (Zilberman) Increased use of chemical fertilizers and pesticides has produced growing contamination of groundwater stocks, especially in areas such as the Northern High Plains where chemicals are applied in irrigation water on sandy soils. The spread of irrigation has increased overdraft of groundwater stocks; in the Southern High Plains, depletion of the Ogallala Aquifer is forcing reductions in cultivated acreage. Soil erosion remains a serious concern in many areas. Disposal of toxic drainage water has become a severe problem affecting considerable irrigated acreage in the West.

Many believe that government farm commodity programs have exacerbated these resource and environmental quality problems. By keeping prices above free market levels and restricting acreage, commodity programs give farmers additional incentives to increase yields through increased use of chemicals, adoption of irrigation and use of pesticide-intensive and erosion-prone crop rotations.

To date, however, there has been little empirical evidence on the magnitudes of these environmental and resource effects. Dixon, Dixon and Miranowski used a linear programming model to analyze the impact of the cotton program of the 1960s on pesticide use, showing that restrictions on acreage base prevented cotton production from shifting location to drier, less pest-infested areas and therefore maintained pesticide usage at higher than necessary levels. Using the method proposed by Lichtenberg and Zilberman for incorporating the deficiency payment program into welfare estimation of environmental policies, Kopp and Krupnick showed that the benefits of reducing ozone for corn and soybean production were quite sensitive to the level of market distortion induced by this program. Anderson, Opaluch and Sullivan estimated some tradeoffs between pest damage and groundwater contamination from aldicarb used on potatoes in Rhode Island, but were hampered by a lack of data on pest infestation and damage rates. Lichtenberg estimated the impact of prices and costs (and hence, indirectly, commodity program parameters and tax policies) on adoption of irrigated agriculture in western Nebraska, but did not link irrigation adoption directly to groundwater depletion. The remaining literature on erosion control, pesticide use, and so on is overwhelmingly normative in nature.

The studies contained elsewhere in this volume extend our understanding of the magnitudes of these environmental and resource effects somewhat further. Miranowski, Hrubovcak and Sutton examine the impacts of removal of agricultural subsidies on chemical use and use of other inputs using a computable general equilibrium model and on erosion with and without the Conservation Reserve Program using an econometric simulation model of the major agricultural crops. They show that chemical use would fall slightly and that the Conservation Reserve Program moderates significantly the increases in erosion and nitrogen and herbicide applications that would result. Johnson, Atwood and Thompson focus on policies aimed at reducing agricultural pollution, such as mandatory conservation compliance, a nitrogen tax, targeting the Conservation Reserve Program to surface water pollution and and ban on corn rootworm insecticides in the Corn Belt. Their results imply that pollution could be reduced substantially without much impact on crop production and farm income, suggesting that there is considerable scope for bringing agricultural and resource policies into harmony.

This paper attempts to assess quantitatively the impact of changes in the structure of farm commodity programs on an important agricultural resource, the stock of groundwater in the northern Ogallala Aquifer. Until the mid-1960s, low rainfall and low water holding capacity of the region's predominantly sandy soils made dryland wheat and pasture the principal crops. Gravity-based irrigation systems could not be used because of the rolling terrain, while hand-move sprinkler systems had excessive labor requirements. The introduction of center-pivot irrigation systems made irrigated farming economical in the region, and between 1965 and 1980 irrigated agriculture spread rapidly. Between 1965 and 1980, the irrigated crop acreage in western Nebraska, increased at an average annual rate of more than 10 percent.

By the late 1970s, declining water tables had become a serious source of concern in the region. In response, the state of Nebraska has established water conservation districts in many areas to limit groundwater pumping. Groundwater quality has also become a source of concern. Fertilizers and pesticides are applied in the irrigation water; because the soil is sandy, chemicals tend to leach readily. As a result, contamination of drinking water wells by nitrates and herbicide residues has spread.

We proceed as follows. We begin by integrating and extending the work of Caswell and Zilberman and of Lichtenberg to obtain a dynamic model of adoption of center-pivot irrigation in the Northern High Plains that takes into account the salient features of the adoption process, namely differential adoption according to land quality, crop switching and changes in pumping lift. This approach focuses on land heterogeneity as a key determinant of adoption decisions. Second, we use data from western Nebraska to estimate irrigation adoption and groundwater dynamic equations. We then develop an empirical model of the grain-livestock sector that models the impacts of changes in commodity program parameters. Finally, we combine these models and simulate the effects of changes in price supports, target prices and diversion requirements for wheat and feed grains on irrigated acreage and groundwater depletion in the short and medium runs.

A Model of Irrigation Adoption

Consider the problem of optimally allocating total available acreage between an irrigated and a dryland crop, both of which are subject to government commodity programs (for example, corn (irrigated) and wheat (dryland)) in a region like the Northern High Plains in which groundwater is the sole source of irrigation water.

Let q be a scalar measure of land quality, normalized for convenience to lie between zero and one, and $G(q)$ represent total acreage of quality no less than q. Assume that both the dryland and irrigated crops exhibit constant returns to scale in land, and that their production functions f^D and f^I are neoclassical in all inputs and land quality. Let the per acre profit function for the irrigated crop be $\pi^I(p_I,w,K,q,\gamma)$, where p_I is the price of the irrigated crop, w is a vector of input prices, K is the fixed investment cost of the irrigated crop and γ is pumping lift, an inverse measure of the groundwater stock. Clearly profit is increasing in p_I and q, and decreasing in w, C and γ, the latter because increases in pumping lift increase both the cost of pumping water and the depth and therefore the cost of an irrigation well. Let the corresponding per acre profit function for the dryland crop be $\pi^D(p_D,w,q)$, increasing in p_D and q and decreasing in w. Following the literature on optimal groundwater depletion (see for instance Gisser), assume that the change in pumping lift over time is a linear function of the stock of groundwater and irrigation activity, measured by irrigated acreage A^I,

(1) $\dot{\gamma} = \beta A^I - \rho$,

where ρ is natural recharge of the aquifer.

Let $\ell_I(q)$ be the fraction of land of quality q allocated to the irrigated crop. The optimal land allocation is found by choosing $\ell_I(q)$ to

$$\max \int_0^\infty \int_0^1 (\ell_I(q)\pi^I(p_I,w,K,q,\gamma)+(1-\ell_I(q))\pi^D(p_D,w,q))e^{-rt}G_q(q)dqdt$$

subject to (1), where r is the appropriate discount rate. The necessary conditions include

(2) $\pi^I - \pi^D - \mu\beta = 0$

(3) $r\mu + \int_0^1 \ell_I \pi^I_q G_q dq = \dot{\mu}$

plus equation (1), where μ is the negative of the spot (current) shadow price of pumping lift. Since profit is decreasing in lift, $\mu > 0$.

Equation (2) implies that the optimal solution is to set $\ell_I(q) = 1$, i.e., allocate all land of quality q to the irrigated crop, if $\pi^I(q)-\pi^D(q) > 0$, and $\ell_I(q) = 0$ otherwise. The assumption that $f^I(q)$ and $f^D(q)$ are neoclassical in q ($f^i_q > 0$, $f^i_{qq} < 0$) implies that four patterns of land allocation are possible:

I. There will be a critical land quality q* defined by

$$(4) \quad \pi^I(p_I,w,K,q^*,\gamma) = \pi^D(p_D,w,q^*).$$

All land of quality less than q* will be allocated to the irrigated crop, all land of quality greater than q* to the dryland crop. This implies that π^I will intersect π^D from above (see Figure 1), so that

$$(5) \quad \Delta^* = p_I f^I_q(q^*) - p_D f^D_q(q^*) < 0.$$

Acreage of the irrigated crop will be

$$(6.I) \quad A^I = G(q^*).$$

This case applies to what Caswell and Zilberman have termed "land quality augmenting" technologies.

II. There will be a single critical land quality q*, defined as above. All land of quality greater than q* will be allocated to the irrigated crop, all land of quality less than q* to the dryland crop. This implies that π^I will intersect π^D from below (see Figure 1), so that $\Delta^* > 0$. Acreage of the irrigated crop will be

$$(6.II) \quad A^I = (1-G(q^*)).$$

III. There will be two critical land qualities, q* and q**, defined as above. All land of quality q* < q < q** will be allocated to the dryland crop, the rest to the irrigated crop. This implies that π^I will intersect π^D from above at q* and below at q** (see Figure 1), so that $\Delta^* < 0$ and $\Delta^{**} > 0$. Acreage of the irrigated crop will be

(6.III) $A^I = 1-G(q^{**})+G(q^*)$.

IV. There will be two critical land qualities, q^* and q^{**}, defined as above. All land of quality $q^* < q < q^{**}$ will be allocated to the irrigated crop, the rest to the dryland crop. This implies that π^I will intersect π^D from below at q^* and above at q^{**} (see Figure 1), so that $\Delta^* > 0$ and $\Delta^{**} < 0$. Acreage of the irrigated crop will be

(6.IV) $A^I = G(q^{**})-G(q^*)$.

The short run impact of changes in farm commodity programs on land allocations can be represented by simultaneous changes in the effective supply prices of the two crops, p_I and p_D. Suppose that the two are correlated, as grain prices typically are. The effect of a simultaneous change can be captured by writing p_D as a function of p_I, $\alpha(p_I)$, where $\alpha' > 0$ denotes a positive correlation and $\alpha' < 0$ a negative correlation. In each of the four possible cases, an general increase in price support levels will increase irrigated acreage and decrease dryland acreage as long as

(7) $p_I f^I(q^*) - \frac{\alpha'}{\alpha} p_D f^D(q^*) > 0$,

that is, as long as the revenue per acre earned by the irrigated crop on the critical quality (or qualities) of land exceeds that earned by the dryland crop by at least a factor equal to the elasticity of the effective supply price of the dryland crop with respect to the irrigated crop. In western Nebraska, for example, revenue per acre of irrigated corn is typically 2-3 times revenue per acre for dryland wheat, while the elasticity of the effective supply price of wheat with respect to corn during the 1965-1981 period was 1.16. One would thus expect increases in the general support level to increase irrigated acreage at the expense of dryland acreage in this region.

The short run impact of changes in farm commodity programs can similarly be found by differentiating totally equation (1) and using equations (6.I)-(6.IV). As long as the inequality in equation (7) holds, such as in the case of western Nebraska, an increase in price support levels will increase the rate of groundwater depletion (the rate of increase of pumping lift) in addition to increasing irrigated acreage.

Long run equilibrium requires $\dot{\gamma} = \dot{\mu} = 0$, which implies

$$(8) \quad \beta A^{I} - \rho = 0$$

$$(9) \quad r\mu + \int_{0}^{1} \ell_{I} \pi_{\gamma}^{I} G_{q} dq = 0$$

must hold as well as equation (1). For Cases I and II, equation (8) implies that the long run equilibrium critical quality of land $\tilde{q}^{*}$ will be uniquely determined by the parameters ρ and β in equation (8). For example, in Case I $\tilde{q}^{*}$ will be defined by

$$(10.\text{I}) \quad G(\tilde{q}^{*}) = \rho/\beta,$$

while in Case II $\tilde{q}^{*}$ will be defined by

$$(10.\text{II}) \quad G(\tilde{q}^{*}) = 1-\rho/\beta.$$

It is obvious from equation (8) that changes in commodity programs will have no effect on long run equilibrium irrigated and dryland acreages in any of the four possible cases. In general, however, one would expect that an increase in price support levels will lead to greater long run depletion of groundwater stocks For Case I, this can be demonstrated as follows. The long run equilibrium shadow price of groundwater in Case I is

$$(11) \quad \tilde{\mu} = \frac{1}{r} \int_{0}^{\tilde{q}^{*}} \pi_{\gamma}^{I} G_{q} dq$$

and the long run equilibrium pumping lift is thus given by

$$(12)\quad \pi^I(\tilde{\gamma}) - \pi^D - \frac{\beta}{r}\int_0^{\tilde{q}^*}\pi_\gamma^I G_q dq = 0.$$

Totally differentiating equation (12), one obtains

$$(11)\quad \frac{\partial\tilde{\gamma}}{\partial p_I} = \frac{-rf^I}{r\pi_\gamma^I - \beta\int_0^{\tilde{q}^*}\pi_{\gamma\gamma}^I G_q dq}$$

which will be positive whenever the denominator is negative, and vice versa. If, as is typically assumed, the cost of pumping is linear or nearly linear in lift and the cost of drilling a well is linear or nearly so in well depth, so that $\pi_{\gamma\gamma} \cong 0$, then the denominator will be negative and $\partial\tilde{\gamma}/\partial p_I > 0$. The demonstration for Case II is identical; the same results can be obtained for Cases III and IV as well.

<u>Irrigation Adoption and Groundwater Depletion Models</u>

In this section we develop an empirical model to quantify the short and long run effects of changes in farm commodity program parameters on irrigated farming, center-pivot adoption and groundwater depletion under the assumption that the western Nebraska, the study area, accounts for a small share of wheat and corn production. We use data from 22 counties in western Nebraska for the period 1965-1981, when the bulk of center-pivot adoption took place.

Following equation (1), changes in pumping lift were estimated as a function of lagged irrigated acreage and components of natural recharge. The average lift in new irrigation wells drilled in each year was used to estimate pumping lift (γ_{it}). In cases where no new irrigation wells were drilled, pumping lift was estimated by regressing lift in all years when wells were drilled on lift in the nearest county with similar soils and using predicted lift for the missing years. (The results obtained when these observations were omitted were quite similar.) Data on rainfall were unavailable, so the only component of recharge used was county-wide average available water capacity in the top six feet of soil (AWC_i). In semi-arid areas like western Nebraska, soils tend to be sandier (have lower water holding capacity) in areas receiving less rainfall; thus average available water capacity can be considered as a proxy for average rainfall. Data on irrigated acreage (A_{it}) were taken from the Nebraska Department of Agriculture.

A variety of specifications were examined, and the following was chosen on the basis of goodness-of-fit and plausibility:

$$\ln(\gamma_{it}) = \underset{(13.155)}{1.106496} \ln(AWC_i) + \underset{(8.908)}{0.277878} \ln(A_{i,t-1})$$

SSE = 168.33 (T-statistics in parentheses).

The corresponding equation of motion of the groundwater stock is

$$\dot{\gamma}/\gamma = AWC^{1.106496}\, A^{0.277878}/\gamma - 1$$

As anticipated, pumping lift tends to be higher and groundwater depletion more rapid in areas with sandier soils (less average rainfall) and more irrigated farming.

Following Caswell and Zilberman and Lichtenberg, a logit model was used to capture the limitations imposed by land availability on adoption of center-pivot irrigation systems. The dependent variable was the fraction of total available cropland allocated to irrigated farming. Estimates of total available cropland in each county were taken from the Census of Agriculture; irrigated acreage was taken from the annual reports of the Nebraska Department of Agriculture. The independent variables included pumping lift (γ_{it}), county-wide average available water holding capacity in the top six feet of soil(AWC_i), the fixed cost of a center pivot system (K_t) and expected variable profits per acre for corn (π_t^I) and wheat (π_t^D), the predominant irrigated and dryland crops. Pumping lift was estimated as above. Available water holding capacity was used as a measure of land quality. For soils which are predominantly sandy like those in western Nebraska, available water capacity is the best scalar measure of land quality because it is highly correlated with fertility and tilth as well as ability to hold water and nutrients. The fixed cost of a center-pivot system was estimated as the annualized per acre cost of a standard system, consisting of a well 250 feet deep, a pump and gearhead, a fuel tank and diesel power unit and a ten-tower sprinkler system designed to irrigate one quarter-section of land (see Lichtenberg for details).

Expected variable profits per acre for irrigated corn and wheat were constructed as follows. Estimated variable production costs for corn and hard red winter wheat in the Northern Plains region for the years 1975-1981 were taken from the total variable expenses estimates reported in McElroy and Gustafson. Factor proportions for the years 1965-1974, were assumed to be the same as in 1975. The indices of prices paid for seed, fertilizer, chemicals, energy, repairs, custom/drying/other expenses reported in the U.S. Department of Agriculture (1979) were used to account for changes in factor costs. Expected revenue per acre for irrigated corn and wheat was estimated as the product of expected price and expected yield. The expected price was estimated as the maximum of the expected market price and the target price adjusted for diversion requirements as described below. Three-year moving averages of corn and wheat yields in each county were used to estimate expected yields. In cases where there was no acreage of either corn or wheat in a county, yields during years for which there was acreage were regressed on yields in a nearby county with similar land quality, and the yields predicted by the regression were used. The producer price index for all commodities reported in the U.S. Department of Agriculture (1979, 1984) was used as a deflator to obtain real prices.

The estimated coefficients of the adoption equation are shown in Table 1. As anticipated, adoption is increasing in expected corn profit and decreasing in expected wheat profit, pumping lift and center-pivot system cost. Contrary to the results obtained by Lichtenberg, it is increasing in available water holding capacity, suggesting that center-pivot systems do not behave as land quality augmenting systems as defined by Caswell and Zilberman. This result may be due to the imposition of linearity. The coefficients of expected corn and wheat profit are virtually identical in absolute value, suggesting that adoption depends on the simple difference in expected profit. The coefficient of center-pivot system cost, on the other hand, is about 10 times larger than the coefficient of expected corn profit, suggesting that factors such as credit constraints, tax treatment and loss aversion (assuming higher fixed costs increases bankruptcy risk) play an important role in adoption decisions.

The Grain and Livestock Market Model

This section describes an estimated market model of wheat and feed grains (which also necessitates modeling livestock markets) that depicts the role of government programs. The grain demand component disaggregates demands by consumption, market inventory, and exports following the specifications of Just and Chambers (1981). Demand for government stocks and the farmer owned reserve follows the work of Rausser and Love with somewhat more structure to reflect the qualitative nature of policy instruments. The livestock component follows along lines used by Just (1981) with revisions to incorporate some refinements developed by Rausser and Love. The grain supply model uses logit equations to represent program participation decisions following the spirit of the work by Chambers and Foster and later empiricized by Rausser and Love. The acreage equations depart significantly from previous econometric practice and incorporate more structure among important program and market variables in the spirit of the intuitive and conceptual framework developed by Gardner (1988) and Lins. They examine the gains and losses associated with the wheat and corn programs by means of a quantitative graphical analysis of the various policy instruments through which wheat and feed grain commodity policies are administered.

The Crop Supply Structure

The basic form of the acreage equations is as follows. First, acreage in a market free of government programs is assumed to follow

(12) $A_f = A_f(\pi_n, \pi_a, A_{f,-1})$

where

A_f = free market acreage of the crop in question

π_n = anticipated short-run profit per acre from production of the crop in question with free market price

π_a = anticipated short-run profit per acre from production of competing crop(s)

$A_{f,-1}$ = lagged free market acreage (to represent production fixities, etc.).

Profit per acre is defined by price times yield less per acre production cost, e.g.,

(13) $\pi_n = P_m Y_a - C$

where

P_m = market price

Y_a = expected yield

C = short-run cost per acre.

When government programs are voluntary, the nonparticipating component of acreage is assumed to follow equation (12) on the nonparticipating proportion of the acreage so nonparticipating acreage is

(14) $A_n = (1 - \phi)\ A_f(\pi_n, \pi_a, A_{f,-1})$

where

A_n = nonparticipating acreage

ϕ = rate of participation in the relevant government program.

The participating acreage is largely determined by program limitations with

(15) $A_p = B\ \phi\ (1 - \theta) - D(G_a)$

where

B = program base acreage

θ = minimum diversion requirement for participation

D = additional diversion beyond the minimum

G_a = payment per acre for additional diversion.

The estimating equation for observed total acreage given the participation level is obtained by combining (14) and (15),

(16) $A_t = B\ \phi\ (1 - \theta) - D(G_a) + (1 - \phi)\ A_f(\pi_n, \pi_a, A_{f,-1})$,

where $D(\cdot)$ and $A_f(\cdot)$ follow linear specifications.

Determining the level of participation in this framework is crucial. Each farmer is assumed to participate if his/her perceived profit per acre is greater under participation than under nonparticipation ($\pi_p^i > \pi_n^i$). Assuming that individual perceived profits differ from an aggregate by an amount characterized by an appropriate random distribution across farmers, the participation rate can be represented by a logistic relationship with

$$(17) \quad \ln \frac{\phi}{1 - \phi} = \phi^*(\pi_n, \pi_p)$$

where

π_p = the profit per acre under compliance.

Given the qualitative nature of numerous agricultural policy instruments, a conceptually plausible specification of short-run profit per unit of land (producing plus diverted) on complying farms follows

$$(18) \quad \pi_p = (1 - \theta - \mu)\pi_z + \theta \cdot G_m + \mu \cdot \max(G_v, \pi_p)$$

where μ is the maximum proportion of base acreage that can be diverted in addition to minimum diversion, G_m is the payment per unit of land for minimum diversion (zero is no payment is offered for minimum diversion), G_v is the payment per unit of land for volutary diversion beyond the minimum, and π_z is the short-run profit per unit of producing land under compliance. The latter term suggests no voluntary additional diversion if $G_v < \pi_z$ and voluntary addtional diversion to the maximum if $G_v < \pi_z$.

Conceptually, π_z follows

$$(19) \quad \pi_z = \left[\max(P_t, P_m) \cdot Y_p + \max(P_s, P_m) \cdot \max(Y_a - Y_p, 0) + \max(r_m - r_g, 0) \cdot P_s \cdot Y_a - C\right]$$

where P_t is the government target price, Y_p is the program yield, P_s is the price support, r_m is the market rate of interest, and r_g is the government subsidized rate of interest on commodity loans under the program (Love). Equation (19) reflects the complicated relationship through which a participating farmer is entitled to at least the target price on his program yield, at least the (lower) support price on all of his production, and gains an additional interest subsidy on a loan against his stored crop (at harvest time) evalated at the support price. These benefits must be balanced against the opportunity loss of having to divert some of land from production reflected by equation (18).

Once acreage is determined in this framework, it is simply multiplied by yield and added to carryin to determine crop supply. Of course, the relationships in (18) and (19) do not necessarily apply exactly. For example, an uncertain anticipated market price may be discounted by a farmer compared to a target or support price which is known with certainty at the time of acreage decisions. Also, not all farmers place their crop under federal loan to take advantage of the interest subsidy. Nevertheless, intuition and experience implies that equations (18) and (19) apply as reasonable approximations and, furthermore, the approximations apply in a global sense. By comparison, the large number of variables with numerous qualitative relationships involved in these relationships suggests significant problems with objective econometric identification and makes the possibility of obtaining even plausible signs remote with estimation of ad hoc or flexible forms.

To illustrate the difference in performance of the approach of simply adding π_p and G_v to equation (23),

(20) $A_f = A_f(\pi_n, \pi_p, \pi_a, A_{f,-1}, G_v)$

compared to that in equations (16) and (17), both were used to estimate acreage response of wheat and of feed grains in the U.S. over the period 1962 to 1982 and then to forecast acreage in the 1983-1986 period. The results are given in Table 2. The results for equation (16) take the participation rate as exogenous whereas the results where the model is specified as equations (16) and (17) include forecasting errors for the participation rate as well.

In the case of feed grains, the ad hoc formulation leads to a much smaller standard error in the sample period than the structural form in (16) even though the structural form performs better than the ad hoc form in ex ante forecasting of the post-sample period. The model combining equations (16) and (17) obtains an even lower standard error. In the case of wheat, the structural form fits the sample data better than the ad hoc form and performs substantially better in ex ante simulation.

This superior performance of the structural model carries through when errors in forecasting the participation rate are also considered. The reason the structural form can outperform the ad hoc model even in the sample period is that nonlinearities and kinks in response over a wide range of policy parameters put a premium on global properties of the function. The participation rate over the sample period ranges from zero (a kink point) to near 90 percent in others. As a result, the effects of profits with and without compliance cannot be well represented by a smooth approximating function.

The Crop Demand Structure

Following numerous previous studies, the demand for crops is broken into food, feed, export, and inventory components for purposes of specification and estimation of a quarterly model. The inventory component is further broken into farmer owned reserve, government owned, and market components for crops with government programs. The demand system for a given crop is thus of the form

$$
\begin{aligned}
&Q_i = Q_i(P_m, X_i), \quad X_i = \{Q_{i,-1}, Y_c, T_j\} \\
&Q_f = Q_f(P_m, X_f), \quad X_f = \{Q_{f,-1}, F_j, P_j, T_j\} \\
&Q_x = Q_x(P_m, X_x), \quad X_x = \{Q_{x,-1}, E, T_j\} \\
(21)\quad &Q_r = Q_r(P_m, X_r), \quad X_r = \{Q_{r,-1}, P_s, P_r, r_m - r_g, D, T_j\} \\
&Q_g = Q_g(P_m, X_g), \quad X_g = \{Q_{g,-1}, P_s, D, T_j\} \\
&Q_m = Q_m(P_m, X_m), \quad X_m = \{Q_{m,-1}, Q_r, Q_g, r_m, D, T_j\} \\
&Q_{r,t-1} + Q_{g,t-1} + Q_{m,t-1} + A_t \cdot Y_a = Q_i + Q_f + Q_x + Q_r + Q_g + Q_m
\end{aligned}
$$

including the supply-demand identity where

Q_z = quantity demanded (i = industry or food, f = feed, x = export, r = farmer owned reserve, g = government stocks, m = market stocks)

P_m = market price

X_z = exogenous variables which determine the relevant demand

Y_a = actual average yield

Y_c = per capita consumer income

T_j = quarterly shift terms

F_j = numbers of various types of livestock on feed

P_j = prices of various types of livestock meat

E = trade weighted exchange rate

P_s = support price

P_r = release price

D = shift term reflecting the 1983 PIK program.

The demand system was not estimated in the form of (21) because a system that determines price through an identity equation tends to produce erratic price estimates particularly when demands are inelastic. Alternatively, a demand equation in (21) can be solved for price,

(22) $P_m = Q_i^{-1}(Q_i, X_i)$,

and then the identity can be used to determine Q_i. This approach suffers in practice because the coefficient estimates of exogenous variables in the inverted equation are susceptible to spurious correlations with other factors in the system. This can lead to an unreasonably large contribution of these variables relative to other exogenous variables in the system in determining price predictions in practice. The approach used in this study is to solve the system in (21) for a partial reduced form price equation which is then used to replace one of the demand equations in (21). This partial reduced form equation can be regarded as a convex combination of equations such as (22) which essentially produces a composite price forecasting equation in the sense of Johnson and Rausser where the weights are estimated simultaneously with the coefficients of the price equation. The number of such equations to combine in this manner is roughly determined by the tradeoff between increased forecasting accuracy of combining more forecasting equations and reduced identification as the total number of variables in the composite forecasting equation increases. See Just (1989) for a detailed specification and justification.

To capture the qualitative nature of government market involvement on the demand side, the government inventory demand equation is estimated including a qualitative relationship between market and support price. For example, the government inventory demand for feed grains equation is

$$Q_g = \underset{(0.32)}{.3873} + \underset{(7.62)}{.5838}\, Q_{g,-1} + \underset{(6.53)}{39.85}\, \max(0, (P_s - P_m)\phi)$$

$$+ \underset{(5.83)}{20.37} D - \underset{(-0.07)}{.1172} T_1 + \underset{(1.12)}{1.821} T_2 + \underset{(0.38)}{.5981} T_3$$

$R^2 = .898$, $\bar{R}^2 = .886$, DW = 0.96, Sample = 1973:1-1987:3

where variables are as defined above and t-ratios are in parentheses (see Just, 1989, for a complete definition of variables and data sources). This equation captures the qualitative relationship whereby whereby stocks are not turned over to the government until the market price falls to the government support level but are increasingly turned over as the market price falls below the support (note that only grain produced under voluntary compliance with the program is supported so the market price can fall below the support price). Here the price variable is highly significant as compared to standard cases where a continuous function of market and support prices is used as a term explaining government stocks (see, e.g., Rausser, 1985, where the price term is a ratio of support price to market price and an implicit t-ratio of 1.48 is obtained in an otherwise similar equation).

The Livestock Supply Structure

The supply of livestock accounts for the dynamic nature of breeding herd adjustment and the long lags in breeding and raising livestock to market weight. The basic form of the model for each species is as follows. First, a stock equation is included for the size of the national breeding herd of the form

$$(23)\quad H_i = H_i(P_c/P_i, H_{i,-1}, r_m, T_j)$$

where H_i is herd size for species i (e.g., i = cattle), P_c is the price of corn, P_i is the price of meat from species i (e.g., beef for i = cattle), and T_j represents quarterly shift terms. Next, an equation is included for numbers on feed of the form

(24) $F_i = F_i(H_{i,-k}, P_c/P_i, T_j)$

where k is the number of quarters required to reach feeding age in species i. Finally, a meat production equation is included of the form

(25) $M_i = M_i(F_i, H_i - H_{i,-1}, P_c/P_i, r_m, T_j)$

where M_i is the production of meat from species i. The term $H_i - H_{i,-1}$ is included to capture the addition to meat production caused by culling breeding herds.

The livestock production model consists of a set of equations similar to (23)-(25) for cattle, hogs, and poultry.

<u>The Meat Demand Structure</u>

The meat demand system is considered independently of the crop demand systems since meats and grains are not very closely related except as grain prices affect meat supply. Each demand equation is estimated in price dependent form with

$$P_i/Y = P_i(P_j/Y_c, P_o/Y_c, C_i/N, T_j)$$

where Y is per capita income, P_j represents prices of other meats (included individually), P_o is a price index for non-farm prices, C_i is domestic consumption of meat i, and N is population. The meat demand system is completed by net import/export equations of the form

$$I_i = I_i(P_i \cdot E, I_{i,-1}, E, T_j)$$

where I_i is net imports (negative for net exports) and E is a trade weighted exchange rate and identities of the form

$$M_i + I_i = C_i.$$

Policy Simulation Results

Using the model discussed above, several policy alternatives were simulated to determine the effects of major changes in farm commodity programs on the farm level prices of wheat and corn. The policy alternatives considered are as follows:

1. A reduction of 10 percent in price supports for wheat and corn (with corresponding changes in price controls for the farmer owned reserve).

2. An increase of 10 percent in price supports for wheat and corn.

3. A reduction of 10 percent in both price supports and target prices for wheat and corn.

4. An increase of 10 percent in both price supports and target prices for wheat and corn.

5. A reduction of the diversion requirement by 10 percent.

6. Maintaining the high diversion and support of 1983.

Short run impacts were investigated by simulating the changes beginning with the 1984 crop year for a period of two years assuming macroeconomic conditions are unaffected by the changes. Longer run impacts were simulated by simulating the changes over a 5 year period under the same assumptions regarding macroeconomic conditions. The adjustment of target and support prices is investigated in both directions because the qualitative nature of the model generates different types of changes in different directions. The results of the simulations are presented in Table 3 and Figure 1.

Consider first the impacts of changes in price supports alone. A simultaneous increase in price supports for both wheat and corn led to substantial increases in irrigated acreage. A 10 percent increase in price supports for wheat and corn (Scenario 2) would increase irrigated acreage by about 1.9 percent and pumping lift by an average of 0.5 percent in two years. Over 5 years, irrigated acreage would increase by 13.6 percent and pumping lift by an average of 3.6 percent. This occurs because an increase in price supports increased government demand for stocks, which in turn produces a rise in the free market price for corn. At the same time, participation in the wheat program is unaffected; in fact, it remains optimal for wheat growers to participate in every scenario except one. The net result of these changes in the wheat and corn markets is an increase in the profitability of corn relative to wheat, hence acceleration of groundwater depletion.

The fact that an increase in price supports accelerates irrigation adoption while making participation in the feed grains program suggests that a simultaneous increase in price supports and target prices for both crops would not have too much larger an impact than increasing support prices alone. Scenario 4 bears this out. A 10 percent increase in both price supports and target prices for wheat and corn increases irrigated acreage by 2.9 percent in the short run and 16.6 percent in the longer run, respectively 1 and 3 percentage points more than an increase in price supports alone,while pumping lift increases by an average of 0.8 percent in the short run and 4.4 percent in the longer run, respectively 0.25 and 0.77 percentage points more than an increase in price supports alone.

A simultaneous decrease in price supports for both crops (Scenario 1), on the other hand, would have a negligible effect on groundwater depletion. Irrigated acreage would actually increase slightly (0.2 percent) over 2 years, and then decrease slightly (0.2 percent) over 5 years. Pumping lift would follow the same pattern, increasing by 0.04 percent in 2 years and then decreasing by 0.06 percent in 5 years. This occurs because a reduction in price supports depresses the free market price of corn and therefore increases participation rates in the feed grains program. The target price, adjusted for diversion requirements, becomes the effective supply price for corn. Thus, the feed grains program mitigates any fall in the effective supply price for corn.

This logic suggests that a simultaneous decrease in price supports and target prices for both crops would have a much larger effect on irrigation adoption and groundwater depletion than a reduction in price supports alone. The results of Scenario 3 bear this out. A 10 percent reduction in both price supports and target prices for wheat and corn decreases irrigated acreage by 2.8 percent in the short run and 9.9 percent in the longer run, and pumping lift by an average of 0.8 percent in the short run and 0.3 percent in the longer run.

These findings highlight the importance of careful modeling of commodity programs, especially participation decisions. The asymmetry in responses to increases and decreases in price supports and target prices occurs because switches from participation to non-participation induced by changes in support levels reduce changes in effective supply prices to a considerable extent.

Scenario 5 shows the impact of reducing the diversion requirement by 10 percent. In the short run, the effect is roughly comparable to increasing the price supports for wheat and corn by 10 percent (scenario 2): irrigated acreage increases by 1.7 percent and pumping lift by an average of 0.5 percent. In the longer run, though, the impact is much smaller: irrigated acreage increases by only 7.9 percent and pumping lift by only 2.1 percent. This occurs because relaxing diversion requirements simultaneously makes participation more attractive and increases the effective supply price under participation. Because it is nearly always optimal for farmers to participate in the wheat program, the impact is greater for corn than wheat, meaning that irrigation adoption and groundwater depletion are accelerated.

It is widely believed that the combination of high support prices and high diversion requirements is a key factor in inducing adoption of intensified farming methods like irrigation. The effects of such a combination are explored in scenario 6. In the short run, diversion requirements appear to be quite effective in limiting adoption of irrigated farming and groundwater depletion: irrigated acreage increases by only 0.4 percent and pumping lift by an average of only 0.09 percent. In the longer run, though, irrigated acreage increases by 10.0 percent and pumping lift by an average of 2.7 percent, almost as much as under a 10 percent increase in price supports. This occurs because the high support price and high diversion requirements increase the free market price of corn, reducing participation. Participation in the wheat program remains unaffected; however, the effective supply price for wheat actually declines slightly, increasing the attractiveness of corn and therefore irrigation adoption and groundwater depletion.

Conclusions

In recent years, a growing number of economists have argued that commodity programs have exacerbated natural resource and environmental quality problems of agriculture by accelerating the use of intensive agricultural technologies such as pesticides, fertilizers and irrigation. To date, though, there has been little empirical evidence regarding the potential magnitude of the impacts of commodity programs on agricultural natrual resources such as groundwater quantity and quality, pest resistance or environmental loadings of pesticides.

This paper presents some empirical evidence about the impact of commodity programs on groundwater depletion in the northern Ogallala Aquifer. We show that increases in target prices and price supports produce sizeable increases in the adoption of irrigation and therefore groundwater depletion. Interestingly, high price supports coupled with more stringent diversion requirements increase irrigation and groundwater depletion substantially in the longer run, bearing out quantitatively previous conjectures that efforts at supply control give farmers a strong incentive to increase yields by intensifying cultivation.

Overall, the results demonstrate that there is profound interaction between farm commodity programs and the depletion of natural resources such as groundwater stocks, hence that the potential gains from greater coordination between agricultural and resource policies are substantial.

Heterogeneity, targeted as crucial by Antle and Just eslewhere in this volume, was also seen to be important: Adoption and groundwater depletion patterns differed significantly across land quality. Although these differences were not addressed in the empirical analysis, it is clear from the structure of the empirical models that depletion problems will be more acute in some areas and of less urgency in others. This variability raises the question of interactions between different levels of government, i.e., of jurisdiction, discussed by Cummings and Harrison elsewhere in this volume. Groundwater depletion is managed at the local level in Nebraska; yet the programs considered here, as well as the problem of management of the Ogallala Aquifer, are national in scope. Heterogeneity thus complicates both the analysis and the problems of coordination among government agencies.

An equally important lesson is that changes in farm program parameters do not necessarily have simple, straightforward effects on resource use. In the case considered here, changes in farm program parameters operated through a variety of mechanisms, including changes in free market prices, profitability under participation and participation decisions. This implies that research in this area needs to focus on the real pathways through which commodity programs affect resource use, that is, that the models used much capture the structure of the interactions between farm programs and resource use. It also implies that policy must bear these structural interactions in mind, that is, that policies aimed at addressing both agricultural and resource concerns must be designed with an eye toward detail and and understanding of the roundabout impacts of program specifications.

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Table 1

Estimated Coefficients of the Irrigation Adoption Model

Independent Variable	Estimated Coefficient	T-Statistics
Constant	-2.329865	4.19
Pumping Lift	-0.00344957	3.29
Water Holding Capacity	0.332371	8.16
Center Pivot Cost	-0.015861	1.03
Corn Profit	0.00166884	1.64
Wheat Profit	-0.00165613	1.39
R^2	0.2460	
$\bar{R}^2$	0.2335	

* Significantly different from zero at the 1 percent level.

** Significantly different from zero at the 10 percent level.

Table 2

The Performance of Structural Versus Ad Hoc Models:
The Case of U.S. Wheat and Feed Grain Acreage[a]

Crop	Model Definition (Equation)	Estimation Period	Forecast Period	Standard Error Within Sample (million acres)	Standard Error Post-Sample (million acres)
Wheat	(20)	1962-82	1983-86	4.41	14.90
Wheat	(16)	1962-82	1983-86	3.32	6.21
Wheat	(16),(17)	1962-82	1983-86	b	9.07
Feed Grain	(20)	1962-82	1983-87	1.73	6.40
Feed Grain	(16)	1962-82	1983-87	6.26	6.38
Feed Grain	(16),(17)	1962-82	1983-87	b	5.50

[a] See the text for equations which define the various models.
[b] No within sample error is computed since the model is derived by combining the estimated equations corresponding to (16) and (17).

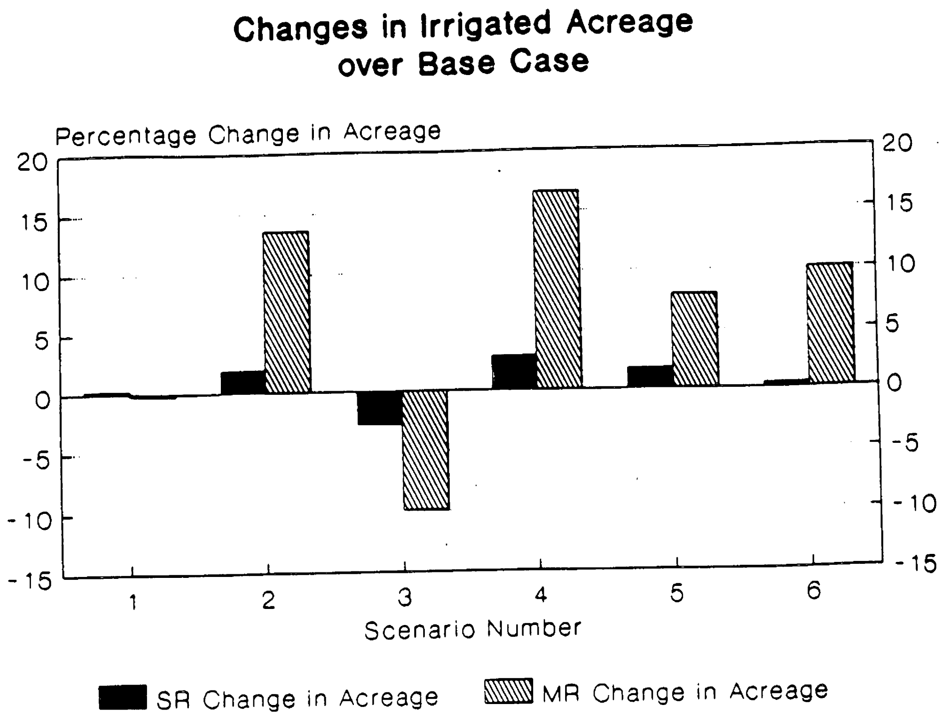
Table 3

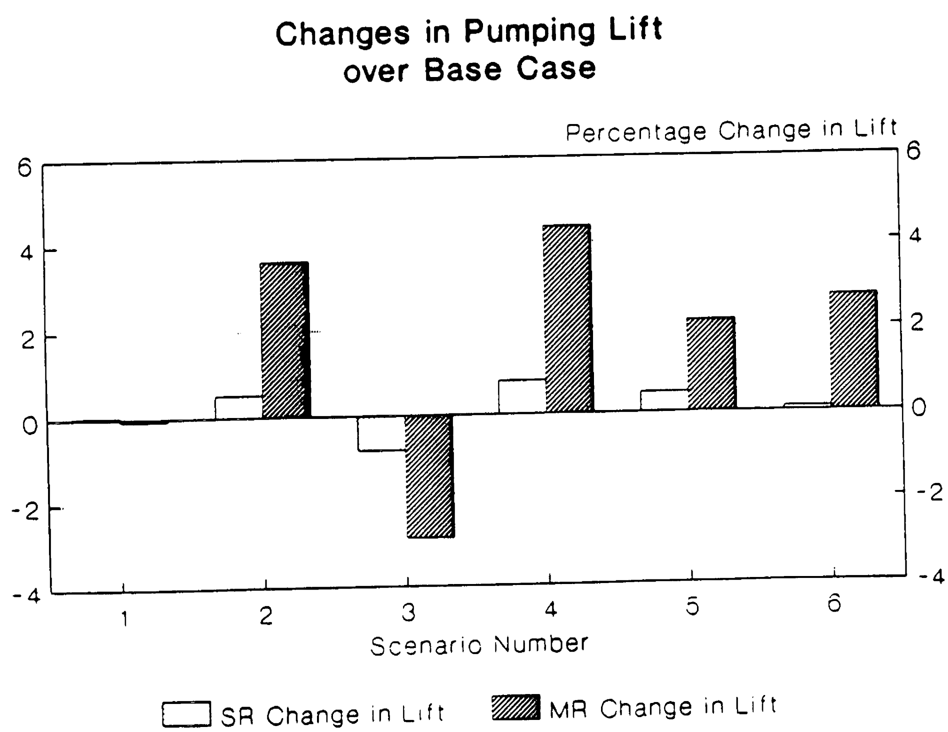
Results of Policy Simulations

Case	Effective Price of Wheat (Dollars per bushel)			Effective Price of Corn (Dollars per Bushel)			Irrigated Acreage		Average Pumping Lift (Feet)	
	1984	1985	2004	1984	1985	2004	1985	2004	1985	2004
Base	3.8354	3.7949	3.7700	3.1600	2.8719	2.8527	710,066	701,561	123.59	125.82
1	3.8341	3.7932	3.7569	3.0737	2.8714	2.8527	711,209	711,208	126.25	125.75
2	3.8366	4.0125	4.8647	3.2495	3.0950	4.0869	723,757	796,816	126.85	130.27
3	3.5961	3.4882	3.4168	3.0542	2.5992	2.0187	690,377	632,134	125.23	122.28
4	4.1304	4.1022	5.6325	3.2652	3.1449	4.5065	730,475	818,173	127.17	131.20
5	4.0164	3.9877	4.7115	3.1323	3.0290	3.6735	722,443	757,055	126.79	128.46
6	4.0964	4.0431	4.0313	3.1600	2.9946	3.6475	712,554	772,019	126.31	129.16

Case 1 - Ten percent reduction in price supports for wheat and corn.
Case 2 - Ten percent increase in price supports for wheat and corn.
Case 3 - Ten percent reduction in price supports and target prices for wheat and corn.
Case 4 - Ten percent increase in price supports and target prices for wheat and corn.
Case 5 - Ten percent reduction in diversion requirements.
Case 6 - High diversion requirements and support of 1983.

Figure 1


Changes in Irrigated Acreage
over Base Case
Percentage Change in Acreage
20
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
Scenario Number
SR Change in Acreage
MR Change in Acreage


Changes in Pumping Lift
over Base Case
Percentage Change in Lift
6
4
2
0
-2
-4
1
2
3
4
5
6
Scenario Number
SR Change in Lift
MR Change in Lift