IN

GENERAL EQUILIBRIUM ANALYSIS OF SUPPLY CONTROL IN U.S. AGRICULTURE

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I. Introduction

There is a long tradition in U.S. agriculture of attempting to restrict supplies in order to boost farm prices. This continues to be a cornerstone of farm policy. In fact, recent proposals by Senator Harkin and others would increase the level of supply control dramatically in an effort to lessen the financial stress currently experienced by some members of the farm community. The purpose of this paper is to analyze the economy-wide implications of a variety of different approaches to agricultural supply control which have surfaced in the recent debate.

Floyd's (1965) paper provided a thorough partial equilibrium analysis of supply control. In that paper he demonstrated that most of the benefits of acreage controls are capitalized into land values. Furthermore he predicted that when land use is restricted, the employment of labor, capital, and other purchased inputs in agriculture are actually increased as cultivation is intensified on the remaining acreage. Output controls were found to have the opposite effect on the use of non-land inputs. In Section II of this paper, Floyd's partial equilibrium analysis is updated, based on a less restrictive production technology and more recent econometric evidence. There are several changes in Floyd's results and this serves as a useful introduction to the general equilibrium analysis presented later in the paper.

There are also important off-farm effects of supply control. Agribusinesses supplying farm inputs are very sensitive to changes in planted acreage and intensity of cultivation. Marketing and processing sectors are also affected by supply control. Utilizing the U.S. input-output accounts, Harrington, Schluter, and O'Brien estimate that the Harkin proposal to raise farm prices to 80% of parity would cost the economy two million jobs and $64 billion in GNP. However, as the authors are careful to point out, their analysis abstracts from price-induced factor and commodity substitution effects and does not permit redeployment of factors of production into other

II. Partial Equilibrium Analysis of Supply Control

Before resorting to general equilibrium analysis of supply control, it is instructive to re-examine the single output partial equilibrium model utilized by Floyd. His results were developed based on a CES production function for the farm sector. This is quite restrictive in the many input case, as it imposes the condition that all inputs substitute equally well for one another. This is clearly contradicted by more recent studies of aggregate agricultural technology (Binswanger, Antle). For this reason the present paper utilizes a flexible functional form for U.S. agriculture which does not *a priori* restrict the cross-partial elasticities of substitution among inputs. This gives rise to a more general formulation of the Floyd model. For simplicity, and in order to focus attention on the role which agricultural technology plays in determining the impact of supply control, factor supplies are assumed to be either perfectly elastic or absolutely inelastic. Intermediate cases could easily be introduced.

The Model

The basic equations in this model (assuming locally constant returns to scale) are stated below in differential notation (e.g., $\hat{X}$ denotes the vector of percentage changes in the elements of vector X).

$$(1)\quad \hat{X} = \Sigma\, \bar{C}\, \hat{W} + \hat{Y}$$

$$(2)\quad \hat{P}_F = C^T \hat{W}$$

$$(3)\quad \hat{P}_F = \hat{P}_M - \hat{t}$$

$$(4)\quad \hat{y} = \epsilon_D \hat{P}_M$$

X is the (Nx1) vector of derived demands in the controlled sector and Y is a vector with all elements equal to the single output level (y). The (NxN) matrix of Allen partial elasticities of substitution is given by Σ and $\bar{C}$ is a diagonal matrix of the N cost shares. Thus, equation (1) gives the change in

(7) $\epsilon_S = -(1^T \Sigma_Z^{-1} 1)^{-1}$,

where 1 denotes a unit vector and Σ_Z is the $(\ell x \ell)$ submatrix of Σ associated with the fixed factors.

Condensing (1)-(4) and (6) into a single set of fixed factor demand equations yields:

(8) $\hat{X}_Z = (\Sigma_Z + \underline{E}_D)\ \bar{C}_Z \hat{W}_Z + E_D \hat{t}$,

where $\underline{E}_D$ is an $(\ell x \ell)$ matrix with all elements equal to ϵ_D while E_D is an $(\ell x 1)$ vector, also with elements ϵ_D. Given a change in production quota ($\hat{t} \neq 0$) or input restrictions ($\hat{X}_Z \neq 0$), equation (8) may be solved for the change in unit payments to fixed factors ($\hat{W}_Z$) which in turn permits computation of $\hat{p}_F$, $\hat{p}_M$, $\hat{y}$, and $\hat{X}_V$.

If land is the only fixed factor (our long-run analysis) then (8) becomes:

(9) $\hat{x}_L = (\sigma_{LL} + \epsilon_D)\ c_L \hat{w}_L + \epsilon_D \hat{t}$.

In the case of acreage controls ($\hat{x}_L < 0$, $\hat{t} = 0$), this gives rise to:

(10) $\hat{w}_L = c_L^{-1}\ (\sigma_{LL} + \epsilon_D)^{-1}\ \hat{x}_L = -\ \hat{x}_L / c_L(\epsilon_S - \epsilon_D) \geq 0$.

The impact on individual variable input demands is also of interest:

(11) $\hat{x}_j = (\sigma_{jL} + \epsilon_D)(\epsilon_D - \epsilon_S)\ \hat{x}_L \gtrless 0$.

Note that restricting acreage can actually increase the demand for those variable inputs which are strong substitutes for land ($\sigma_{jL} > |\epsilon_D|$). This was Floyd's predicted outcome.

Analogous equations for the case of output controls (with only land in fixed supply, i.e., $\hat{t} > 0$, and $\hat{x}_L = 0$) are given by (12) and (13):

(12) $\hat{w}_L = c_L^{-1}\ \epsilon_D\ (\epsilon_S - \epsilon_D)^{-1}\ \hat{t} < 0$

(13) $\hat{x}_j = (\sigma_{jL} + \epsilon_S)\ \epsilon_D\ (\epsilon_S - \epsilon_D)^{-1} < 0$.

When output is restricted, the fixed factor in agriculture becomes relatively more slack, thus the marginal value product of land (w_L) drops. Variable

Table 1. Aggregate Allen Partial Elasticities of Substitution and Assumed Cost Shares in the Controlled Crops Sector.

Allen Partials (standard errors in parentheses)

	Land	Crop Capital[a]	Labor	Fertilizer	Livestock Capital[b]	Feed	Other Inputs
Land	-2.94	.39	.03	.26	.06	.58	
	(3.51)	(.68)	(.50)	(.78)	(.58)	(.36)	
Crop Capital		-4.05	-1.13	.69	.32	.95	
		(.68)	(.44)	(.70)	(.39)	(.32)	
Labor			-.27	1.79	.48	.19	[Homogeneous]
			(.90)	(.89)	(.38)	(.29)	
Fertilizer				-5.32	1.05	-.21	
				(1.94)	(.50)	(.44)	
Livestock Capital		[Symmetric]			-2.90	.66	
					(.46)	(.22)	
Feed						-1.00	
						(.26)	
Other Inputs							

Cost Shares Assumed for Controlled Crops

	Land	Crop Capital	Labor	Fertilizer	Livestock Capital	Feed	Other Inputs
	.37	.21	.10	.07	0	0	.25

[a] Crop capital includes tractors, trucks, autos, and other durable equipment.
[b] Livestock capital includes livestock herds and structures.

Table 2. Partial Equilibrium Effects of Supply Control (percentage change as a result of supply control measures which raise market price by 10%).

	Production Quota	Acreage Restrictions
	Short Run (land and capital fixed)	
$\hat{p}_M$	+10.0	+10.0
$\hat{y}$	-6.3	-6.3
$\hat{w}_{land}$	-6.5	+28.4
$\hat{w}_{capital}$	-8.6	-2.5
$\hat{x}_{land}$	0	-37.0
$\hat{x}_{capital}$	0	0
$\hat{x}_{labor}$	-4.3	-5.4
$\hat{x}_{fertilizer}$	-8.1	-3.9
	Long Run (land only fixed and elastic export demand)	
$\hat{p}_M$	+10.0	+10.0
$\hat{y}$	-8.7	-8.7
$\hat{w}_{land}$	-8.0	+27.0
$\hat{w}_{capital}$	0	0
$\hat{x}_{land}$	0	-38.1
$\hat{x}_{capital}$	-9.9	-4.8
$\hat{x}_{labor}$	-8.8	-8.4
$\hat{x}_{fertilizer}$	-9.5	-6.1

Model Limitations

The single output, partial equilibrium analysis presented above is useful in clarifying the role which a flexible agricultural technology plays in determining the impact of supply control. However, there are numerous assumptions which limit the credibility of these results. For example, feedgrains and foodgrains are likely to face different demand conditions. Export demand response is relatively much more important for the foodgrains sector. Furthermore, there may be significant substitution among the controlled crop products and between these and other outputs. On the factor market side, the controlled crops sectors must compete with other agricultural and non-farm sectors for scarce inputs. Partial equilibrium factor supply assumptions do not satisfactorily capture these effects.

In addition to improving the reliability of the estimates in Table 2, it would be nice to have measures of the effect of supply control on variables such as other agricultural prices, total purchased input usage, consumer prices, budgetary outlays and aggregate welfare. Estimates of all of these effects may be obtained with a sufficiently detailed multicommodity partial equilibrium model. However, an applied general equilibrium model has the advantage of permitting all prices and quantities to adjust simultaneously, while providing a full accounting of firm expenditures and receipts, and household gains and losses. The next section outlines the structure of such a model.

Expenditures in Initial Equilibrium

The economy-wide set of accounts developed for this study is constructed in two parts. First, a consistent set of dollar flows is established for the entire U.S. economy. This is based on the most recent input-output table available (1977). A detailed discussion of the data base modifications and manipulations is available in Hertel and Tsigas. The next step involves inserting a set of 1984 policy wedges into these accounts. (See Hertel, Chattin, and Tsigas for a more detailed treatment of this topic.) These wedges are crucial in determining the excess burden associated with any new policy intervention.

Figure 1 identifies the types of distortions incorporated into the initial equilibrium. They reflect 1984 policies and are modeled as ad valorem price wedges. Those government payments tied explicitly to output are treated as output subsidies. A variety of farm programs serve to lower the per unit cost to farmers of using capital and land. Dairy and sugar programs raise the prices received by domestic producers and those paid by U.S. consumers, relative to world price levels. The final farm program effect treated here is that of acreage reduction. In contrast to all of the previous wedges, this limitation in land used for program commodities tends to reduce output.

Economy-wide price wedges are also important for this analysis, particularly to the extent that they affect agriculture differentially. Transport subsidies refer to the annual cost of inland waterways not covered by users. These subsidies tend to lower the cost of mining and agricultural outputs, relative to other products. Differential treatment of farm and food sectors in the basic tax structure has also been shown to have an important impact on the size and mix of U.S. agriculture (Hertel and Tsigas). Average tax rates on the use of labor and capital, as well as output, retail sales and income taxes are approximated with ad valorem price wedges.

A condensed version of this baseline data set is reported in Table 3, which provides net expenditures by industries and households on goods and services. The first row of Table 3 describes the sale and purchase of the aggregated, net output of the 40 producing sectors in 1977 dollars. This totals \$1.88 trillion. Final demands for these products are as follows: investment = \$366 billion, private consumption = \$1.29 trillion, government purchases = \$187 billion and exports = \$140 billion. The presence of output and consumption taxes means that consumers of a given product pay more than producers receive. This gives rise to a positive row total equal to the resulting tax revenue. (This total would be larger in the absence of agricultural output subsidies.)

In order to handle savings and investment in a static model, we follow Johansen and Keller by introducing a "dummy" capital goods sector which collects and distributes investment goods. Replacement investment is assumed to equal purchases of scrap and depreciation, and is entered in the capital goods row for the 37 non-livestock sectors. (Livestock sectors are assumed to generate their replacement investment internally.) The remaining portion of capital goods output (net investment) is allocated to the domestic household as savings.

The bulk of the imports in this model serve to augment the domestic availability of output from the 40 producing sectors. When combined with direct sales to final demand, total imports (\$167 billion) are obtained. These are supplied by the foreign household.

The remaining rows of Table 3 document the flows of primary factor service payments to the private domestic household. Note that labor is disaggregated into farm and non-farm components. Similarly capital stocks generating capital service flows to the private households are disaggregated into crop capital (e.g., tractors and combines), three types of livestock capital, and all other (non-farm) capital. Finally, the payments to land are accounted for. Each of these factor service flows generates net tax revenue. In the case of livestock capital, the estimated value of credit subsidies exceeds estimated tax revenue and the row totals are negative. A total of $625 billion in taxes (net of subsidies) is collected by the treasury (sum of row totals) which must equal the sum of transfers to households.

Behavioral Assumptions

Firm Behavior: In order to utilize the matrix of substitution effects presented in Table 1 of Section II, while permitting each sector to face a different vector of factor prices, the same (6x6) matrix of Allen partials was assigned to each of the seven individual farm sectors: foodgrain, feedgrains, oilcrops, other crops, dairy, poultry, and red meat. Since the sectoral demand elasticities are equal to the Allen partials weighted by the cost share of the relevant price, these will differ across commodities. For example, the demand elasticity for feed in the crops sectors will be zero due to a zero cost share for feed in those activities. However, the shape of the aggregate farm sector isoquants will reflect the substitutability implied by the multi-product cost function.

Figure 2a provides the overall structure of domestic production in the agricultural sectors. Note that total supply is modeled as a CES aggregation of foreign and domestic production. Following Armington, they are treated as imperfect substitutes--in this case a unitary substitution elasticity is assumed. Figure 2a also shows the feed input into livestock production as a nested CES aggregate of the on-farm feed mix and purchases from the prepared feeds sectors. The on-farm mix is in turn a combination of feedgrains and soymeal. Substitution between these inputs varies across livestock types and is identical to the grain-protein substitution parameter used for prepared feeds.

Production technology in each of the prepared feeds sectors is summarized in Figure 2b.[2] Once again imports are assumed to comprise a constant share of product expenditures. Domestic output consists of a nested CES technology whereby separability between protein sources and grains is assumed. The protein aggregate is obtained by combining soymeal with other protein sources, while foodgrains may substitute for feedgrains on the other side. These two elasticities of substitution, as well as the substitutability of grains for proteins, depend on the type of feed being produced. For example, the dairy and beef industries can substitute more easily between grains than can poultry producers. Substitution parameters for each of the three types of prepared feeds are provided at the bottom of Figure 2b and are based on the work of Zeitsch for the OECD.

While the aggregate availability of agricultural land is fixed in this model, acreage supplied to individual crops is responsive to changes in relative rental rates. This feature is incorporated through the use of a constant elasticity function which "transforms" one type of land into another (Figure 2c). Four land groups are distinguished: foodgrain, feedgrain, oilcrop, and other crop land. The latter is employed in the production of both other crops and livestock. We assume the elasticity of transformation among land types to be equal to 0.2 which gives plausible partial equilibrium acreage response elasticities.

In keeping with the agricultural emphasis of this model, the remainder of the productive economy is handled in a relatively simple way (Figure 2d). Following Ballard, et al., capital and labor are combined with a constant elasticity of substitution, in order to produce a value-added aggregate. The values of these substitution parameters are taken from their study (Ballard, et al., pp. 132-34) as described in Hertel and Tsigas. Value-added is then combined with intermediate inputs using the Leontief assumption of fixed coefficients, and the expenditure share on imports is assumed constant.

IV. General Equilibrium Results

Output vs. Acreage Controls Revisited

As was the case in Section II, the general equilibrium supply control experiments are defined by output reductions sufficient to yield a 10% market price increase in each of the controlled crops sectors. These include feedgrains, foodgrains, and oil crops. Since the demand for each of these three sector's products differs, as do their cost shares, we expect compositional effects to alter the aggregate results presented in Table 2. Also, the factor markets are now explicitly handled within the model. In the short run, farm labor is mobile across agricultural enterprises but immobile out of the farm sector; crop capital is mobile across crop commodities, but otherwise immobile; and livestock capital is sector-specific. In the long run all of these factors can move out of agriculture. This results in an equalization of factor prices in the farm and non-farm sectors. Also, the fact that not all crop production is controlled means that land and crop capital can move into alternative uses, even in the short run. A final factor distinguishing the results in this section from the aggregate, partial equilibrium analysis of Section II is the adjustment of all other prices and quantities in the model to the supply control shock.

Table 4 provides selected general equilibrium results for both output and acreage control experiments in the short and long runs. Consider first the column referring to short run output control effects. Keep in mind that the requisite output quotas are auctioned off and the resulting rents are collected by the treasury. (However, these will be returned to farm households in the welfare analysis.) The amount of output reduction required to raise prices 10% is now determined not only by the slope of the farm level demand curve, but also by shifts in this curve. These may arise due to changes in the prices of competing products, or due to income effects. The first column of Table 4 shows feedgrain output being restricted by 7% while foodgrain and oil crop output only need to drop by about 4%. This difference can be attributed to the price responsiveness of feed requirements in the livestock sectors.

The impact of output controls on the land and crop capital markets is reported next in column one of Table 4. In the aggregate, land prices drop by only 3.5%, as opposed to 6.5% in Table 2. This difference may be attributed to the fact that the other crops sector absorbs some of the program crop land. The factor price of crop capital actually increases due to an increased demand in the non-controlled crops sector, which uses about half of the crop capital in initial equilibrium.

Perhaps the most striking difference between Tables 2 and 4 is the impact of output controls on the farm labor market. The increased use of labor by the other crops sector and by the three livestock sectors is insufficient to offset the downward pressure on wages (-11%) as a result of labor being released from the controlled crops sectors. Finally, note that the drop in fertilizer use in column one of Table 4 (-8.3%) is very similar to the partial equilibrium result (-8.1%). This is because the price of fertilizer is unchanged by this experiment.

The next column in Table 4 shows the effects of output controls when capital and labor are mobile out of agriculture and export demand is elastic. In order to maintain the 10% increase in output prices in the long run, larger program crop reductions are necessary (see Table 5). As a result, most input quantities drop by more than in the short run. Exceptions are the demands for capital in the livestock sectors which increase by 1-2%. The decline in the price of the fixed land input is also larger in the long run (-5%).

Next turn to the acreage control experiment. The general equilibrium land market clearing condition means that this factor cannot simply disappear. We choose to modify the government demand for aggregate land, making it perfectly elastic. The supplies of foodgrain, feedgrain, and oilcrop land are then taxed to reduce their use and hence the level of output in those sectors. (The proceeds of this tax are returned, as additional land rents, to landowning households in the welfare accounting.) Thus the market price of aggregate land remains unchanged, while firm prices (and hence the value marginal product) of program land rise. In this case, the necessary output reduction is somewhat smaller than for production controls (Table 5). This is because other crop prices now rise as the overall supply of agricultural land is reduced by about 32%. Land use in the three program crops sectors falls by 35-37%. This is quite similar to the partial equilibrium result in Table 2.

As a result of the higher land prices, crop capital (an important land substitute) becomes relatively scarce and its price increases by 10.3%. This serves to dampen the demand for the complementary labor input. Since labor does not substitute very effectively for land its price falls by almost 15% under acreage controls.

Alternative Marketing Quotas

Thus far we have only discussed quotas which are assumed to apply bear directly on the production of individual commodities. In fact, farms are multiproduct enterprises and it is difficult to regulate the sale or transfer of intermediate inputs within the agricultural sector. For this reason it may be more realistic to consider marketing controls which apply only to transfers out of the farm sector. This gives rise to two prices for controlled crops. Non-farm users face a 10% price increase while the on-farm price drops to a level which will clear any surplus capacity from the marketplace. This will be referred to as the "cheap feed" scenario, for obvious reasons.

Table 5 provides information on output levels for the four crops sectors under a variety of supply control regimes. Comparing the first two columns, we see a dramatic effect on feedgrains output when controls are not applied to intra-farm sector uses. In this case the shadow price of feedgrains to farm factor owners and are measured as "sources of income" incidence in the CGE model. There are three households in this particular model. To save space the domestic private and government households are combined into a single column (domestic) in Table 6. The second column measures welfare effects on the foreign household, and the final column (E.B.) may be ignored for the time being. Entries in Table 6 are in millions of 1977 dollars and represent first order approximations to the compensating variations required to return the household in question to its pre-intervention level of utility. Thus a negative number indicates that the household is actually made better off in its consumption (or supply) of that particular item.

The first group of columns in Table 6 refers to the farm level output control scenario. Domestic consumers are $1.6 billion worse off as a result of higher food prices. The foreign household, which purchases much of the controlled crop output, also suffers in this dimension. Non-food prices rise, relative to the numeraire, hence giving rise to a positive compensating variation. With inelastic export demands for the controlled crop products a slight appreciation of the dollar is required to balance the trade flows. This gives rise to cheaper imports which is good for the domestic household, but bad for the foreign household.

Non-farm labor is the numeraire good and has no incidence effects. Once the slight increase in the price of non-farm capital services is accounted for, the total non-farm incidence of supply control may be assessed. (Farmers only represent 2.5% of the population. Thus their role as consumers and suppliers of non-farm capital is ignored.) It is hardly surprising that non-farm households are worse off as a result of additional supply control measures.

The farm household incidence of supply control is essentially determined by the returns to farm assets and labor. These are grouped together at the bottom of Table 6. While output controls depress returns to farm labor and land, this is more than offset by $5.2 billion in quota rents (assuming these are returned to farm households). As a result, farm households are $3 billion better off, which more than outweighs the non-farm household losses.

The transfer row at the bottom of Table 6 represents the net change in the treasury's position as a result of the intervention. In the case of output controls the fisc raises a bit less revenue and the private domestic household must transfer $27 million back to the treasury to cover this deficit. Summing across all the rows shows that net gains to the aggregate domestic household are roughly equivalent to the foreign household's losses. Thus in the short run output controls transfer income from foreign and domestic non-farm households to the U.S. farm sector.

Long run results are presented for each of the subtotals in Table 6. Once labor and capital are permitted to leave agriculture, even more of the burden of supply control is shifted forward to domestic consumers in the form of higher product prices. By contrast, the foreign household now experiences a terms of trade change in its favor, due to its elastic export demand for farm products. As a result it is slightly better off. Farm households are also better off in the long run since the price of agricultural labor returns to the non-farm level. This, together with the increased tax revenue realized as labor and capital move into higher tax (non-farm) sectors, just about offsets the effect of higher commodity prices on the domestic household.

Some discussion of the third column, labeled E.B., is now in order. This reports partial measures of excess burden generated in the various markets as a result of output controls. The first entry indicates that the associated reduction in farm and food output actually benefits the economy by roughly $314 million. This is because in 1984 the restricted sectors received sizable output subsidies, which in turn encourage overproduction. There are also slight improvements in the allocation of non-food commodities, imports, and non-farm labor. By contrast, the allocation of farm assets is somewhat more distorted. However, the net effect of output controls is to reduce the excess

V. Summary and Conclusions

This paper has extended previous analysis of supply control in U.S. agriculture by introducing a flexible agricultural technology into an empirical general equilibrium model of the economy. Section II demonstrated how the estimated technology modifies partial equilibrium results of Floyd. After developing the full model structure in Section III, a series of general equilibrium supply control experiments are conducted.

Based on 1984 policy wedges, we find that incremental marketing controls actually increase allocative efficiency in the economy, relative to the distorted initial equilibrium. Furthermore, in the short run marketing quotas benefit the aggregate U.S. household at the expense of other countries. In the long run this gain is largely eliminated by a negative terms of trade effect. By contrast, acreage restrictions result in large increases in excess burden and domestic welfare losses. It is ironic, to say the least, that acreage controls are the preferred method for supply control, as evidenced by current U.S. farm programs.

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Appendix: Derivation of Results in Table 2.

Production Quota

Equations (1) and (4) give:

$\hat{X}_Z = 0 = \Sigma_Z \bar{C}_Z \hat{W}_Z + \hat{Y}_Z$, and

$\hat{Y}_Z = E_D \hat{p}_M = E_D(.10)$

for a 10% market price increase. Therefore,

$\hat{W}_Z = -\bar{C}_Z^{-1} \Sigma_Z^{-1} E_D(.10)$.

$\hat{p}_F$ follows from equation (2), and

$\hat{X}_V = \Sigma_V \bar{C}_Z \hat{W}_Z + \hat{Y}_V$,

where Σ_V is the (n-m)xm submatrix of Allen partials relating $\hat{W}_Z$ to $\hat{X}_V$, and $\hat{Y}_V$ is an (n-m)x1 vector of y's.

Land Restriction

Using $\hat{Z} = 0$, equation (8) gives:

$\hat{X}_Z = (\Sigma_Z + \underline{E}_D) \bar{C}_Z \hat{W}_Z$, so that

$\hat{S}_Z = \bar{C}_Z^{-1} (\Sigma_Z + \underline{E}_D)^{-1} \hat{X}_Z$.

From equations (2) and (3) we have: $\hat{p}_M = \hat{p}_F = C^T \hat{W} = C_Z^T \hat{W}_Z$

where C_Z^T is the (mx1) subvector of C^T referring to fixed inputs.

Thus $\hat{p}_M = C_Z^T \bar{C}_Z^{-1}(\Sigma_Z+\underline{E}_D)^{-1}\hat{X}_Z$, or $\hat{p}_M = 1^T(\Sigma_Z+\underline{E}_D)^{-1}\hat{X}_Z$.

This may be solved for the land retirement ($x_L < 0$) necessary to induce $\hat{p}_M = .10$:

$\hat{x}_L = .10 \ (1^T \theta)^{-1}$,

where θ is the column of $(\Sigma_Z + \underline{E}_D)^{-1}$ corresponding to $\hat{w}_L$.

Thus for $X_Z = x_L$ (m=1), we have:

$\hat{x}_L = .10 \ (\sigma_{LL} + \epsilon_D) = .10(\epsilon_D - \epsilon_S) < 0$.