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by

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AN EQUILIBRIUM MODEL OF DISTRIBUTIONAL EFFECTS OF LAND CONTROLS IN AGRICULTURE

The agricultural industry is often cited as a classic example of a competitive market. The observed performance of such markets, however, is the result not only of competitive forces but also of governmental intervention. Such intervention is often motivated by equity or distributional concerns. Typically, the impact of such governmental intervention is evaluated only in terms of output markets (G. E. Brandow). Such investigations are grossly inadequate since governmental policies impinge directly on asset as well as flow markets for both inputs and outputs. In general, the distributional consequences depend upon the ownership, utilization, quality, and technology associated with the assets.

This paper develops a framework for capturing the distributional implications of governmental intervention in the agricultural sector recognizing its most important features. These features include (1) inelastic domestic demand, (2) competitiveness, (3) asset fixity, (4) rapid technological change, (5) variable asset qualities, (6) institutional limits to credit availability, and (7) partial separation of asset ownership and utilization. The first four features are documented by Theodore Schultz, Willard Cochrane, and Glenn Johnson. Theodore Schultz has also called attention to the large differences in the rates of return to resources among regions as well as across producers. Much of this variation emanates from differences in production techniques, land quality, human capital, and wealth controlled by individual producers. The limitations of credit availability for producers of different size classes have been noted by recent empirical evidence. This evidence strongly suggests that larger farmers borrow more; they borrow more to invest in capital; and their ability to borrow more stems, in part, from their higher repayment capacity (C. B. Baker; Olin Quinn; Chris Riboud).[1]

In the evaluation of governmental intervention, land and rental markets, along with tenant arrangements, must be given special attention. Over the last decade, there has been a rapid escalation in farmland prices.[2] This rapid appreciation has been associated with another emerging phenomenon, namely, the disruption of the traditional unity between ownership and operation of farm units.

A specification of the agricultural production structure, which admits all of the special features noted above, is the so-called putty-clay framework (Leif Johansen; W. E. G. Salter). This framework recognizes the technically embodied capital available for adoption by farmers. Moreover, at least some of the "new" capital is indivisible which, in turn, leads to unequal degrees of return to scale in using the new technology for large- versus small-scale producers. Particularly in the case of machinery, these capital goods are often specialized to the extent that their input-output ratios cannot be altered. Of course, prior to investment decisions, producers can select an alternative technology described by conventional neoclassical production functions.[3]

Over the post-World War II period, governmental intervention in agriculture has assumed a number of alternative forms. These forms include price supports, accumulation of public stocks, acreage set-asides and diversions, deficiency payments, diversion payments, stockholding subsidies, and target prices under both mandatory and voluntary participation. Governmental programs have focused on wheat, feed grains, cotton, and rice as well as a number of other commodities.

Unfortunately, little in the way of concrete results--conceptual or empirical--are available. As for the distributional implications of these policies, Bruce Gardner has noted: "The current state of affairs, in sum, is that agricultural economists have not been able convincingly to establish a connection one way or the other between policy and the structure of agricultural production . . . ." (page 842).

The analysis which follows introduces a framework for investigating the influence of governmental intervention on the structure of agricultural production. The framework is sufficiently general to determine the effects of both mandatory and voluntary governmental programs under which producers are required to divert or set aside some portion of their available land (asset control) and possibly receive as an incentive a subsidy or diversion payment. The policy variables, acreage set-asides or land retirement programs, and associated subsidies have been the key elements in land-use related governmental programs over the last two decades.[4] These forms of intervention have been instituted principally in the United States, Canada, and Australia. The distributional implications of such programs depend not only on the typically examined output markets but, as well, upon land and rental markets. These implications will be drawn by noting the limitations of rural credit markets along with the importance of technological change. The heterogeneity of agricultural production is explicitly recognized by allowing variations in land quality across producers as well as for a particular production unit.[5]

I. Putty-Clay Agricultural Production

In general, the distributional implications of agricultural policy depend on farm size, land quality, equity, capital, and existing technology. Assume an agricultural sector consisting of I farms denoted by indexes, $i = 1, \ldots, I$. To reflect the distribution of farm size and land quality, let $L_i = (L_{i1}, \ldots, L_{iJ})'$ represent acreage endowments of qualities $j = 1, \ldots, J$ owned by farm i at the beginning of a production period. Before implementing production decisions, a producer may choose either to buy additional land or sell existing land. Thus, let $\Delta L_i = (\Delta L_{i1}, \ldots, \Delta L_{iJ})'$ be a vector representing the change in ownership of various land qualities ($\Delta L_{ij} > 0$ represents net purchases and $\Delta L_{ij} < 0$ represents net sales). In addition, the farmer may choose to augment his landholdings for the duration of the production period by renting additional land from external sources represented by $Z_i = (Z_{i1}, \ldots, Z_{iJ})$ where $Z_{ij} < 0$ corresponds to leasing some of his own land to another farmer.

In this context the vector A_i of acreages of various qualities utilized by farm i in crop production must satisfy

(1) $$0 \leq A_i \leq L_i + \Delta L_i + Z_i$$

and, of course, the farmer can neither sell nor lease to another farmer more land than is actually owned,

(2) $$\Delta L_i \geq -L_i$$

(3) $$Z_i \geq -L_i - \Delta L_i.$$

To consider the distribution of capital stock and technology in the industry, suppose there are S_0 types of existing technologies in the industry, and every farm's existing technology, S_i^0, may be classified into one of these types denoted by $s = 1, \ldots, S_0$. The technology type thus specifies the complete machinery complement, structures, etc. In addition, with the new production period, $S_1 - S_0$ new technologies become available. Following the putty-clay approach, a farm may continue operating with its existing technology or incur costs of investment k_s in adopting a new technology s, $s = S_0 + 1, \ldots, S_1$ (for simplicity, assume $k_s = 0$ for $s = 1, \ldots, S_0$).[6] The cost of new technological investments attributable to the present production period is thus γk_s where γ reflects the cost of capital and depreciation and, thus, appropriately "annualizes" the relevant investment value.

Moreover, following the putty-clay assumption, each technology is associated with fixed input-output coefficients which may be arrayed in an L x J matrix H_s where elements $H_{s\ell j}$ denote the amount of variable input ℓ required per acre of type j land using technology s. In addition, each technology is associated with a 1 x J vector of productivities, y_s, where elements y_{sj} define the yield per acre on land of type j under technology s. And, finally, each technology is associated with a linear capacity constraint, $\tilde{c}_s A_i \leq b_s$, which may be rewritten without loss of generality as

$$c_s A_i \leq 1 \tag{4}$$

where $c_s = (c_{s1}, \ldots, c_{sJ})$ is a 1 x J vector of constraint coefficients. For example, c_{sj} reflects the maximum of type j land that can be farmed with technology s (e.g., with machine sizes specified by technology s). In addition, the constraint implies that capacity utilization may be substituted proportionally between land types. Of course, realistically, capacity may be doubled by purchasing twice as much machinery, buildings, etc. (incurring investment costs $2k_s$), but this may be simply represented as an alternative technology, $s' \neq s$.

Assuming a competitive industry, each farm regards its output price P and the vector of input prices $V = (V_1, \ldots, V_L)$ as given.[7] Thus, with technology s, total revenue from the sale of production is $Py_s A_i$, and variable costs of production (excluding rental expense) are $\mu_s A_i$ where $\mu_s = VH_s$ is a vector of average costs per acre. Suppose, also, that the land and rental markets are competitive with respect to 1 x J price vectors, $W = (W_1, \ldots, W_J)$, and $R = (R_1, \ldots, R_J)$ corresponding to the various land types. Thus, the net investment in new land is $W\Delta L_i$, and net rental expense is RZ_i.

Now further suppose each farmer expects land to appreciate and has a subjective expectation of land prices W_i^* at the end of the production period. Expected capital gains on landholdings are thus given by $[W_i^* - (1 + \theta) W] (L_i + \Delta L_i)$ where θ is the effective interest rate on the farmer's land investment (including opportunity cost on land held free of debt). In this context, suppose the farmer has a myopic objective for the present production period of maximizing his total gains π_i defined by the sum of short-run profits less the annualized cost of new capital investments plus capital gains from land appreciation,[8]

$$\pi_i = (Py_s - \mu_s) A_i - RZ_i - \gamma k_s + [W_i^* - (1 + \theta) W] (L_i + \Delta L_i). \tag{5}$$

Finally, to reflect the role of equity in allowing farms to capitalize on opportunities offered or encouraged by new policies to expand landholdings or upgrade technologies, assume that the industry does not have access to a perfect capital market. Suppose that farms have different credit lines available to them, possibly depending on their equity, management, etc. Let m_i represent the total funds available to farm i at the beginning of the production period including both internal liquidity and external credit. Then the new investment in land and alternative technologies must satisfy

(6) $$k_s + W\Delta L_i \leq m_i.$$

The farmer's myopic decision problem thus becomes maximization of π_i in (5) subject to the constraints in (1), (2), (3), (4), and (6). The farmer's decision involves choice of a production technology, the quantities of output and inputs including land rental, and land portfolio adjustment. For conceptual purposes, the decision problem may be broken into two stages. First, optimal production plans and land transactions can be determined by linear programming for a given technology, i.e.,

(7) $$\max_{A_i, Z_i, \Delta L_i} \pi_i,$$

subject to constraints (1), (2), (3), (4), and (6). Suppose the resulting decisions, which are functions of P, R, V, and W, are denoted by A_i^*, Z_i^*, and ΔL_i^*, and let the resulting maximum under technology s be denoted by $\pi_i(s)$. The optimal technology is then found by maximizing over s,

(8) $$\max_{s \in \mathcal{S}_i} \pi_i(s),$$

where $\mathcal{S}_i = (s_i^0, S_0 + 1, S_0 + 2, \ldots, S_1)$ is the set of potential technology choices for farm i. Let the optimal technology choice from the problem in (7), which is also a function of prices P, R, V, and W, be denoted by η_i^*.

Given the above framework for each individual farm, the farm responses can be simply aggregated into market relationships. Each farm's output supply curve for given input, rental, and land prices is $y_{\eta_i^*} A_i^*$; hence, market supply is $X^S(P) = \Sigma_{i=1}^{I} y_{\eta_i^*} A_i^*$. Letting $X^D(P)$ represent market demand for agricultural output ($X^{D'} < 0$), the market equilibrium condition is thus

(9) $$X^D(P) = \sum_{i=1}^{I} y_{\eta_i^*} A_i.$$

Similar equilibrium conditions can also be developed for input markets, but they are not given here explicitly since the results in the remainder of this paper are derived assuming fixed input prices (elastic input supply).

While input and output prices are determined by the interaction of the agricultural sector with external forces from the rest of the economy, the prices and rental rates of land are determined internally. For example, for given input and output prices and given rental rates, an individual farm's demand for lands of various types (supply if negative) is $\Delta L_i^*(W)$, which is a function of land prices according to the above optimization problem. Supply is equal to demand for each type of land, and equilibrium prevails in the industry only if

(10) $$\sum_{i=1}^{I} \Delta L_i^*(W) = 0.$$

Similarly, the demand for rental land of various types (supply, if negative) is given by $Z_i^*(R)$ for given prices of land, other inputs, and output. The rental markets are thus in equilibrium only if

(11) $$\sum_{i=1}^{I} Z_i^*(R) = 0.$$

II. Diversion-Payment and Acreage-Control Instruments

Consider now the role of agricultural policy instruments corresponding to diversion policies. Specifically, consider the introduction of voluntary acreage controls and diversion payments. Suppose a farmer has the option of either diverting or not diverting a fraction, $1 - \omega$, of the land he farms (including rented land). If he diverts $1 - \omega$ of his land, he receives a payment for normal production on the nondiverted land. Since the payment is based on regional average yields, he receives a payment of $\tilde{P}$ per acre of nondiverted land where $\tilde{P}$ is based on a payment rate per acre and normal average yields for the region. If the farmer does not comply and divert $1 - \omega$ of his land, then he receives only the market price. Let λ_i be a dichotomous decision variable where $\lambda_i = 1$ corresponds to compliance with the diversion program and $\lambda_i = 0$ corresponds to noncompliance. The farmer's decision problem for a given technology choice in (7) thus becomes[9]

(12) $$\max_{\lambda_i, A_i, Z_i, \Delta L_i} \tilde{\pi}_i(s) = [Py_s + \tilde{P}\lambda_i \, e - \mu_s] \, A_i - RZ_i - \gamma k_s + [W_i^* - (1 + \theta) \, W] \, (L_i + \Delta L_i)$$

subject to

(13) $$\lambda_i \, e \, [\omega \, (L_i + \Delta L_i + Z_i) - A_i] \geq 0$$

and the constraints in (1), (2), (3), (4), and (6) where $e = (1, 1, \ldots, 1)$ is a 1 x J row vector.

III. Individual Firm Behavior Under Diversion Policy

In the context of the above problem, the effects of agricultural policy on individual farm behavior can be examined by comparing the results of compliance with noncompliance using the results of the Appendix. To facilitate the discussion, definitions of three quantities of land are important: owned land ($L_i + \Delta L_i$), controlled land ($L_i + \Delta L_i + Z_i$), and utilized land (A_i). In the case of utilized land, the relevant shadow value is

$$\text{(14)}\quad \phi_{1ji} = \begin{cases} Py_{sj} + \tilde{P}\lambda_i - \mu_{sj} - \phi_{4i}\, c_{sj} - \phi_{6i}\, \lambda_i > 0 & \text{if } A_{ij} = L_{ij} + \Delta L_{ij} + Z_{ij} \\ 0 & \text{if } A_{ij} < L_{ij} + \Delta L_{ij} + Z_{ij}. \end{cases}$$

Thus, if type j land is utilized, then from (A.33)

$$\text{(15)}\qquad R_j = Py_{sj} + \tilde{P}\lambda_i - \mu_{sj} - \phi_{4i}\, c_{sj} - \phi_{6i}\, \lambda_i\, (1 - \omega)$$

while, if it is not utilized, then from (A.34)

$$\text{(16)}\qquad R_j = \phi_{6i}\, \lambda_i\, \omega.$$

Solving (15) for ϕ_{4i}, the quasi rent to technology, and noting that this rent measure will exceed program net returns $[Py_{sj} + \tilde{P}\lambda_i - \mu_{sj} - \phi_{6i}\, \lambda_i\, (1 - \omega)]$ less the rental rate adjusted for the capacity measure $1/c_{sj}$ for all types of land which are not utilized obtains

$$\text{(17)}\qquad \phi_{4i} = \max \left\{ \max_j \left[\frac{Py_{sj} + \tilde{P}\lambda_i - \mu_{sj} - \phi_{6i}\, \lambda_i\, (1 - \omega) - R_j}{c_{sj}} \right], 0 \right\}.$$

If the first term on the right-hand side of (17) is negative for all land types, then $\phi_{4i} = 0$ and no land is utilized. In the case of noncompliance ($\lambda_i = 0$), ϕ_{4i} is simply the maximum profit (returns to land minus rental payments) per unit of capacity over all types of land controlled by the farm.[10]

To further interpret ϕ_{4i} for the case of compliance ($\lambda_i = 1$), note from (A.33) and (A.34) that $\phi_{6i} \leq (R_j - \phi_{1ji})/\omega$ for all j where $\phi_{1ji} \geq 0$. Thus, $\phi_{6i} \leq R_j/\omega$ for all j. But the diversion requirement cannot be satisifed unless some land is controlled but not utilized ($A_{ij} < L_{ij} + \Delta L_{ij} + Z_{ij}$); clearly, from (17), $\phi_{6i} = R_j/\omega$ for some land type j and, hence,

(18) $$\phi_{6i} = \min_j \left\{ \frac{R_j}{\omega} \right\}.$$

Thus, the farm will divert only land with the lowest rental rate. The shadow price of diversion is the rental rate on diversion quality land[11] adjusted upward by a factor reflecting the proportional amount of land for which the marginal diversion acre satisfies the diversion requirement.

Turning to land transactions, (A.33) and (A.34) of the Appendix imply that the gain from either controlling or leasing out land of type j is equal to the market rental fee. This result, along with relationships (A.31) and (A.32), reveals that land of type j will be held if the expected capital gains from ownership, plus the gains from controlling the land (represented by R_j), are equal to the opportunity cost of the credit constraint, i.e.,

(19) $$\Delta L_{ij} \begin{cases} > -L_{ij} & \text{if} \quad W^*_{ij} - (1 + \theta)\, W_j + R_j = \phi_{5i}\, W_j \\ = -L_{ij} & \text{if} \quad W^*_{ij} - (1 + \theta)\, W_j + R_j < \phi_{5i}\, W_j . \end{cases}$$

The opportunity cost or shadow price of credit may be determined from

$$\phi_{5i} = \max \left\{ \max_j \left[\frac{W^*_{ij} - W_j + R_j}{W_j} - \theta \right], 0 \right\}; \tag{20}$$

i.e., if any land is held, ϕ_{5i} is the expected rate of return on land minus the rate of interest.

The above results on rental rates, (15)-(18), and land transactions, viz., $W^*_{ij} - (1 + \theta) W_j = \phi_{5i} W_j - R_j$ for held land, allow a useful simplification of the criterion function (12). That is, substituting these results into (12) for the land types where not all land is rented out and not all land is sold and using (18) with $\bar{R} = \min_j R_j$ leads to

$$\pi_i(s) = \phi_{4i} + \lambda_i \bar{R} \frac{1 - \omega}{\omega} eA_i - R (L_i + \Delta L_i + Z_i - A_i) \tag{21}$$

$$+ \phi_{5i} W (L_i + \Delta L_i) - \gamma k_s.$$

Note that, since $L_i + \Delta L_i + Z_i - A_i$ is a vector of diverted acreages and $\bar{R}$ applies to all types of land which are diverted, the third term on the right-hand side of (21) is $\bar{R}$ times total diverted acreage if $\bar{R} > 0$. However, since $[(1 - \omega)/\omega] eA_i$ is also total diverted acreage, the sum of the second and third terms of (21) vanishes. Hence,

$$\pi_i(s) = \phi_{4i} - \gamma k_s + \phi_{5i} W (L_i + \Delta L_i) \tag{22a}$$

or, using (A.26) and (A.27), it is evident that either $\phi_{5i} = 0$ or the credit constraint in equation (6) holds in strict equality; therefore, (22a) can be rewritten as

$$\pi_i(s) = \phi_{4i} - (\gamma + \phi_{5i}) k_s + \phi_{5i} (WL_i + m_i). \tag{22b}$$

Equation (21) implies that the overall gains for the farm are made up of two components, viz., $\phi_{4i} - \gamma k_s$ represents the gains from operation and ϕ_{5i} W $(L_i + \Delta L_i)$ represents the gains from wealth (in landholdings).

IV. Market Equilibrium Under Diversion Policy: The Case of Fixed Technology

To examine the distributional implications of diversion policy and the performance of markets, assume initially that firms do not have the opportunity of adopting new technology. Hence, every farm operates with its existing technology s_i^0. Moreover, for the sake of simplicity and without loss of gererality, assume the capacity of each technology is independent of the land quality utilized, i.e., $c_{sj} = c_s$, for all s_{ij}. Finally, the total amount of land available of quality j is presumed fixed at L_j.

The assumption of fixed technology implies that, along with a fixed amount of available land of quality j [as equation (27) suggests], land utilization and associated gains from operations can be treated separately from landownership and its associated gains. The component k_s is zero, and thus the link between landownership and land utilization is eliminated. In other words, the trade-off between land transactions and capital good investment does not exist. Given a perfect rental market, the optimal land utilization will involve the maximization of industry gains from operation. This can be shown by comparing the equilibrium conditions derived from individual firm behavior and conditions obtained from industry maximization of gains from operation.

A. *Firm Land-Use Equilibrium Conditions*

The key determinant of the equilibrium is the degree of compliance. The conditions for compliance are summarized in Proposition 1.

PROPOSITION 1: *The key determinants of compliance are the diversion payment per diverted acre,* $[\omega/(1 - \omega)]\,\tilde{P}$, *and the minimum rental rate,* $\bar{R}$. *Specifically, for full compliance,* $[\omega/(1 - \omega)]\,\tilde{P} > \bar{R}$; *for partial compliance,* $[\omega/(1 - \omega)]\,\tilde{P} = \bar{R}$; *and for no compliance,* $[\omega/(1 - \omega)]\,\tilde{P} < \bar{R}$.

PROOF:

Introducing (18) into (17) obtains

$$(23)\qquad \phi_{4s} = \max\left\{\max_{j,\lambda_i}\left[\frac{Py_{sj} - \mu_{sj} - R_j + \lambda_i\left(\tilde{P} - \frac{1-\omega}{\omega}\bar{R}\right)}{c_s}\right],\ 0\right\}.$$

Since λ_i is a choice variable, $\lambda_i = 1$ for all i if $\tilde{P} > (1 - \omega)/\omega\,\bar{R}$, while $\lambda_i = 0$ for all i if $\tilde{P} < (1 - \omega)/\omega\,\bar{R}$. Hence, λ_i will be selected in accordance with the largest value of ϕ_{4i}. The participation decision is given by

$$(24)\qquad \lambda_i(s) = \begin{cases} 1 & \text{if} \quad \tilde{P} \geq \frac{1-\omega}{\omega}\bar{R} \\ 0 & \text{otherwise.} \end{cases}$$

For $\tilde{P} = (1 - \omega)/\omega\,\bar{R}$, each farmer will be indifferent between compliance and noncompliance which will generally result in partial compliance.

The case of no compliance is, of course, of little relevance to our analysis. Hence, we shall investigate the cases of partial and full compliance for a given P. To examine the equilibrium conditions for these two cases, note first that firms with the same technology for land quality j are indistinguishable. Thus, they can be treated as a single aggregate, viz., the total land of quality j employing technology s is defined by

$$\tilde{A}_{sj} = \sum_i A_{isj} \tag{25}$$

where A_{isj} refers to land of type j utilized by firm i with technology s. Since the capacity of each technology is independent of land quality, the aggregate defined in (25) is constrained by

$$\sum_j \tilde{A}_{sj} \leq N_s \frac{1}{c_s}, \qquad s = 1, \ldots, \bar{S} \tag{26}$$

where N_s is the number of firms employing technology s. Similarly, $\phi_{4s} = \phi_{4is}$; and since ϕ_{4s} is the dual value for the capacity constraint for each firm employing technology s,

$$\phi_{4s}\left(\frac{N_s}{c_s} - \sum_j \tilde{A}_{sj}\right) = 0. \tag{27}$$

To admit the effects of diversion policy, define the amount of land-type j diverted as $\tilde{A}_{0j}$. Since all the land is either utilized or diverted,

(28) $$\sum_{s=0}^{S_0} \tilde{A}_{sj} = L_j;$$

and similar to (13) for individual farms, the aggregate limit on diversion is

(29) $$\sum_j \tilde{A}_{0j} \leq (1 - \omega) \sum_j L_j.$$

Thus, using Proposition 1 in the cases of partial and full compliance obtains immediately

(30) $$\left\{(1 - \omega) \sum_j L_j - \sum_j \tilde{A}_{0j}\right\} \left\{\tilde{P} - \frac{1 - \omega}{\omega} \bar{R}\right\} = 0.$$

To complete the statement of firm land-use equilibrium conditions, introduce (18) into (14) and (15) and use the assumption of at least partial compliance, $\tilde{P} - (1 - \omega)/\omega \, \bar{R} \geq 0$, to obtain

(31) $$Py_{sj} - \mu_{sj} + \tilde{P} - \frac{1 - \omega}{\omega} \bar{R} - R_j - \phi_{4s} c_s \leq 0,$$

(32) $$\tilde{A}_{sj} \left[Py_{sj} - \mu_{sj} + \left(\tilde{P} - \frac{1 - \omega}{\omega} \bar{R}\right) - R_j - \phi_{4s} c_s\right] = 0.$$

Conditions (26) and (27)-(32) determine the firm land-use equilibrium values of R_j, $\bar{R}$, ϕ_{4s}, and $\tilde{A}_{sj}$ $(s = 0, \ldots, S_0;\ j = 1, \ldots, J)$ for a given P. This equilibrium can be easily determined from the following proposition.

PROPOSITION 2: *The firm land-use equilibrium (26) and (27)-(32), for a given output price maximizes industry total gain from utilization and diversion, where diversion is treated as an additional technology, i.e., the land-use equilibrium satisfies*

(33)
$$\max \sum_j \left\{ \sum_{s=1}^{S_0} (Py_{sj} - \mu_{sj}) \tilde{A}_{sj} + \tilde{P} \frac{1-\omega}{\omega} \tilde{A}_{0j} \right\}$$

subject to the constraints:

(34)
$$\sum_j \tilde{A}_{0j} \leq (1-\omega) \sum_j L_j$$

(35)
$$\sum_j \tilde{A}_{sj} \leq N_s \frac{1}{c_s}, \qquad s = 1, \ldots, S_0$$

(36)
$$\sum_{s=0}^{S} \tilde{A}_{sj} = L_j, \qquad j = 1, \ldots, J.$$

PROOF:

Define α_0, α_s, and δ_j as the shadow values associated with (34), (35), and (36), respectively. The resulting first-order conditions for (33)-(36) are

(37)
$$\alpha_0 \left[(1-\omega) \sum_j L_j - \sum_j \tilde{A}_{0j}\right] = 0$$

(38)
$$\alpha_s \left(\frac{N_s}{c_s} - \sum_j \tilde{A}_{sj}\right) = 0$$

(39)
$$\delta_j \left(L_j - \sum_s \tilde{A}_{sj}\right) = 0$$

(40)
$$Py_{sj} - \mu_{sj} - \delta_j - \alpha_s \leq 0$$

(41)
$$\tilde{A}_{sj} \left(Py_{sj} - \mu_{sj} - \delta_j - \alpha_s\right) = 0$$

(42)
$$\tilde{P} \frac{\omega}{1-\omega} - \delta_j - \alpha_0 \leq 0$$

$$\tilde{A}_{0j}\left(\tilde{P}\,\frac{\omega}{1-\omega} - \delta_j - \alpha_0\right) = 0. \tag{43}$$

To establish the equivalence between aggregate firm behavior and the programming solution, the following identities are needed:

$$\alpha_s = \phi_{4s}\, c_s \tag{44}$$

$$\delta_j = R_j - \left(\tilde{P} - \frac{1-\omega}{\omega}\,\bar{R}\right) \tag{45}$$

$$\alpha_0 = \omega\left[\tilde{P} - \frac{1-\omega}{\omega}\,\bar{R}\right] \tag{46}$$

and

$$\bar{\delta} = \frac{1}{\omega}\,\bar{R} - \tilde{P} \tag{47}$$

where $\bar{\delta}$ is the shadow price, δ_j, for which $\tilde{A}_{0j} > 0$. The conditions (34)-(43) are satisfied by the firm land-use equilibrium (26)-(32). Conditions (34), (35), and (36) are identical to equilibrium conditons (29), (26), and (28), respectively. Introducing (46) into (30) obtains (37); introducing (44) into (27) yields (40); (39) is implied by (28); introducing (44) and (45) into (31) results in (40); introducing (44) and (45) into (32) implies (41); and introducing (45)-(47) into $\tilde{A}_{0j}\,[\bar{R} - R_j]$ and noting by construction that $R_j \geq \bar{R}$ verifies conditions (42) and (43).

The equivalence between the firm land-use equilibrium and the linear programming formulation can be easily established for $\delta_j > 0$, at least when $\tilde{A}_{0j} > 0$ and the equilibrium solution exists by noting that the optimal linear programming solution will lead to an optimal solution to the equilibrium problem. This can be shown by solving (42)-(46) in terms of R_j, $\bar{R}$, and ϕ_{4s} and performing the needed substitutions.[12]

B. *Changes in Diversion Policies*

Proposition 2 allows analysis of the impacts of changes in diversion payments and requirements on total diversion, output, rental rates, and gains from operation in the context of the simplified linear programming framework. In this analysis an explicit representation of the dual to (33)-(36) will prove useful. The dual problem is:

$$\text{(48)} \qquad \text{Min} \sum_{j=1}^{J} L_j \delta_j + \sum_{s=1}^{S_0} N_s \alpha_s + \alpha_0 (1 - \omega) \sum_{j=1}^{J} L_j$$

subject to

$$\text{(49)} \qquad \delta_j + \alpha_s \geq Py_{sj} - \mu_{sj}$$

$$\text{(50)} \qquad \delta_j + \alpha_0 \geq \tilde{P} \frac{\omega}{1 - \omega} .$$

First, consider the impact of changes in $\tilde{P}$ on total diversion measured by $T = \Sigma_{j=1}^{J} \tilde{A}_{0j}$ for a given P. An increase in $\tilde{P}$ will augment the value of $\tilde{A}_{0j}$ in the primal. Under partial compliance, this increase will result in larger diversion while under full compliance, of course, no effect will be registered on diversion.

The impact of increased diversion payments under a state of partial participation can be captured by the use of the dual representation, (48)-(50). For partial participation prior to the increase in diversion payments, the initial level of the shadow price α_0 is 0. Hence, from (49) and (50), it follows that all land-technology combinations for which the return, $Py_{0j} - \mu_{sj}$, is smaller than the payment for diverted land, $\tilde{P}\ \omega/(1 - \omega)$, will not be utilized (i.e., $\tilde{A}_{0j} = 0$). Given a nonbinding aggregate diversion limit, as $\tilde{P}$ increases at some point, the effective diversion payment, $\tilde{P}\ \omega/(1 - \omega)$, surpasses the net gain measure, $Py_{0j} - \mu_{sj}$; and the associated (s, j) land-technology combinations will be diverted. Such lands receive a higher return when allocated to diversion than when utilized with initial technologies. Note that utilization of these lands with more efficient technologies is unprofitable since, if the new higher level of diversion payments were feasible and profitable, it would have been feasible and profitable as well as for the initial level of $\tilde{P}$. Finally, if $\tilde{P}$ increases but does not surpass any (s, j) land-technology combinations for which the net gain measure is larger than the initial $\tilde{P}\ \omega/(1 - \omega)$, the land-use pattern will not change.

An increase in diversion requirements on total diversion, T, has two impacts which may be captured in terms of the primal (33)-(36). First, it makes the diversion constraint in (34) less binding; second, it diminishes the gain from diversions, $\tilde{P}\ \omega/(1 - \omega)$, the price of $\tilde{A}_{0j}$'s. The second impact has the same effect as a reduction in diversion payments. Hence, if the initial participation is partial, an increase in $1 - \omega$ will affect T only through the reduction in $\tilde{P}\ \omega/(1 - \omega)$. In this event, total participation and the amount of diverted land will decline. On the other hand, for the case of full participation, both before and after the increase in $1 - \omega$, total diverted land $(1 - \omega)\ \Sigma_j^J\ L_j$ will rise. Clearly, if participation is complete prior to the rise in $1 - \omega$, partial participation may result after the increase. In this case, the effect of an increase in the diversion requirement on total diversion is unclear.

As with total diversion, the impact of changing diversion payments and requirements on the aggregate supply depends upon the degree of participation.

Under full participation, given output price, an increase in $\tilde{P}$ will not change land-use patterns or total output. However, under partial participation, an increase in $\tilde{P}$ may result in the diversion of some previously utilized land, with the nondiverted land continuing to employ its initial technology. Hence, an increase in $\tilde{P}$ tends to reduce aggregate output. Moreover, under partial participation, a rise in diversion requirements has the same qualitative impact on aggregate supply as a decrease in $\tilde{P}$; namely, output is increased. On the other hand, if participation is complete both before and after a change in diversion requirements, an increase in $1 - \omega$ will reduce total utilized land, forcing a reduction in the utilization of some of the technologies without increasing the utilization of others. Under these circumstances, total output will fall.

Some of the more interesting qualitative effects relate to changes in $\tilde{P}$ and $1 - \omega$ on land rental rates and farm operators' quasi rents. For full participation, equations (34)-(43) indicate that the new optimal solution to the primal for higher $\tilde{P}$ will be identical to the original solution. However, the solution for the dual for alternative levels of $\tilde{P}$ will differ. That is, to insure that equation (50) will not be violated, α_0 must increase sufficiently to compensate for the increase in diversion payments, i.e.,

(51) $$\Delta\alpha_0 = \frac{\omega}{1 - \omega} \Delta\tilde{P}.$$

Hence, from Proposition 2 and the equivalence conditions (44)-(47), we find that, under full participation, an increase in $\tilde{P}$ will not alter the industry production pattern or the gains or quasi rents from operation (ϕ_{4s}). The additional income from diversion payments will increase the rents for land. From (45), (46), and (51), these changes are given by

(52) $$\Delta R_j = \frac{1}{1 - \omega} \Delta\tilde{P}.$$

In the case of partial participation before and after the change in $\tilde{P}$, the fact that the shadow value of the diversion constraint (α_0) must be zero along with (43), (45), and (47) implies that $R_j = \delta_j$. Thus, changes in rental rates R_j are equal to changes in δ_j in the linear programming formulation. Recalling that an increase in $\tilde{P}$ results in the diversion of all land operated with those technologies for which $Py_{sj} - \mu_{sj}$ is smaller than the new effective diversion payment, $\tilde{P}\ \omega/(1 - \omega)$, the change in rental fees will be equal to the change in the effective diversion payment. The quasi rents after this increase to the operators of those technologies that were employed on diverted land falls to zero. For land-technology combinations that continue to operate with the new diversion payment, if the land is of diversion quality, (49) and (50) indicate that the quasi rent to the operator must decline to compensate for the increase in $\tilde{P}\ \omega/(1 - \omega)$. Constraint (50) implies that δ_j must increase since $\alpha_0 = 0$; thus, for constant $Py_{sj} - \mu_{sj}$, some elements of α_s must tend to decrease. These changes will spread to other land qualities and technologies; thus, land rental rates will tend to increase to absorb the gains from increases in the diversion payments, while quasi rents will decline to absorb the loss from reduced production. In the case of partial participation, where the rise in $\tilde{P}$ $(\omega/1 - \omega)$ is not large enough to increase diversion, as (50) indicates, the resulting increase will be reflected in increased rental fees for diversion-quality land with the result that, for other types of land, the quasi rent will decline accordingly by (49).

The above results can be summarized by:

PROPOSITION 3: *Given output price, an increase in diversion payments will be reflected by rental rate adjustments such that all increased benefits will accrue to landowners rather than operators. In the case of full participation, the increased diversion payment will increase rental rates leaving quasi rents unchanged. In the case of partial participation, the increase in the diversion payment tends to increase land rental rates and reduce quasi rents.*

Proposition 3 implies that, for the case of partial participation, increases in diversion requirements tend to decrease rental rates and increase quasi rents. To examine the impact of more stringent diversion requirements in the case of full participation, the rental rate for this case can be derived from (44) and (45), i.e.,

$$R_j = \delta_j + \frac{\alpha_0}{\omega}. \tag{53}$$

Under full participation, an increase in $1 - \omega$ will reduce the amount of utilized land; thus, some (s, j) combinations will no longer be operated. In these cases, those elements of α_s associated with the discarded technology are reduced to zero; and since $Py_{sj} - \mu_{sj}$ is given, associated elements of δ_j must rise so that (49) is not violated. The increase in elements of δ_j may result in the reduction of other elements of α_s associated with technologies combined with land type j; and this reduction may, in turn, increase still other elements of δ_j. Thus, the reduction in utilized land due to higher diversion requirements will reduce quasi rents while simultaneously increasing the rental rates for land through increases in some δ_j's. By (53), the increase in $1 - \omega$ also tends to increase R_j through the reduction in ω which contributes to increases in α_0/ω. However, by (51), the reduction in the effective diversion payment will reduce $\bar{\delta} + \alpha_0$; and since $\bar{\delta}$ may increase, α_0 will fall leading to reduced R_j. In other words, the reduction in the gain from diverted acres, $\omega/(1 - \omega)\ \tilde{P}$, tends to reduce the rental rate. The net result of these opposing effects is unclear.

The implications of diversion requirements may be summarized as:

PROPOSITION 4: *For given output price under partial participation, an increase in diversion requirements tends to reduce rental rates and increase quasi rents. Under full participation, more stringent diversion requirements will result in lower quasi rents, but their effect on rental rates is unclear. Reduction in utilized land tends to increase rental rates, but the reduction in payments per diverted acre tends to reduce rental rates.*

A corollary of some importance follows immediately from Propositions 3 and 4—namely, an increase in $\tilde{P}$ and/or ω, under partial participation, reduces α_s and thus forces some technologies and associated farms to cease operation. Hence, some operating farms included in N_s before the increase will exit from the industry and, thus, concentration will increase. That is,

COROLLARY 1: *An increase in diversion payments or a reduction in diversion requirements, under partial participation, leads to increased concentration measured by the average land size of active farms.*

The above results presume given output prices. However, since demand for the final good is not completely elastic, it follows that changes in $\tilde{P}$ and $1 - \omega$ tend to change output prices. To be sure, the second-order effects resulting from price changes must be taken into account when the overall influence of changes in $\tilde{P}$ and $1 - \omega$ is evaluated. These second-round effects modify somewhat the results in Propositions 3 and 4, but the qualitative directions implied by these propositions remain unaltered.

Under full participation, an increase in $\tilde{P}$ will not affect output prices; and the results of Propositions 3 and 4 remain unchanged. Under partial participation, an increase in $\tilde{P}$ will increase output price; and that increase will offset the initial increase in diversion that results. Nevertheless, the overall impact of an increase in $\tilde{P}$ will be to increase diversion and reduce output. This is the case since, if the second-order effect led to reduced diversion and increased output, ultimately the price would decline; and the second-order effect would be reversed. Similarly, the increase in output price resulting from an increase in $\tilde{P}$ will strengthen the increase in rental rates by Proposition 3 and will tend to offset reductions in quasi rents.

Under partial participation, an increase in diversion requirements will reduce output prices. This will partially offset the reduction in total diversion. It will also increase the quasi rents and strengthen the increase in rental rates (by Proposition 4). Under full participation, the increase in diversion requirements will increase output prices. Finally, the increase in prices will lead to similar movements in quasi rents and rental rates.

C. *Cost-Reducing Technologies*

The equilibrium level of diversion, rental rates, and quasi rents can be determined graphically for the special case where land productivity is independent of technology ($y_{sj} = \bar{y}_j$) and the cost of each technology is independent of land quality ($\mu_{sj} = \bar{\mu}_s$). The dual, (48)-(50), indicates that in this case there will be a critical j* such that all types of land with higher productivity ($\bar{y}_j > \bar{y}_{j*}$) will be utilized, while lower productivity lands ($\bar{y}_j < \bar{y}_{j*}$) will not. There also will be a marginal technology, s*, such that all the lower cost technologies ($\bar{\mu}_{s*} > \bar{\mu}_s$) will be fully utilized (hereafter referred to as efficient technologies) and all the less-efficient technologies will not be utilized. Moreover, by the independence of land productivity and technology, a unique correspondence between land quality types and technologies (a unique $\tilde{A}_{sj}$ - s) will not exist. For the optimal solution, diverted lands may be utilized with any efficient technology. Only the optimal level of total diversion is captured; this total diversion determines the marginal land quality, $\bar{y}_{sj*}$, and the marginal technology, $\bar{\mu}_{s*}$, along with their utilization levels. In Figure 1(a), qualities of land are arrayed by declining quality along the land axis with total revenues per acre shown in the upper bar graph. Existing technology capacities are also arrayed along the land axis by declining efficiency with operating costs per acre shown in the lower bar graph. Subtracting operating costs from revenues allows gains from operation, $P\bar{y}_j - \bar{\mu}_s$, to be determined as shown in Figure 1(b). The aggregate diversion requirement, if all farms comply, is $\omega\bar{L}$. Thus, if $\omega/(1 - \omega)\ \tilde{P} > a$, all farms will comply since the diversion payment per diverted acre exceeds the gain possible on all land to the right of $\omega\bar{L}$. If $a > \omega/(1 - \omega)\ \tilde{P} > b$, then gains from operation exceed the diversion payment per diverted acre on the land $(\omega\bar{L}, L_a)$ so that utilization increases to L_a. Thus, from Figure 1(a), all of land qualities 3 through 6 are utilized while some of the marginal technology, $s_0 - 3$, continues to stand idle. Now suppose the diversion payment is lowered so that $b > \omega/(1 - \omega)\ \tilde{P} > c$. Then, following the above reasoning, utilization increases from L_a to L_b so that all of technology, $s_0 - 3$, is utilized but land quality 2 is only partially utilized. Finally, if the diversion payment is lowered such that $d > \omega/(1 - \omega)\ \tilde{P}$, then the gains from operation on all land exceed the diversion payment per diverted acre. Hence, no compliance will result.

Since any land utilization pattern consistent with Figure 1 is optimal, the equality in (49) will hold for $j \geq j*$ and $s \geq s*$. This equality implies that rental rate differences between two types of utilized land will be equal to the difference in the values of their output, i.e.,

(54) $$R_k - R_j = P\bar{y}_k - P\bar{y}_j \qquad k, j \geq j*.$$

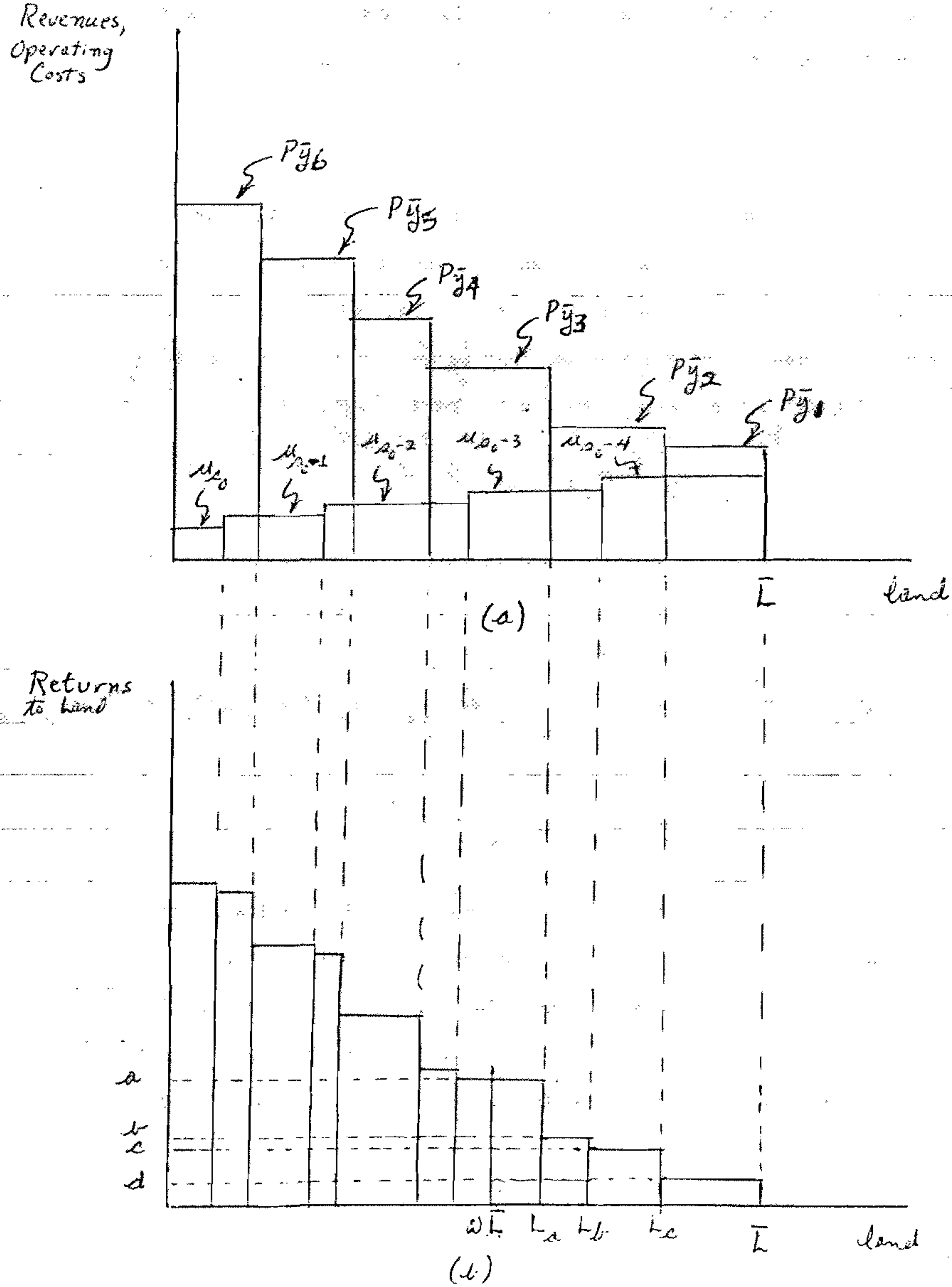

Figure 1. Determination of Aggregate Compliance

Similarly, quasi rents per acre among utilized technologies will differ by the amount of the differences in their respective costs per acre, i.e.,

(55) $$\alpha_{s_1} - \alpha_{s_2} = \mu_{s_2} - \mu_{s_1} \qquad \text{if} \qquad s_1, s_2 \geq s^*.$$

As Figure 1 illustrates, two types of equilibrium are likely under partial participation. In one case, for example, when $b < \tilde{P}\ \omega/(1 - \omega) < a$, the marginal land is fully utilized and the marginal technology is partially utilized. In this case the quasi rent for the marginal technology is zero; and by (49) and (50), using (47), the rental rate for the marginal land is

(56) $$R_{j*} = P\bar{y}_{j*} - \bar{\mu}_{s*} > \tilde{P}\ \frac{\omega}{1 - \omega}\ .$$

In the second case the marginal land is partially diverted, while the marginal technology is fully utilized [for example, when $c < \tilde{P}\ \omega/(1 - \omega) < b$]. In this case the rent for the marginal land is equal to $\tilde{P}\ \omega/(1 - \omega)$; and the quasi rent for the marginal technology is determined from (44), (49), and (50),

(57) $$\phi_{4s*} = \frac{P\bar{y}_{j*} - \omega/(1 - \omega)\ \tilde{P} - \bar{\mu}_{s*}}{c_{s*}}\ .$$

In the case of full participation, the optimal solution likely results in both marginal technology and marginal land being partially utilized. In this case the quasi rent of the marginal technology is zero, and the rental fee for the marginal land is equal to the rental fee of diverted land. Introducing these results into (47) and (49) yields the rent for diversion quality land,

(58) $$\bar{R} = R_{j*} = \omega\ (P\bar{y}_{j*} - \bar{\mu}_{s*} + \tilde{P}).$$

Note that the rental fees for any utilized land quality can be derived by introducing the rental fee for marginal land in (55). The quasi rents for each technology can be determined similarly. These results and Figure 1 illustrate the use of Propositions 3 and 4. Under partial participation a reduction in the diversion payment per acre, $\tilde{P}\ \omega/(1-\omega)$, may reduce total diversion, the productivity of the marginal land [if $\tilde{P}\ \omega/(1-\omega)$ moves from segment ab to bc], and the efficiency of the marginal technology (if it moves from bc to cd), while production may increase.

The effects of changes in effective diversion payment on rental rates and quasi rents depends on the segments over which such changes occur. If effective diversion payment is increasing over segment ab, only the rental fee for diversion quality land will increase; while, by (54) and (55), other rental rates and all quasi rents will not change. If, however, effective diversion payment is rising within a segment such as bc, (54)-(57) indicate that all rental rates will increase and all quasi rents will decrease. An increase in effective diversion payment, which involves a shift from one segment to another (from bc to ab), will increase all rents and reduce all quasi rents. If demand is negatively sloped, the change will increase output price; and this, in turn, will, by (54) and (56), increase the rental rates for utilized land and the rental rate differentials.

D. *Landowner Distributional Effects*

The above results related to distributional effects on operators can be extended to landowners. To simplify this extension, a specific assumption on the form of land-price expectations will prove expeditious. Suppose each individual merely holds a subjective expectation on the rate of appreciation which applies to all types of land; hence, $W^*_{ij} = (1 + \psi_i) W_j$ where ψ_i is the subjective rate of appreciation for farmer i. Thus, from (20), the shadow price of credit for individual i is

(59) $$\phi_{5i} = \psi_i - \theta + \frac{R_j}{W_j}$$

where j is any type of land owned by individual i in the new production period; if individual i owns no land in the new production period, then $\phi_{5i} = 0$. Using (59) in (19) thus implies that each individual will own only land types for which $R_j/W_j = \max_k R_k/W_k$ and, hence, ownership of all land implies

(60) $$\frac{R_1}{W_1} = \frac{R_2}{W_2} = \cdot\ \cdot\ \cdot = \frac{R_J}{W_J} = \frac{\bar{R}}{\bar{W}}$$

via the equilibrating market mechanism where $\bar{W}$ is the price of diversion quality land. Thus, (59) becomes

(61) $$\phi_{5i} = \begin{cases} \psi_i - \theta + \frac{\bar{R}}{\bar{W}} & \text{if} \quad \psi_i - \theta + \frac{\bar{R}}{\bar{W}} \geq 0 \\ 0 & \text{if} \quad \psi_i - \theta + \frac{\bar{R}}{\bar{W}} \leq 0. \end{cases}$$

Using (59) in (19), along with conditions (A.26) and (A.27) of the Appendix, implies that all farmers with $\psi_i > \theta - \bar{R}/\bar{W}$ will buy land until their credit is exhausted, while all farmers with $\psi_i < \theta - \bar{R}/\bar{W}$ will sell all their landholdings; farmers with $\psi_i = \theta - \bar{R}/\bar{W}$ will be indifferent to owning land, i.e.,

$$W\Delta L_i = m_i \qquad \text{if} \qquad \psi_i > \theta - \frac{\bar{R}}{\bar{W}}$$

(62)
$$-WL_i \leq W\Delta L_i \leq m_i \qquad \text{if} \qquad \psi_i = \theta - \frac{\bar{R}}{\bar{W}}$$

$$W\Delta L_i = -WL_i \qquad \text{if} \qquad \psi_i < \theta - \frac{\bar{R}}{\bar{W}}.$$

Thus, a critical $\bar{\psi}$ will exist, viz.,

(63)
$$\bar{\psi} = \theta - \frac{\bar{R}}{\bar{W}},$$

such that all farmers with $\psi_i > \bar{\psi}$ buy land; all farmers with $\psi_i < \bar{\psi}$ will sell land. The critical $\bar{\psi}$ will be determined by the land market equilibrium equation in (11) which, when premultiplied by W, becomes

(64)
$$\sum_{\psi_i \geq \bar{\psi}} W\Delta L_i + \sum_{\psi_i < \bar{\psi}} WL_i = 0.$$

Substituting equation (62) in (64) and using (61) obtains

(65)
$$\sum_{\psi_i < \bar{\psi}} WL_i - \sum_{\psi_i = \bar{\psi}} W\Delta L_i = \sum_{\psi_i > \bar{\psi}} m_i.$$

Hence, land transactions in the marginal group with $\psi_i = \bar{\psi}$ must adjust so that the total new purchase of land by farms with $\psi_i > \bar{\psi}$ is equal to their credit availability.

Introducing (63) into (65) yields

(66a)
$$\sum_{\psi_i < \bar{\psi}} RL_i \leq (\theta - \bar{\psi}) \sum_{\psi_i \geq \bar{\psi}} m_i$$

(66b)
$$\sum_{\psi_i \leq \bar{\psi}} RL_i > (\theta - \bar{\psi}) \sum_{\psi_i > \bar{\psi}} m_i.$$

Thus, $\bar{\psi}$ can be determined by ranking ψ_i and then performing tests with $\bar{\psi} = \psi_i$, $i = 1, 2, \ldots$, using R as determined in the previous section until a ψ_i is found where (65) holds. Note that equilibrium is obtained only if $\theta - \psi_i > 0$ for some i; otherwise, the equilibrium condition in (63) cannot hold for positive prices.

PROPOSITION 5: *An increase in the diversion payment and a reduction in the diversion requirement under partial participation tends to increase land prices but at a lower rate than rental fee increases resulting from such changes.*

PROOF:

First, prove by negation that $\bar{R}/\bar{W} = \theta - \bar{\psi}$ may rise with $\tilde{P}\,\omega/(1 - \omega)$ under partial participation. Suppose an increase in $\tilde{P}\,\omega/(1 - \omega)$ raises $\bar{\psi}$ from $\bar{\psi}_0$ to $\bar{\psi}_1$. From (66a),

$$\sum_{\psi_i<\bar{\psi}_1} R_1\, L_i \leq (\theta - \bar{\psi}_1) \sum_{\psi_i\geq\bar{\psi}_1} m_i \tag{67}$$

at the new equilibrium where R_0 and R_1 are vectors of the initial and new rental rates. By (66b),

$$\sum_{\psi_i\leq\bar{\psi}_0} R_0\, L_i \geq (\theta - \bar{\psi}_0) \sum_{\psi_i>\bar{\psi}_0} m_i. \tag{68}$$

at the initial equilibrium. By Propositions 3 and 4, $R_1 \geq R_0$; and, assuming $\bar{\psi}_1 > \bar{\psi}_0$,

$$\sum_{\psi_i<\psi_1} R_1\, L_i \geq \sum_{\psi_i\leq\psi_0} R_0\, L_i. \tag{69}$$

Also,

$$(\theta - \bar{\psi}_1) \sum_{\psi_i\geq\bar{\psi}_1} m_i \leq (\theta - \bar{\psi}_0) \sum_{\psi_i>\psi_0} m_i. \tag{70}$$

Combining (70), (69), and (68) contradicts (67); thus, an increase in $\tilde{P}\ \omega/(1-\omega)$ may reduce $\bar{\psi}$ and raise R. To show that an increase in $\tilde{P}\ \omega/(1-\omega)$ may increase but never reduce land prices, note that the possible reduction in $\bar{\psi}$ due to the increase in $\tilde{P}\ \omega/(1-\omega)$ will cause the equality in (65) to be violated; and the only way for restoration is for land prices to increase.

V. Technological Adoption

In the context of the above framework, what are the major effects of diversion policies on the adoption of new technologies? To investigate this issue, technologies cannot be presumed fixed; the introduction of new technologies must be allowed. In this event the trade-off between land transactions and capital good investments can no longer be neglected. Specifically, the link between landownership and land utilization, the component k_s [see (29)], is now positive. Necessary and sufficient conditions for the adoption of a new technology s_1 instead of s_0 are that technology s_1 yields higher gains, i.e., [by (21)],

$$\pi_i(S_1) - \pi_i(S_0) = \phi_{4s_1} - \phi_{4s_0} - \phi_{5i}\, k_{s_1} \geq 0 \tag{71}$$

and that the new technology can be financed, i.e.,

$$k_s \leq m_i + W\Delta L_i. \tag{72}$$

As implied by (71), policy changes will augment the tendency to adopt technology s_1 if the new technology is feasible before and after the policy changes and $\pi_i(S_1) - \pi_i(S_0)$ becomes positive after the policy changes. Under these conditions, the policy changes operate through two distinct effects: (a) a quasi-rent effect (an increase in the difference, $\phi_{4s_1} - \phi_{4s_0}$) and (b) a credit price effect (a reduction in the shadow price of credit, i.e., a reduction in $\phi_{5i} = \psi_i - \theta + \bar{R}/\bar{W}$).

Condition (72) implies that policy changes may increase the tendency to adopt the new technology through a third effect, viz., the credit availability effect. This effect is realized if the new technology, which was previously infeasible due to credit limitations, becomes more profitable and feasible after the policy changes.

The overall effect of diversion policies cannot be determined unequivocally. Nevertheless, under partial participation, Proposition 5 implies that an increase in $\tilde{P}$ and a reduction in $1 - \omega$ will not only increase credit availability (through increased land prices) but also increase the cost of credit (through an increase in $\bar{R}/\bar{W}$). Moreover, the increases in output price and rental rates resulting from an increase in $\tilde{P}\ \omega/(1 - \omega)$ allows determination of the effects of diversion policy changes on the quasi-rent differential, $\phi_{4s_1} - \phi_{4s_0}$, since, by (23), $\phi_{4s} = \left[Py_{sj_s} - \mu_{sj_s} - R_{j_s}\right]/c_s$ for partial participation where j_s denotes land utilized with technology s_1.

The above results imply:

PROPOSITION 6: *Under partial participation, an increase diversion payment and a reduction in diversion requirement will affect the tendency to adopt the new technology through (a) a positive credit effect, (b) a negative capital cost effect, and (c) a negative quasi-rent effect for a given output price assuming that the modern technology has larger capacity.*

Since output price may rise when $\tilde{P}\ \omega/(1 - \omega)$ increases, (23) indicates that the quasi-rent effect of Proposition 6 may be reversed when the modern technology is yield increasing. Thus, the direction of the quasi-rent effect depends on the nature of the modern technology.[13] Therefore, COROLLARY 2: *If the modern technologies are not smaller in scale than the older ones, an increase in diversion payment and a reduction of diversion requirement under partial participation will affect the quasi-rent differential between the new and the old technologies such that (a) the tendency to adopt new cost-reducing technologies will decline and (b) the tendency to adopt new output-increasing technologies may increase. This effect is stronger when the demand elasticity is lower.*

The second part of Corollary 2 indicates that diversion policies which intend to reduce production and increase prices may have the opposite effect in the long run since they may accelerate the adoption of output-increasing technologies. The magnitude of the quasi-rent effect depends also on the characteristics of the initial farm technology. Equations (71) and (23) imply that farms operating older technologies with lower quasi rents will have more incentive to adopt than those operating newer technologies. Hence, an increase in effective diversion payment which encourages adoption will generally accelerate the scrapping of the oldest technologies.

VI. Concluding Remarks

As shown, the distributional effects of agricultural policy can be distinguished in terms of three behavioral units: operators (active farms), landowners, and investors in new technology. Introduction of a policy in which the effective diversion payment on diverted land, $\tilde{P}\,\omega/(1-\omega)$, exceeds the existing minimal rental rate will influence operators by decreasing their number (Corollary 1), increasing the minimal rental rate (Propositions 3 and 4), and decreasing the quasi rent to technology (Propositions 3 and 4). These are the initial effects. The second-round effects result from increasing output prices as a result of reduced supply. The minimal rental rate increases further in the second round, while the quasi rent to technology and the number of active farmers increase. These results suggest that the compliance percentage would decrease after second-round effects.

The initial effect of the above policy on owners is an increase in land prices with a further increase in such prices after the second-round effect on output prices. These effects, in conjunction with the effects on active farms, suggest that the number of absentee owners will initially increase; but this increase will be tempered by the second-round effects on output prices. In other words, for the short run (with fixed technology), the net result of increased diversion payments and/or reduced diversion requirements is to motivate a separation between operation of farm units and ownership, i.e., an increase in absentee ownership.

For technology adoption, a distinction may be made between operators and owners as investors. In the case of operators, the effect of increased diversion payments and reduced diversion requirements is to increase rental rates and reduce quasi rents to technology for both output-increasing and cost-reducing investments. The second-round effects through the output markets simply augment the change in rental rates while partially reversing the change in quasi rents to technology. For the owner-operator, land prices initially increase and are followed by a further increase once the reduced supply generates a higher output price. This change augments the wealth position of owners; it improves their collateral and expands the availability of credit. The expanded availability of credit, along with perhaps better credit terms, provides further incentives for large landowners to adopt modern technologies; hence, a high correlation is expected between large landowners and large-scale technologies.

The short-run effects of policy on distribution and equity must be distinguished from the long-run effects. The usual conclusions of static analysis, which suggest that producers are able to capture the gains from technological progress under diversion policies, must be modified once dynamic effects are explicitly recognized. As Corollary 2 clearly illustrates, under certain circumstances, increases in diversion payments and reductions in the diversion requirements (under partial participation) can possibly increase the tendency to adopt new output-increasing technologies. Ultimately, such technologies, given the inelastic nature of output demand, will lead to augmentations of consumer surplus as a direct result of such diversion policies. Moreover, the short-run effects of such policies enhance credit availability and thus motivate further technology adoption. This latter effect sheds light on the importance of agricultural credit policies in capturing the effects of diversion policies. In any dynamic empirical analysis of agricultural policy on the distribution and structure of landownership in U. S. agriculture, both credit and diversion policy must be examined simultaneously.

Some of the more interesting results of this paper pertain to program compliance across various agricultural regions. In particular, land and rental markets are separated by geographical boundaries beyond which transportation and coordination costs make farm expansion unprofitable. Hence, the results of this analysis can be applied to agricultural regions individually or by groups. In particular, diversion program compliance tends to be greater in agricultural regions with higher costs, less efficient marginal technology, and lower quality marginal land.

Appendix

The Appendix characterizes the solution of the individual farm's decision problem given the technology choice and compliance decision. Based on equations (1), (2), (3), (4), (6), (13), and (14), this decision may be formulated as a linear programming problem,

$$\text{(A.1)} \quad \max_{A_i,\, Z_i^+,\, Z_i^-,\, \Delta L_i^+,\, \Delta L_i^-} \pi_i (s, \lambda) = (Py_s + \tilde{P}_i \lambda - \mu_s) A_i - R (Z_i^+ - Z_i^-) - \gamma k_s + [W_i^* - (1 + \theta) W] (L_i + \Delta L_i^+ - \Delta L_i^-)$$

subject to

$$\text{(A.2)} \quad A_i - L_i - \Delta L_i^+ + \Delta L_i^- - Z_i^+ + Z_i^- \leq 0$$

$$\text{(A.3)} \quad \Delta L_i^- - L_i \leq 0$$

$$\text{(A.4)} \quad Z_i^- - L_i + \Delta L_i^- - \Delta L_i^+ \leq 0$$

$$\text{(A.5)} \quad c_s A_i \leq 1$$

$$\text{(A.6)} \quad W\Delta L_i^+ - W\Delta L_i^- \leq m_i - k_s$$

$$\text{(A.7)} \quad \lambda e \, [A_i - \omega (L_i + \Delta L_i^+ - \Delta L_i^- + Z_i^+ - Z_i^-)] \leq 0$$

where $\Delta L_i = \Delta L_i^+ - \Delta L_i^-$, $Z_i = Z_i^+ - Z_i^-$, and thus all decision variables can be appropriately constrained to be nonnegative. Defining Φ_1, Φ_2, Φ_3, ϕ_4, ϕ_5, and ϕ_6 as shadow prices for the respective constraints in (A.2)-(A.7), the

Kuhn-Tucker conditions for maximization, aside from those associated with the constraints, are

(A.8) $$\mathcal{L}_1 \equiv (Py_s + \tilde{P}_i \lambda - \mu_s) - \Phi_1 - \phi_4 c_s - \phi_6 \lambda e \leq 0$$

(A.9) $$\mathcal{L}_1 A_i = 0$$

(A.10) $$\mathcal{L}_2 \equiv [W_i^* - (1 - \theta) W] + \Phi_1 + \Phi_3 - \phi_5 W + \phi_6 \lambda\omega e \leq 0$$

(A.11) $$\mathcal{L}_2 \Delta L_i^+ = 0$$

(A.12) $$\mathcal{L}_3 \equiv -[W_i^* - (1 - \theta) W] - \Phi_1 - \Phi_2 - \Phi_3 + \phi_5 W - \phi_6 \lambda\omega e \leq 0$$

(A.13) $$\mathcal{L}_3 \Delta L_i^- = 0$$

(A.14) $$\mathcal{L}_4 \equiv -R + \Phi_1 + \phi_6 \lambda\omega e \leq 0$$

(A.15) $$\mathcal{L}_4 Z_i^+ = 0$$

(A.16) $$\mathcal{L}_5 \equiv R - \Phi_1 - \Phi_3 - \phi_6 \lambda\omega e \leq 0$$

(A.17) $$\mathcal{L}_5 Z_i^- = 0$$

(A.18) $$\mathcal{L}_6 \equiv A_i - L_i - \Delta L_i^+ + \Delta L_i^- - Z_i^+ + Z_i^- \leq 0$$

(A.19) $$\Phi_1 \mathcal{L}_6 = 0$$

(A.20) $$\mathcal{L}_7 \equiv \Delta L_i^- - L_i \leq 0$$

(A.21) $$\Phi_2 \mathcal{L}_7 = 0$$

(A.22) $$\mathcal{L}_8 \equiv Z_i^- - L_i + \Delta L_i^- - \Delta L_i^+ \leq 0$$

(A.23) $$\Phi_3 \mathcal{L}_8 = 0$$

(A.24) $$\mathcal{L}_9 \equiv c_s A_i - 1 \leq 0$$

(A.25) $$\mathcal{L}_9 \phi_4 = 0$$

(A.26) $$\mathcal{L}_{10} \equiv W\Delta L_i^+ - W\Delta L_i^- - m_i + k_s \leq 0$$

(A.27) $$\mathcal{L}_{10} \phi_5 = 0$$

(A.28) $$\mathcal{L}_{11} \equiv \lambda e \ [A_i - \omega (L_i + \Delta L_i^+ - \Delta L_i^- + Z_i^+ - Z_i^-)] \leq 0$$

(A.29) $$\mathcal{L}_{11} \phi_6 = 0.$$

Combining (A.8), (A.9), (A.18), and (A.19) verifies equation (15) where $\Phi_1 = (\phi_{11}, \ldots, \phi_{1j})$. Similarly, from (A.10), (A.11), (A.20), and (A.21),

(A.31) $$\Delta L_i^+ \begin{cases} \geq 0 & \text{if} \quad \phi_{1j} + \phi_{3j} + W_{ij}^* - (1 + \theta) W_j - \phi_5 W_j + \phi_6 \lambda\omega = 0 \\ = 0 & \text{if} \quad \phi_{1j} + \phi_{3j} + W_{ij}^* - (1 + \theta) W_j - \phi_5 W_j + \phi_6 \lambda\omega < 0. \end{cases}$$

Also, using (A.12), (A.13), (A.20), and (A.21) obtains

$$\Delta L_{ij}^{-} = L_{ij} \quad \text{if } \phi_{2j} = W_j\ \phi_5 - W_{ij}^{*} + (1 + \theta)\ W_j - \phi_{1j} - \phi_{3j} - \phi_6\ \lambda\omega > 0$$

$$\text{(A.32)} \quad 0 < \Delta L_{ij}^{-} < L_{ij} \quad \text{if } \phi_{2j} = W_j\ \phi_5 - W_{ij}^{*} + (1 + \theta)\ W_j - \phi_{1j} - \phi_{3j} - \phi_6\ \lambda\omega = 0$$

$$\Delta L_{ij}^{-} = 0 \quad \text{if} \quad W_j\ \phi_5 - W_{ij}^{*} + (1 + \theta)\ W_j - \phi_{1j} - \phi_{3j} - \phi_6\ \lambda\omega < 0.$$

Finally, from (A.14), (A.15), (A.22), and (A.23), one finds

$$\text{(A.33)} \qquad Z_{ij}^{+} \begin{cases} \geq 0 & \text{if} \quad R_j = \phi_{1j} + \phi_6\ \lambda\omega \\ = 0 & \text{if} \quad R_j > \phi_{1j} + \phi_6\ \lambda\omega \end{cases}$$

and, from (A.16), (A.17), (A.22), and (A.23),

$$Z_{ij}^{-} = L_{ij} + \Delta L_{ij} \qquad \text{if} \quad \phi_{3j} = R_j - \phi_{1j} - \phi_6\ \lambda\omega > 0$$

$$\text{(A.34)} \qquad 0 \leq Z_{ij}^{-} \leq L_{ij} + \Delta L_{ij} \qquad \text{if} \quad \phi_{3j} = R_j - \phi_{1j} - \phi_6\ \lambda\omega = 0$$

$$Z_{ij}^{-} = 0 \qquad \text{if} \quad R_j - \phi_{1j} - \phi_6\ \lambda\omega < 0.$$

FOOTNOTES

[1]As Harold Carter and Warren Johnston have observed for U. S. agriculture, rural credit markets have become an important determinant of redistribution within the U. S. agricultural sector. They have cautioned that the intense pressure toward a heavy reliance on capital markets in order to purchase land and equipment may pose a real threat to the existence of the family farm. The basis for this observation is the evidence that "the proportion of [farmland] transfers on which debt was incurred rose from 58% in 1950 to 88% in 1977 and the ratio of debt to purchase price of credit-financed transfers rose from 57% in 1950 to 77% in 1977 . . ." (p. 744). U. S. farmland debt has increased from approximately $30 billion in 1971 to about $72 billion in 1979.

[2]For example, U. S. farmland prices have more than tripled since 1967 and moved from an average of $43 per acre in 1950 to $244 in 1976. A dramatic redistribution of agricultural production has been associated with this increase in prices. The average size of production units increased from 216 acres in 1950 to 390 acres in 1976.

[3]It should be noted that this framework is entirely consistent with empirical specifications of econometric models which have been advanced to estimate supply response in agriculture. Generally, these specifications operate with acreage response equations (*ex ante* choices) and fixed or, at most, additional probability distribution specifications for yields per acre (*ex post*). The latter relationships reflect various micro input-output coefficients which result directly from past investment decisions taken by various producers.

[4] The subsidy corresponds to the deficiency payment of the U. S. 1977 Food and Agricultural Act. Under this Act, the actual subsidy--or deficiency payment--is computed as the minimum of either the difference between the target price and the average farm price or as the difference between the target price and the loan rate or price support. Producers who participate in the program are required to divert or set aside land from historical acreage allotments (prior to 1977) or from "normal crop acreage" (1977 onward). This decision is made at planting time after set-asides and associated subsidies are announced by the USDA. Under the 1977 Act, the deficiency payment subsidy is inversely related to the actual market price, provided this price exceeds the loan rate. The analysis, however, is totally consistent with the case of exogenous diversion payment subsidies. Extensions to the case of market price related endogeneity (as with the current U. S. deficiency payment subsidy) are also possible.

[5] This feature allows an examination of the impact associated with diverting only the most unproductive lands. As numerous authors have noted, average yields tend to increase when acreage restrictions are imposed (P. Weisgerber). Weisgerber estimates that, as a result of acreage set aside or control programs within U. S. agriculture, the combined effects of land selection within farms and the differential impact among areas cause land withdrawn from production to be, on the average, 80-90 percent as productive as the land utilized. This has been referred to in the literature as "slippage"; it is often computed on the basis of past data and is assumed in policy impact analysis. In our model such slippage rates are treated endogenously.

[6] The assumption here is that a farm will only incur investment costs to adopt new technologies because of obsolescence expectations of existing technologies.

[7]For simplicity, assume that input prices include capital costs associated with operating debt.

[8]Output price expectations are assumed rational and common across producers, while land-price expectations vary across producers.

[9]Note that the trade-off between liquidity, as reflected by current or operating income, and capital gains is unity. This simplifying assumption can be easily relaxed by introducing a constant trade-off which, however, would not alter the results obtained here. Moreover, liquidity preferences for current cash flow may be outweighted by more favorable tax rates on capital gains (or zero tax if capital gains are "unrealized").

[10]While this result suggests specialization by each farm in the type of land which gives the farmer the greatest profit per unit of capacity (leasing out all other types of owned land and renting from others enough of the one type to fill his capacity), the equilibrium rental market conditions discussed below lead to adjustment in rental rates which, on average, tend to equate profits per unit of capacity on all types of land.

[11]A land quality j is defined as diversion quality land if it is at least partially diverted.

[12]Note that the linear programming formulation can also provide a non-compliance solution, i.e., $\tilde{A}_{0j} = 0$ for all j.

[13]The quasi-rent effects of changes in $\tilde{P}\,\omega/(1 - \omega)$ are perhaps the most important since they apply to all firms and do not depend on their credit situation.

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