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DYNAMIC SUPPLY ESTIMATION:
THEORETIC AND EMPIRIC REFINEMENTS
APPLIED TO U.S. CASH GRAIN PRODUCTION,
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DYNAMIC SUPPLY ESTIMATION: THEORETIC AND EMPIRIC REFINEMENTS APPLIED TO U.S. CASH GRAIN PRODUCTION, 1965-1984

By

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ABSTRACT

DYNAMIC SUPPLY ESTIMATION: THEORETIC AND EMPIRIC REFINEMENTS APPLIED TO U.S. CASH GRAIN PRODUCTION, 1965-1984

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Agricultural supply relations are commonly characterized as "dynamic" in terms of "lagged adjustment" to price signals and "irreversible" expansions that occur more readily than contractions. The examination of these relations, however, has been rather _ad hoc_ in relation to theory. This study attempts to put such examinations on more secure foundations by introducing lagged adjustment derived from upward-sloping input supply curves and irreversibility derived from input supply constraints.

Mathematic development of a model incorporating flexible input prices points to problems of econometric estimation that are generally ignored. Extension to the case of input supply constraints shows even greater difficulties for econometric applications.

These problems, however, do not make it impossible to test the standard irreversiblity hypothesis. The fact that input suppliers' normal capacity utilization rate is well in excess of fifty percent suggests that input supply is more likely to be constrained by input capacity than input disposal is to be constrained by a lack of desired salvage markets. The resulting conclusion that irreversibility is likely to be the opposite of common belief (that supply, in fact, contracts on average more readily than its expands) is still difficult to measure in terms of magnitude.

Structurally-ordered instrumental variables econometric measurements of dynamic supply relations for acreage planted to feed grains, wheat, and soybeans and for four classes of inputs supplied to agriculture in the United States (1965-1984) was attempted in spite of the theoretic implications that such measurement would be of questionable validity. Some evidence of lagged adjustment was found and some weak irreversibility of the type suggested was detected rather inconclusively.

This study concludes that eclectic studies of complex supply relations may be more reliable and useful than narrow, formal econometrics, and that the question of irreversibility could be a major stumbling-block for any examination of supply. A number of other observations regarding cobweb cycles and other phenomena are also offered to make the study's findings more generally useful.

to Ruth, whose help and support made this effort possible

and whose presence made it seem worth doing

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CHAPTER ONE

PROBLEM STATEMENT

This chapter discusses the policy concerns motivating this study and the analytic concerns that shaped it. It then turns to an overview of the study's central arguments and an outline of the remaining chapters.

Policy Considerations

The high grain prices and related policy decisions of the mid- and late-1970's stimulated considerable expansion of world grain production. When prices then fell, many people debated the merits of raising support prices or restricting domestic production to raise market prices (or both) to increase U.S. farm incomes. Because production responses to such measures would affect their costs and effectiveness, the nature of agricultural supply became a major topic for discussion.

Specifically, attention focused on the difference between short-run and long-run supply response and on whether agricultural supply expands more readily than it contracts. The first issue is often referred to in terms of "length-of-run", "lagged-adjustment", or "partial-adjustment". The second issue is often called "reversibility" or "irreversibility".

These issues were commonly discussed before the 1970's, but were generally limited to domestic considerations (e.g., Tweeten and Quance, 1969, and others cited there.) The expansion of competing foreign productive capacity and export facilities in the 1970's, however, seemed to call for an extension of these concerns to the analysis of world markets. If foreign supply would contract slowly or very little, U.S. policy effectiveness could be seriously impaired.

Analytic Considerations

Because much of the early work on these issues preceeded wide knowledge of appropriate analytic techniques, the adequacy and applicability of available tools has been unclear. Furthermore, empirical studies of these dynamic characteristics of domestic agricultural supply have been far from conclusive. Claims have not been supported by strong evidence, and the empirical evidence that existed has not been built on strong analytic foundations.

Econometric work has been based on two standard models. Partial-adjustment is typically modeled by estimating production as a function of prices, policy variables, and the previous period's production (e.g., Tweeten and Quance, 1969). Irreversibility is modeled with different ("shifted") price coefficients in periods of expansion versus periods of contraction (e.g., Tweeten and Quance; Wolffram, 1971; Houck, 1977). In general, large adjustment lags (the first issue) are not apparent in the findings, but some evidence of expansions occuring more quickly than contractions (the second issue) have been found. The latter conclusion may have been strengthened by the fact that a hypothesis of faster contractions (as opposed to faster expansions) was not considered to be important; statistical results to this effect may well have been considered support for a null hypothesis of no difference in the speed of adjustment.

A belief in faster expansions may also have been fostered by a number of studies of perennial and fruit tree supply (Arak, 1969; French and Matthews, 1971; Baritelle and Price, 1974; Saylor, 1974; Gemmill, 1978; French, King, and Minami, 1985). More responsive expansions are easier to demonstrate in these cases, and the technical uniqueness of these crops may have been overlooked. Rather than deducing that the rest of agriculture would be less responsive in its expansion as a result, the findings may have been uncritically extended to other crops and possibly to agriculture as a whole.

Overview of the Argument

More detailed examinations of the dynamics of agricultural supply have traditionally centered on the analysis of inputs to agriculture (e.g., G. L. Johnson, 1958, and others cited there.) In one approach, agricultural supply elasticity has been explained in terms of the elasticity of the supply of inputs to agriculture (perhaps most notably by D. G. Johnson, 1950). In this view, the more inelastic the supply of inputs, the more inelastic the supply of outputs. A second approach focuses on durable inputs (e.g., G. L. Johnson, 1958). In this view, output supply is more elastic when quantities of durables vary than when they are fixed, so attention shifts to the conditions and time frame that determine fixity.

These two approaches to the question of agricultural supply elasticity are not really at odds, but the focus on durables in the second approach is significant. Whereas the first view does not explicitly include time, the second leads directly to the subject of length-of-run in supply adjustment. A focus on durables also suggests the question of irreversibility: because stocks of durables are often seen as variable in expansions but fixed in contractions, agricultural supply is often held to expand more quickly than it contracts.

This study integrates these two approaches by examining dynamic agricultural supply in relation to the elasticity of inputs supplied to agriculture. It concentrates on: 1) a less-than-perfectly-elastic supply of durable inputs as a source of the "quasi-fixity" of input use that results in partial adjustment, and 2) conditions of perfectly inelastic input supply that result in irreversibility. These conditions are shown in Figure 1.1.

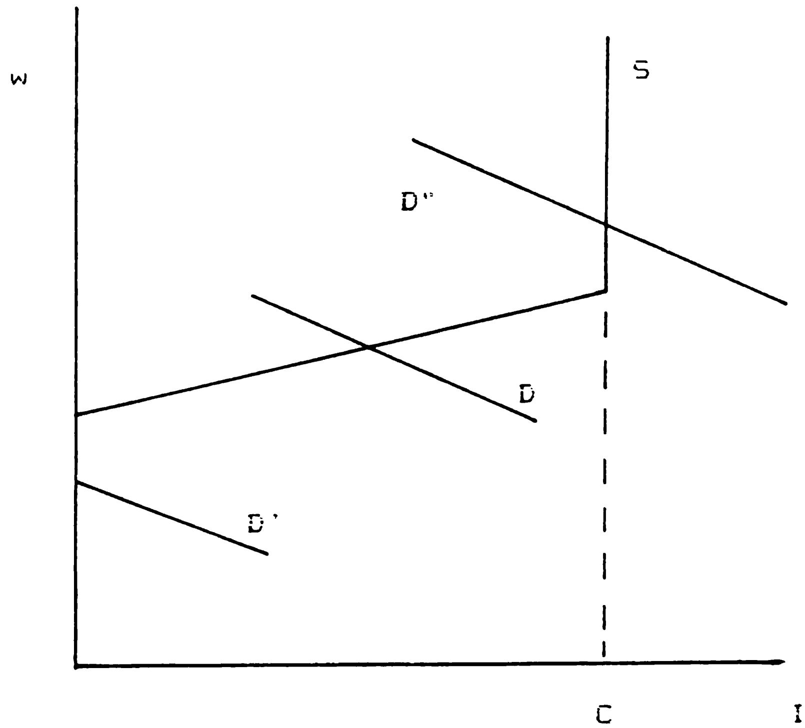

Figure 1.1. Conditions affecting dynamic agricultural supply.

In Figure 1.1, the demand (D) for new purchases (I) of an input is shown as a function of that input's price (w). When input supply is less-than-perfectly elastic (upward sloping), input price is affected by demand (is endogenous) and thereby affects the quantity purchased. When the input in question is a durable, the demand curve is affected by the quantity of input stocks held by farmers, resulting in quasi-fixity and lagged adjustment (as discussed in more detail in Chapter Two).

If demand (D') falls to a point at which no new purchases are desired but at which no salvage market is available, input use becomes perfectly price-inelastic and fixed. Similarly, if demand (D") rises to use all available input production capacity (C), input use is again perfectly inelastic and fixed. As explained in Chapter Two, it is these conditions of "occasional-fixity" that lead to irreversibility of agricultural supply.

The econometric evidence presented in Chapter Five does not suggest that lagged adjustment is a major force in agricultural supply. Furthermore, it is argued below that if either condition of occasional-fixity is more prominent in agriculture, it is likely to be that of the input capacity constraint. This implies that, if a difference exists between the rates of expansion and contraction, it is more likely to be the case that agricultural production contracts more readily than it expands, the opposite of the standard view described in the previous section. This hypothesis is weakly supported by the econometric evidence presented in Chapter Five.

Outline of the Presentation

The remainder of this study consists of five chapters. Chapter Two presents a formal theoretical treatment of quasi-fixity and the two conditions of occasional fixity, and this treatment is related to other literature on economic dynamics. In Chapter Three, characteristics of agricultural production and its input supply are examined to provide informal support for the idea of a more probable capacity-constrained occasional-fixity. Other observations about production cycles, the supply of cash grains, and other factors affecting supply are also made there.

Chapter Four includes a survey of methodological considerations involved in any attempt to examine the ideas of Chapters Two and Three econometrically. This chapter covers both domestic and foreign applications, and concludes with a philosophic note about methods used. Chapter Six draws general conclusions and implications of the study. Six appendices provide details of much of the theoretic and econometric presentations.

CHAPTER TWO

DYNAMIC SUPPLY THEORY

The analysis of dynamic agricultural supply must be based in economic dynamics. That base is developed in this theoretical chapter. A beginning definition of terms and principles in statics is followed by a discussion of quasi-fixed inputs and occasionally-fixed inputs. This will set a foundation for the empirical investigations of the later chapters by showing the role of input fixity in supply elasticity.

Statics

In static ("timeless", per Hicks, 1946, p.115) production theory, a firm's optimum output supply (Q) and variable input demand (vector[1] L) are determined by prices (P for output and vector W for inputs), given decreasing returns at some level of fixed inputs (K). Assuming profit (R) maximization:

$$\max_{L} R = PQ - W'L$$

$$\text{subject to } Q = F(L;K)$$

Optimum factor demand is given by simultaneous solution of the first-order conditions:

---

[1] All vectors are column vectors unless transposed (e.g., W').

$$R_L = PQ_L - W = 0$$

or:

$$Q_L = W/P = w$$

where R_L and Q_L are first partial derivatives[a] of R and Q with respect to L, and w is a vector of input prices "normalized" by output price. The matrix of second partial derivatives (F_{LL}) must be negative definite as a second-order condition and symmetric by Young's Theorem (Chiang, 1974, p. 324). (See Varian, 1984, Chapter 1 for a standard treatment.)

For exposition and econometric estimation, a convenient second-order approximation of the production function F is the quadratic functional form (Lau, 1978, p. 194):

$$Q = c + a'L + 1/2\ L'F_{LL}L$$

This approximation is <u>a priori</u> as a good as any second-order approximation, and leads to linear input demand functions as follows: the first-order conditions derived from the quadratic production function become:

$$Q_L = a + F_{LL}L = w$$

When solved simultaneously for input levels:

---

[a] Capital subscripts denote first partial derivatives. Double capital subscripts denote second partial derivatives. Small case subscripts are labels, unless noted otherwise.

$$F_{LL}L = w - a$$

or:

$$L* = F_{LL}^{-1}(w-a)$$

The resulting set of optimum input demand equations (L*) are linear in normalized input prices and have symmetric cross-price effects (due to symmetric F_{LL}^{-1}). This symmetry is important because it can provide a basis for more efficient econometric coefficient estimates through cross-equation constraints on parameters.

Optimum output supply in this case is expressed as:

$$\begin{aligned} Q* &= F(L*;K) \\ &= c + a'L* + 1/2\ L*'F_{LL}L* \end{aligned}$$

which is quadratic in normalized input prices:

$$\begin{aligned} Q* &= c + a'F_{LL}^{-1}(w-a) + 1/2\ (w-a)'F_{LL}^{-1}(w-a) \\ &= c - 1/2\ a'F_{LL}^{-1}a + 1/2\ w'F_{LL}^{-1}w \end{aligned}$$

Summing the coefficient matrices (F_{LL}^{-1}) across firms yields aggregate input demand and output supply relations.

<u>Multiple outputs</u>. Because of the multiple commodities under consideration in the cash grain sector, a single-aggregate-output analysis is not adequate. To develop the static multi-product case, we shall assume that some output (Q_n) is additively separable from a quadratic function (F) in other outputs (vector Q) and inputs (L and K). (The plausibility of this assumption for agriculture is explained

in Chapter 4.) Normalizing prices by the price of Q_n (P_n) at the outset and maximizing the resulting normalized profit function ($r = R/P_n$, i.e., profits expressed as units of Q_n):

$$\max_{Q,L} r = Q_n + p'Q - w'L$$

$$\text{subject to } Q_n = F(Q,L;K)$$

with F_{YY} [$Y = (Q' \quad L')$, the vector of Q's and L's] again symmetric negative definite, the first-order conditions:

$$F_Q = -p$$

$$F_L = w$$

are again solved simultaneously to get optimum non-numeraire outputs and inputs that are linear and symmetric in prices:

$$(Q*' \quad L*')' = F_{YY}^{-1} (-p-a_q' \quad w-a_l')'$$

and $Q*_n$ quadratic in prices. Although $Q*_n$ can be expressed in terms of Q* and L*, it is no longer possible to express Q* in terms of L* (except under very restrictive conditions). Once again, aggregate relations result from summing across firms.

Hotelling's Lemma (Diewert, 1982, p. 581; Nadiri, 1982, p. 452; Varian, 1984, p. 52) is demonstrated by taking the first partial derivatives of the resulting indirect profit function in normalized output and input prices, which is:

$$r^* = Q^*_n + (p' \quad -w')\ (Q^{*\prime} \quad L^{*\prime})'$$

$$= c - a'F_{YY}^{-1}a + 1/2\ (-p' \quad w')F_{YY}^{-1}(-p' \quad w')'$$

$$+ (p' \quad -w')F_{YY}^{-1}(-p' \quad w')' - (p' \quad -w')F_{YY}^{-1}a$$

in which $a = (a_q' \quad a_l')'$, and which reduces to:

$$r^* = c - a'F_{YY}^{-1}a + a'F_{YY}^{-1}(-p' \quad w')'$$

$$- 1/2\ (p' \quad -w')F_{YY}^{-1}(-p' \quad w')'$$

By Hotelling's Lemma, the first partial derivatives of r^* with respect to p and -w yield Q* and L*:

$$(Q^{*\prime} \quad L^{*\prime})' = (r^*_p{}' \quad -r^*_w{}')' = F_{YY}^{-1}\ [(-p' \quad w')' - a]$$

as shown above.

Endogenous prices. With exogenously determined prices, this competitive supply model is the same for both the firm and the aggregate industry. In this case, output and input prices are not influenced by output supply or input demand, as in Figure 2.1.

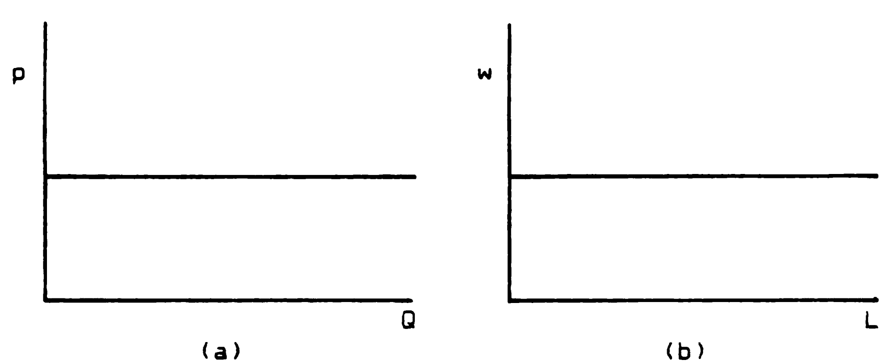

Figure 2.1. Exogenous prices for outputs (a) and inputs (b).

With downward-sloping output demand and upward-sloping input supply curves, however, the analysis becomes more complex at the level of the industry. (The case of the competitive model with exogenous prices would still apply for the firm.) F_{yy}^{-1} is now the aggregate derived from the sum of individual functions. Dropping (*) for simplicity's sake, endogenous prices resulting from less-than-totally-elastic output demand and input supply are represented most simply by:

$$p = p_x + m_q Q$$

$$w = w_x + m_l L$$

in which intercepts p_x and w_x are functions of exogenous price shifters, and m_q and m_l are the slopes of output demand and input supply curves, respectively, as shown in Figure 2.2.

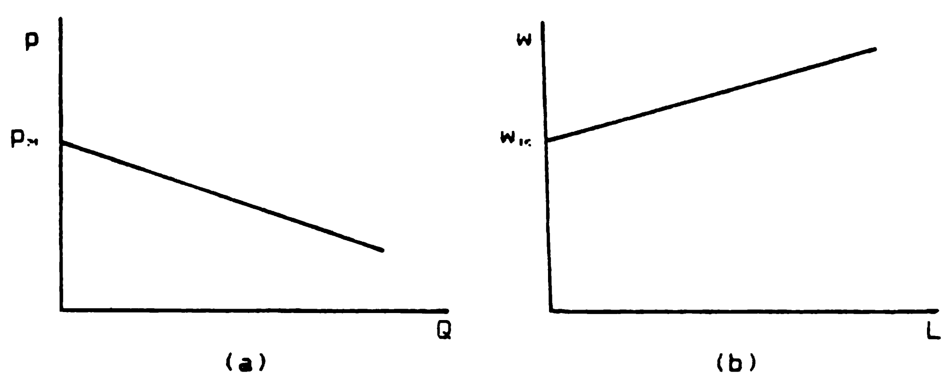

Figure 2.2. Endogenous prices of outputs (a) and inputs (b).

Equating these prices with marginal products:

$$(a_q' \quad a_l')' + F_{YY}(Q' \quad L')' = (-p_x' \quad w_x')' + \begin{pmatrix} -m_q & 0 \\ 0 & m_l \end{pmatrix} (Q' \quad L')'$$

or:

$$(F_{YY}-m)(Q' \quad L')' = (-p_x'-a_q' \quad w_x'-a_l')' \qquad \text{where } m = \begin{pmatrix} -m_q & 0 \\ 0 & m_l \end{pmatrix}$$

optimum quantities become:

$$(Q' \quad L')' = (F_{YY}-m)^{-1}(-p_x'-a_q' \quad w_x'-a_l')'$$

By endogenizing induced price changes, this relationship expresses output supply and input demand as functions of exogenous price shifters only.

With expected signs on the elements of m, Q and L are less responsive to p_x and w_x the more p and w respond to Q and L, demonstrating D.G. Johnson's (1950) major point about output supply elasticity depending on input supply elasticity. (Note that there is no implication of irreversibility.)

If m is diagonal, or at least symmetric, cross-price effects are still symmetric, a case which seems likely. Note that if all inputs were variable, even one upward-sloping input supply curve or one downward-sloping output demand curve would serve the same purpose as diminishing returns in making the coefficient matrix non-singular and invertible, i.e., in uniquely determining quantities. The similarity of the effects of endogenous output and input prices is interesting, but it is not essential to this study. Endogenous input prices will be the focus of the remainer of this work, therefore, and the endogeneity of output prices will be ignored.

Dynamics with Quasi-Fixed Inputs

Time has not been explicitly part of the above static analysis, so no distinction has been drawn between stocks and flows. Simply indexing quantities for time does not alter this approach (Arrow, 1964). When an outcome depends on outcomes in other periods, however, the problem becomes dynamic, and the distinction between stocks and flows becomes important. Such is the case when the problem above includes changing prices and durable inputs with upward-sloping supply curves, known in the literature as "quasi-fixed" inputs. (Good references include: Nerlove, 1972; Treadway, 1970 and 1974; Epstein, 1981; and Nariri, 1982, pp. 477-9). The notion of quasi-fixity is best seen as the analog of quasi-rent: rent is earned by fixed assets, quasi-rent by durable assets which are varied only by affecting their prices (Marshall, 1982(1920), p. 358). The resulting model of dynamic adjustment is the core of the "flexible accelerator" model of macroeconomic dynamics (Lucas, 1967a).

For present purposes, a durable is defined as an input with less-than-total depreciation in a production period. (In the discrete analysis used below, a period is one year.) Depreciation is defined as the periodic reduction in the value and service-yielding ability of inputs. The common rule that depreciation is a constant proportion (d) of the durable stock will be assumed, although this proportion can vary by type of input. (See, e.g., Jorgensen, 1971, pp. 1112 and 1141; Nickell, 1978, p. 8; Burmeister, 1980, p. 42; Gunjal and Heady, 1984; and Appendix A.) This simplification makes it straight-forward to aggregate an input of different vintages after an uneven history of acquisition. It is also assumed that service flows are constant proportions of durable stocks, another very common assumption, which makes it irrelevant whether production function arguments are denominated in stocks or flows. (See, e.g., Treadway, 1970, p. 331, and 1974, p. 19.)

Because the distinction between variable and fixed inputs becomes blurred in this model, the vector L will now be used to represent stocks (after new purchases) of all inputs at the beginning of the production period. (For simplicity, all input purchases are assumed to occur at that time.) Vector I represents new purchases, and vector (1-d)L is stocks at the end of the production period (i.e., after depreciation). By definition, then:

$$L_t = I_t + (1-d)L_{t-1}$$

For durables:

$$0 \leq d < 1$$

For the special case of non-durable inputs:

$$d=1$$

so:

$$L_t = I_t$$

(For the following analyses, the subscript t will be suppressed in all unambiguous cases.)

In the multi-period model needed for dynamic analysis, first-order conditions are derived by maximizing the present value of future profits (J) with respect to current decision variables (Qo, Lo). That is, in each period, output and input levels are chosen so as to maximize the infinite sum:

$$\max_{Qo,Lo} J = \underset{t=0}{\mathrm{INFSUM}}\ (1/(1+i))^{t}(Q_{n} + pQ - wI)$$

$$\text{subject to } Q = F(Q,L)$$

$$L = I + (1-d)L_{t-1}$$

in which i is the opportunity cost of capital funds, so that 1/(1+i) is a discount factor; and w is the vector of input prices. (Acquisition and salvage prices are assumed to be equal for each input.) This is the discrete version of a standard problem in optimal control theory and the calculus of variations. (See, e.e., Gould, 1968; Nerlove, 1972; Kamien and Schwartz, 1981, pp. 7 and 113; and Kendrick, 1982.)

The dynamic analysis does not alter the first-order conditions for outputs (currently assumed to be non-durable):

$$J_{Qo} = Fo_{Qo} + p = 0$$

except that p must now be considered to be prices expected to prevail when outputs go to market. With stationary price expectations, the first-order condition for each input becomes:

$$J_{Lo} = \mathrm{INFSUM}\ (1/(1+i))^{t}F_{Lo} - wIo_{Lo} = 0$$

$$\Rightarrow \mathrm{INFSUM}\ (1/(1+i))^{t}F_{L}L_{Lo} = wIo_{Lo}$$

With F_L constant and $Io_{Lo}=1$:

$$[\text{INFSUM } (1/(1+i))^t L_{Lo}]\ F_L = w$$

Replacing L with $(1-d)^t Lo$, and with $Lo_{Lo}=1$:

$$[\text{INFSUM } (1/(1+i))^t (1-d)^t Lo_{Lo}]\ F_L = w$$

$$[\text{INFSUM } (1/(1+i))^t (1-d)^t]\ F_L = w$$

Calling the constant summation term (which reduces to $(1+i)/(i+d)$) "B":

$$BF_L = w$$

This is the dynamic first-order condition for each input. Note that i+d is the sum of the interest and depreciation cost rates of durable use. When d=1, B=1 and the case of non-durable inputs is still analogous to that of the static analysis. When 0<d<1, B is a multiplier of the annual productive services of an input. When d=0, the multiplier is (1+i)/i.

With exogenous input prices, the first-order conditions:

$$(F_Q' \quad (BF_L)')' = (-p' \quad w')'$$

can be transformed into:

$$(F_Q' \quad F_L')' = (-p' \quad (B^{-1}w)')'$$

in which $B^{-1}w$ is the annual user cost of inputs. The dynamic case then reduces to the static case, as mentioned above, and some fixed input (or downward-sloping output demand) is required to determine equilibrium.

With endogenous input prices linear in purchase quantities (for a justification, see Gould, 1968, p. 49):

$$w = w_k + w_1 I$$

as in Figure 2.3, this simple transformation is not possible.

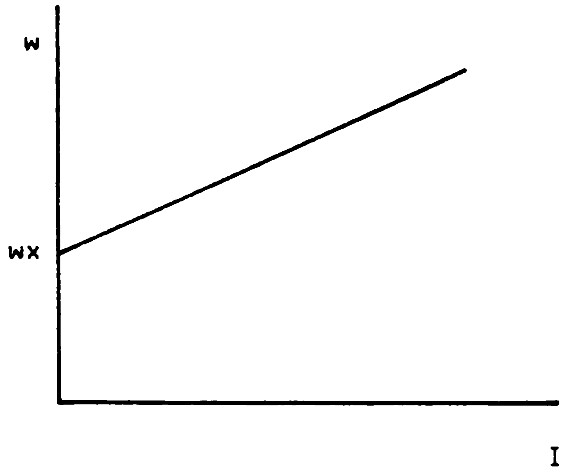

Figure 2.3. Endogenous price of a durable.

Instead:

$$(F_Q' \quad BF_L')' = (-p' \quad (w_k + w_1 I)')'$$

With quadratic F and $I = L - (1-d)L_{t-1}$:

$$((a_Q + F_{QQ}Q + F_{QL}L)' \quad (B(a_L + F_{LQ}Q + F_{LL}L))')' = (-p' \quad (w_k + w_1 L - w_1(1-d)L_{t-1})')'$$

Collecting endogenous terms on the left-hand side and predetermined terms on the right-hand side:

$$((F_{QQ}Q+F_{QL}L)' \quad (BF_{LQ}Q+BF_{LL}L-w_lL)')' =$$

$$((-p-a_q)' \quad (w_k-Ba_l)')' - (0' \quad (w_l(1-d)L_{t-1})')'$$

Factoring out the endogenous variables Q and L yields:

$$\begin{pmatrix} F_{QQ} & F_{QL} \\ BF_{LQ} & BF_{LL}-w_l \end{pmatrix} (Q' \quad L')' =$$

$$((-p-a_q)' \quad (w_k-Ba_l)')' - (0' \quad (w_l(1-d)L_{t-1})')'$$

Let $\underline{F}$ be the matrix:

$$\begin{pmatrix} F_{QQ} & F_{QL} \\ BF_{LQ} & BF_{LL}-w_l \end{pmatrix}$$

then:

$$\underline{F}\ (Q' \quad L')' = ((-p-a_q)' \quad (w_k-Ba_l)')' - (0' \quad (w_l(1-d)L_{t-1})')'$$

and:

$$(Q' \quad L')' = \underline{F}^{-1}(-p' \quad w_k')' - \underline{F}^{-1}(a_q' \quad Ba_l')'$$

$$- \underline{F}^{-1} \begin{pmatrix} 0 & 0 \\ 0 & w_l(1-d) \end{pmatrix} (0' \quad L_{t-1}')'$$

Under these conditions, the short-run price coefficient matrix ($\underline{F}^{-1}$) is no longer symmetric. As in the exogenous price case, it could be rendered symmetric if B or the resulting user costs of durables were known.

In this model, long-run profit maximation results from balancing fluctuations in the value of the marginal product of inputs with correlated fluctuations in their costs. In the case of durable inputs, purchases are timed to reduce these costs by smoothing the scheduling of acquisitions. This is the partial-adjustment model of asset acquisition, shown here as theorectically grounded in external (to the industry) adjustment costs. (For further exposition of this concept, see Alchian, 1977, Proposition 8.)

Note that a common partial-adjustment output supply model (Nerlove, 1958b, p. 26):

$$Q = Q(p,w,Q_{t-1})$$

does not follow from durable-stock-adjustment model just derived:

$$L = L(p,w,L_{t-1})$$

Instead, output supply is a function of leftover durable quantities:

$$Q = Q(p,w,L_{t-1})$$

Whether Q_{t-1} can serve as reasonable proxy for L_{t-1} in econometric estimation is largely an empirical question. It appears that there is no way to derive a theoretical basis for this substitution.

As an alternative to the external adjustment costs derived above, adjustment costs could also be considered to be internal to the firm or industry. Such costs might be thought of as production lost to planning, purchasing, and installing new assets. (See, e.g., Gould, 1968.) Linearly increasing unit costs would be precisely analagous to the linearly increasing unit prices analyzed above (Treadway, 1974, p. 29), and they would produce the same results. If these costs were affected by (or affected) the level of input use (or, for that matter, levels of output production), any symmetry left in the coefficient matrices would be lost (Mortensen, 1973). Such adjustment costs are known in the literature as "non-separable" (Nerlove, 1972), and are included in the analysis in Appendix B.

Although it is often stated that it is irrelevant whether adjustment costs are stated in terms of gross or net (gross minus depreciation) investment (e.g., Lucas, 1967b; Treadway, 1972, p.847), the two are not equivalent. There are reasons to prefer the use of gross investment (Gould, 1968); lacking a reason to also consider net investment, this convention will be used here.

Dynamics with Ocasionally-Fixed Inputs

In the above analysis, all inputs were treated as either variable or quasi-fixed, with the implicit possibility of the existence of fixed factors. In this section, factors that are "occasionally-fixed" (fixed in some periods but not in others) are described and related to irreversibility.

It is worthwhile at this point to emphasize that the term "fixity" means that the level of use of an input is not an endogenous decision at the margin in the current period, although the fact of fixity may be endogenous; fixity does not imply the same level of input use in all periods. It follows, then, that an input that is fixed in one period may be variable or quasi-fixed in another, i.e., occasionally-fixed.

Two constraints that can cause factors to be occasionally-fixed are discussed in this section. They are:

1. the absence of a salvage market for durables, which causes I=0 when it would otherwise be negative; and
2. an input supply capacity constraint that limits I to a level less than otherwise desired.

Note that the first constraint applies to durables, whereas the second could apply to any input. Although such constraints could be thought of merely as more sharply-sloped portions of input supply curves, absolute constraints (vertical portions of supply curves) serve better for exposition purposes. In these cases, the level of I is predetermined, and the price of inputs becomes wholely endogenous.

These cases are exhibited graphically in Figure 2.4. Panel (a) shows the normal case of a quasi-fixed input, with both prices and purchases endogenous to the level of input demand. In panel (b), input demand is so low that none of the durable is purchased, and had price not fallen precipitously as a result of no alternate use, some of the durable would have been sold. In panel (c), demand has risen to and above the point of total input supply capacity utilization, thereby driving up prices to maintain short-run equilibrium. Finally, in panel (d), the input is quasi-fixed, but its marginal value product has fallen below its opportunity value in another use; the sector in question has become a net supplier of the "input", and the rest of the economy has become a net demander. These last three cases are described in more detail below.

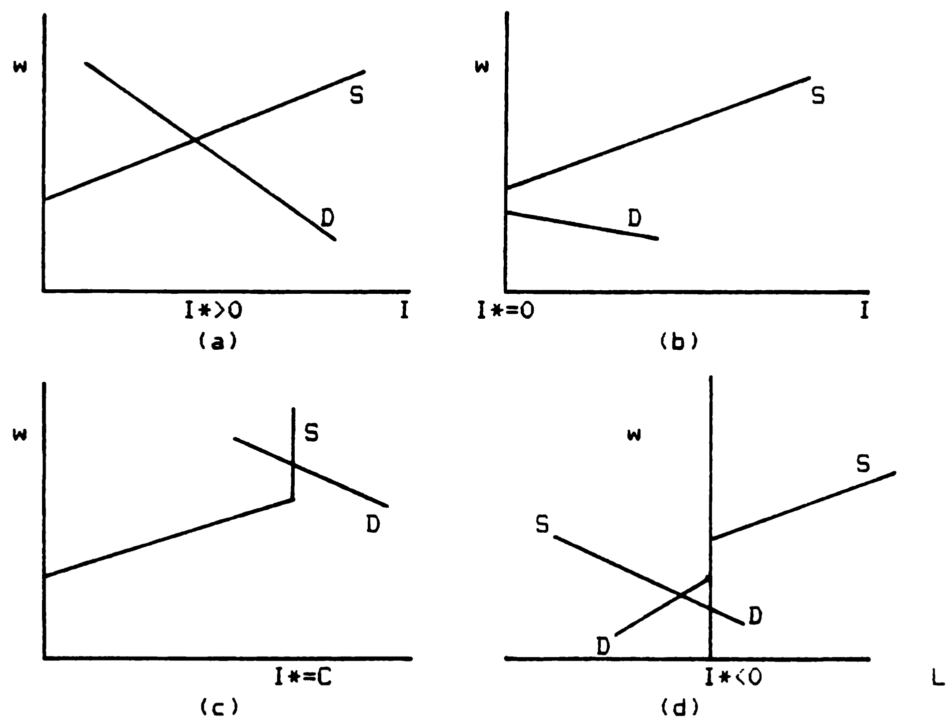

Figure 2.4. Cases of input supply: quasi-fixity (a), salvage-constrained fixity (b), input-capacity-constrained fixity (c), and salvaging (d).

<u>No available salvage market</u>. Although alternative approaches are possible (e.g., Hartman, 1972), it is most common to constrain the model with quasi-fixity to non-negative gross investment solutions. Although this condition need not apply for each firm, it must hold in aggregate unless some external market exists for disposing of assets. (See, e.g., Taylor, 1984, p.353.) There are two approaches to applying this constraint.

The first approach is merely to assume that the constraint is never binding. This approach is justified by observing that, for the sectors examined empirically at the level of aggregation used, gross investment has always been positive (e.g., Treadway, 1971, p. 847; Epstein, 1981, p. 91). This allows for use of the above model without modification, which is the standard approach in the literature. (See also, e.g., Nadiri and Rosen, 1969; Schramm, 1970; and Epstein and Denny, 1983.)

The second approach admits that there will be times when the constraint will bind for at least one significant input for which, at other times, it does not bind (Arrow, 1968). This input will then be occasionally-fixed. In periods in which it is variable or quasi-fixed, its input level will be a function of prices and other fixed input levels. In periods in which it is fixed (at $L = (1-d)L_{t-1}$), its price will be a function of other prices and its own and other fixed input levels. This situation is represented by the equation (see Appendix B for derivation):

$$\begin{pmatrix} Q \\ D_vL+D_fw_l \end{pmatrix} = \begin{pmatrix} F_{QQ} & (F_{QL}+F_{QI})D_v \\ B(D_v-D_f)F_{LQ} & (B(F_{LL}+F_{LI})-w_l)D_v+D_f \end{pmatrix}^{-1} \left[\begin{pmatrix} -p \\ D_vw_l \end{pmatrix} - \begin{pmatrix} a_q \\ B(D_v-D_f)a_l \end{pmatrix} + \begin{pmatrix} F_{QI}D_v-F_{QL}D_f \\ B(F_{LL}D_f+F_{LI}D_v) \end{pmatrix} (1-d)L_{t-1} \right]$$

in which:

D_v is a diagonal matrix of:

ones for inputs that vary in the period,

zeros for inputs that are fixed in the period,

D_f is the identity matrix minus D_v, and

F_{QI} and F_{LI} represent non-separable internal adjustment costs.

In this system of equations, output (Q), some input quantities (L), and some fixed-input rent levels (w_x) are determined simulataneously by exogenous price effects and durable input stocks. The pattern of effects is determined by, F's second partial derivatives and the input supply curve slope (w_s).

This model is important to analyses of agricultural supply because it shows how standard "irreversibility" occurs, with some inputs occasionally-fixed in contractions and occasionally-variable (or quasi-fixed) in expansions. Before explaining how this model generates irreversibilities, four major points about the model should be mentioned:

First, the inverted coefficient matrix includes dummy variables (zero representing fixity of an input, or one for others) in all its elements. (This can be shown by taking the inverse by partitioning. See Appendix B and Ayres, 1962, p. 57.) This means that fixing the level of an input changes the values of all coefficients, not just those of, say, own prices. This is an important finding because not all studies recognize this fact.

Second, as each additional input is fixed, each element of the coefficient matrix shifts to a different value, as implied by Samuelson's (1967, p. 38) Le Chatelier Principle (Varian, 1984, p. 56). (Contrary to this principle, the possibility of internal cross-input adjustment cost terms makes the a priori direction of some of these shifts somewhat ambiguous (Treadway, 1970, p. 329); because the conditions for such ambiguity are unlikely, however, this study will assume that shifts have normal signs.) This point (and the previous point) create great problems for econometric estimation.

Third, although this model accounts for the endogenous level of variable and quasi-fixed input use and the endogenous rental value of fixed inputs, it does not endogenize the occurrence of fixity. Because the variables that represent this occurrence (D_v and D_r) appear on the right-hand side of the equation, this is not a true reduced-form. Unless a way can be found to endogenize the fixity decision, there is no clear way to avoid the resulting inconsistent parameter estimates in econometric work.

Fourth, because nothing in this model changes long-run effects, it is generally only the speed of adjustment that changes when inputs become fixed; long run equilibria are not affected. The exception is when occasionally-fixed inputs have a zero depreciation rate, which implies no determinant long-run response to prices. (In other words, input quantities only affect long-run responses when depreciation or price changes give them occasion to vary.)

The dynamics of adjustment with occasionally-fixed inputs may become clearer with an explanation of how occasional-fixity and irreversibility could occur. The reference point for this exposition is the "normal" condition of quasi-fixity for all durable inputs as shown in Figure 2.4, panel (a). Equilibrium in this condition occurs when, for given prices, new purchases simply replace depreciation, i.e., $L=L_{t-1}$ when $I=dL_{t-1}$. (Without loss of generality, this analysis ignores input use trends resulting from changing technology.)

It is easy and important to show that this is a stable equilibrium, as follows: If, with given prices and endogenous price effects, input purchases are greater (less) than depreciation, input use will increase (decrease):

$$I > dL_{t-1} \quad \text{-->} \quad L > L_{t-1}$$
$$(<) \qquad\qquad\qquad (<)$$

Because input purchase demand (Di) is a decreasing function of input stocks, i.e.:

$$Di_{L_{t-1}} < 0$$

the resulting rise (fall) in input use and depreciation cause input purchases to fall (rise) until they equal depreciation:

$$I = dL_{t-1}$$

and thereby establish equilibrium, at least in the limit.

Graphically (see Figure 2.5), a displacement from equilibrium (D*) could be caused, for example, by a rise in output prices implying a new equilibrium (D**). Adjustment would take place, however, by a larger initial shift in input demand (D'), which would then eventually converge to D**.

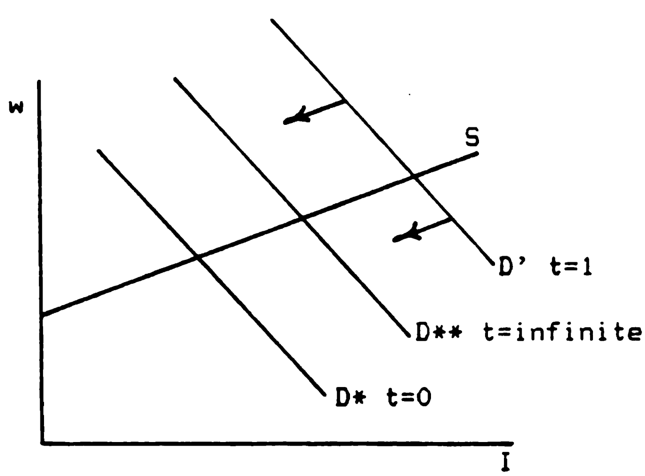

Figure 2.5. Dynamic adjustment to increased output prices with input quasi-fixity.

With input fixity caused by the constraint of non-negative purchases, however, this adjustment process is altered (see Figure 2.6). With output prices falling, D' could fall to the point that new purchases of that input cease (I=0).

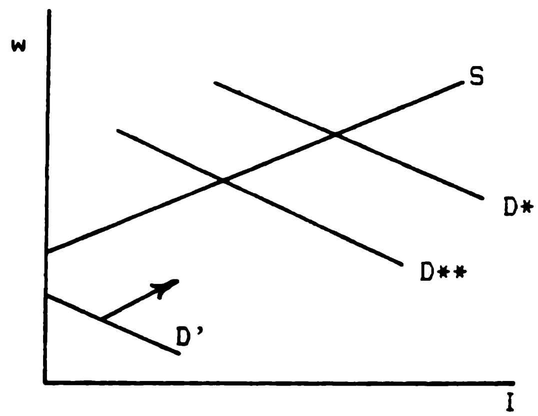

Figure 2.6. Dynamic adjustment to decreased output prices with input fixity (I=0).

In this case, input use cannot fall as fast and, therefore, D' cannot shift back as fast as when I is unconstrained. As a result, adjustment occurs more slowly until the constraint no longer holds; adjustment then proceeds at a "normal" rate.

Depreciation determines the nature of supply irreversibility in the absence of salvage markets. (For a definition of depreciation, see page 14, above.) Because depreciation tends to shift D' out of the condition of fixity, fixity is more likely to occur in contractions than in expansions. If such fixity is a possible occurrence, therefore, contractions will occur more slowly on average than expansions. This is the link between input fixity and the supply irreversibility that is so commonly cited in the literature of agricultural economics.

<u>Input capacity constrained</u>. The obverse of the case just described is that in which input purchases are constrained by the capacity of input-producing industries (I=C), as shown in Figure 2.4, panel (c). The price response of output and the input price flexibility of input demand would be the same, with magnitudes differing only by intercept shifters.

In this case, all the observations made above apply, except that adjustment would occur more slowly in expansions than in contractions, the opposite of the kind of irreversibility found when purchases are occasionally-fixed at zero (I=0). This time, increased stocks tend to shift D' back into the "normal" unconstrained range of the input supply curve following such fixity (see Figure 2.7). (Capacity (C) would tend to shift out through time (C') as long as capacity utilization (I/C) is high.) These factors would tend to make expansions more constrained than contractions. It is also important to note that this analysis applies both to purchased durables and non-durables, whereas the salvage-constrained analysis applies only to durables.

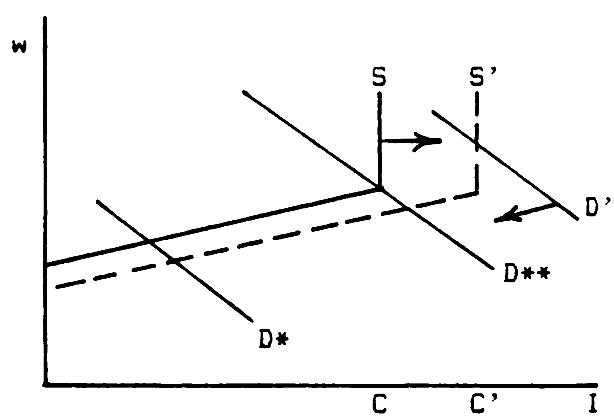

Figure 2.7. Dynamic adjustment to increased output prices with capacity-constrained input supply.

If input supply is constrained by either non-negativity or capacity ($0 \leq I \leq C$), adjustment could be "abnormally" slow in either contractions or expansions. Slow adjustment would result whenever a constraint is binding. Whether contractions or expansions are slower on average would depend on which constraint binds more often. If unavailable salvage markets were more common, contractions, on average, would be more sluggish. If input capacity constraints were more likely to bind, however, expansions would appear more sluggish on average. If neither constraint bound, or if they bound equally often, expansions and contractions would proceed at the same pace on average. In the former case, the speed would not vary; in the latter, it would.

Salvaging inputs. A third type of input occasional-fixity is that shown in Figure 2.4, panel (d), in which an input's stocks are sold to another sector whenever its value in production falls to some base salvage price. Because the salvage market is liable to differ from the acquisition market (in aggregate), price response to quantities sold (if any) generally would differ in magnitude from that to quantities purchased. In other words, as in Figure 2.8, the two curves would not generally have the same slope. (Either could be steeper.)

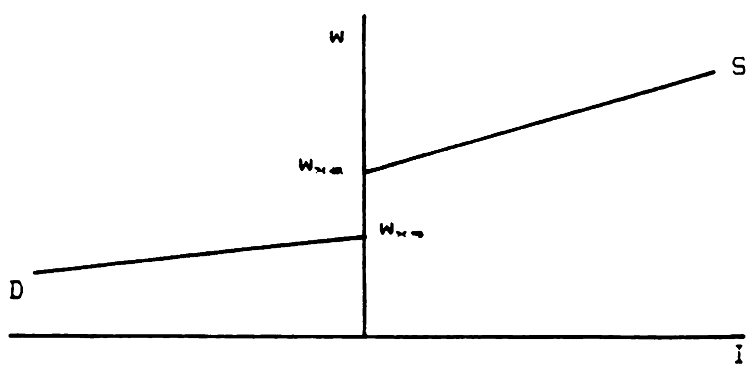

Figure 2.8. Salvage and acquisition markets with different price flexibilities.

Note the distinction between base acquisition and salvage prices (w_{xa} and w_{xs}) in Figure 2.8. This distinction is essential for there to be occasional-fixity in the presence of a salvage market. If the two prices were equal, output response to prices would still differ between acquisition and salvage cases as long as the slopes were unequal. If, on the other hand, slopes were equal and base prices differed, output price response would be the same for the two cases, differing by only an intercept shifter. If base prices were also the same, the shifter would be zero, and the analysis collapses to that of an unconstrained quasi-fixed input.

In terms of adjustment speed, occasional-fixity in the vicinity of w_{xs} would be similar to that with input supply constraints and opposite to that of unavailable salvage markets (the vicinity of w_{xa}). The result, of course, would be to make expansions occur more slowly than contractions.

This analysis is a generalization to an industry aggregate of G.L. Johnson's (1958) notion of asset fixity, which is of most immediate application for individual firms. This generalization works on the assumption that salvage markets generally differ from acquisition markets. If this were not the case, the idea of unconstrained quasi-fixity would be sufficient. Transaction costs, which are the core of Johnson's base-price distinction, are not part of this approach.

<u>Summary of the cases</u>. In summary, four conditions described above could obtain for each input:

1. The case of new purchases (I) constrained by input supply capacity.
2. The "normal" case of I greater than zero.

3. The fixity case of I equal to zero.

4. The salvage case of I less than zero.

Except as qualified above (coefficient equality for parallel vertical or sloped input supply segments), all coefficients would shift for each of these cases for each input. With more complex input supply constraints (e.g., a gradually steeper upwardly-bending supply curve), the number of possible coefficient shifts become infinite. In the case of multiple inputs, possible combinations of these cases multiply as each case for each input implies a different value for each coefficient.

The occurrence of these cases in agriculture, and their effects on agricultural supply, is the subject of the next chapter.

CHAPTER THREE

CHARACTERISTICS OF AGRICULTURAL SUPPLY

The theory just developed can be used to examine agricultural supply elasticity and reversibility in the light of available facts and data. Theoretical guidance is necessary because results depend to a large extent on the form in which data are analyzed.[1] Theory will serve as a guide in this chapter in discussions of agricultural input supply, implications for agricultural output supply, the supply of exported grains, and other factors affecting supply. Although the discussion will be couched in terms of U.S. agriculture, most observations will also apply to agriculture elsewhere; many will apply to other sectors as well. Specific points relevant to other cash grain and oilseed exporters will be covered in the next chapter on empirical methods.

Input Supply in Agriculture

As mentioned in the Introduction, input supply inelasticity has long been used to explain agricultural supply inelasticity. As described above, short-run input supply inelasticity can be related to 1) long-run supply inelasticity, 2) short-run fixity or quasi-fixity of inputs which are supplied elastically in the long run, or 3) input supply shifters (such as non-agricultural demand) that correlate with agricultural input demand. Characteristics of agricultural inputs that

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[1] Intriligater, 1978, pp. 187-90. For a related example of such dependence, see Woods et al. (1981), in which empirical results vary with the empirical formulations used.

produce such supply behavior will be discussed in this section. A position compatible with this discussion can be found in Tweeten (1969). The following categories of inputs are considered:

labor;

machinery and buildings;

purchased non-durables;

farm-produced durables;

farm-produced non-durables; and

land.

The section concludes with an overview of the interactions of inputs, and a summary analysis of agricultural input supply.

Labor. Economists commonly think of labor as a variable input; whether variable or not, laborers are durable assets. Although labor is an important input in agriculture, the sector does not require a net input of new workers and managers, because production of potential farmers within the secor, labor-saving technical change, and low farmer "depreciation rates" make agriculture a net supplier of people to other sectors. As shown in Figure 3.1, the demand for new laborers is so low that the labor demand curve becomes a supply curve for net disinvestment of laborers ($I<0$), and the labor supply curve from other sectors becomes an input demand curve (D) for laborers. Even in the odd periods in which agricultural labor use does not fall, there is a continuous movement of people out of the sector.

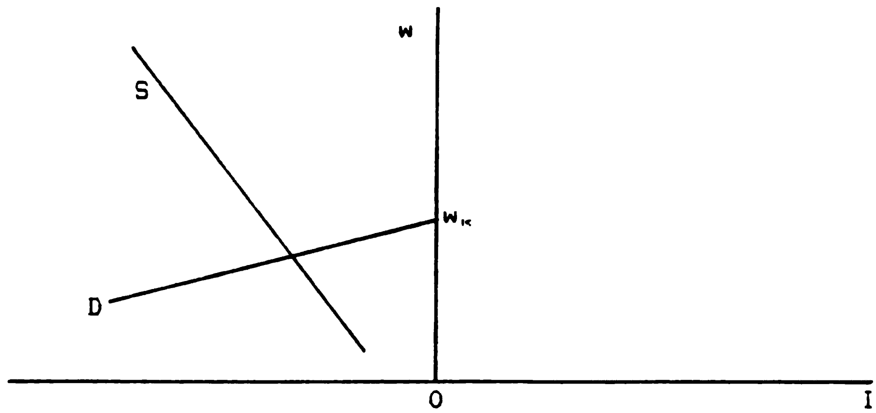

Figure 3.1. Agriculture as a net supplier (S) of laborers (I) to other sectors (D).

Table 3.1. Labor used in U.S. farming (millions of hours), 1965-83.

Year	All Farm Work	All Crops
1965	7,335	3,416
1966	6,858	3,142
1967	6,677	3,104
1968	6,416	3,013
1969	6,198	2,973
1970	5,896	2,788
1971	5,741	2,757
1972	5,433	2,621
1973	5,321	2,667
1974	5,178	2,657
1975	4,975	2,630
1976	4,788	2,556
1977	4,654	2,530
1978	4,446	2,449
1979	4,347	2,436
1980	4,281	2,443
1981	4,202	2,446
1982	4,035	2,372
1983	3,681	2,126

Source: USDA-ERS, 1985b.

The decline in labor use is show in Table 3.1. The slight increases in crop labor in 1973 and 1981 do not necessarily contradict the notion of continuous salvaging for three reasons. First, the labor increases could have come from non-crop farm uses. Second, labor hours per worker may have increased at these times, so worker numbers still could have fallen. Third, even if numbers did not fall, they would not have fallen enough to cut off net out-migration.

Although mobility is easier for young people who prepare for other work, out-migration is more difficult for older people without nonfarm skills. The specialized knowledge and self-discipline of farm managers, in particular, limit their substitutability for other workers both on and off the farm. Spatial isolation, cultural differences, and ingrained preferences are further bottlenecks to movement. In effect, as the demand for farm labor falls and more workers move out of agriculture, the characteristics of the marginal out-migrant change: the base earning potential (w_k) of migrants falls, so demand is lowered, even though the demand curve for any particular kind of worker may be quite flat (due to the greater size of the nonfarm economy). Hiring costs (Nadiri and Rosen, 1969) and labor unions may also constrict movement, as does the correlation of the demands for agricultural and non-agricultural labor (D.G. Johnson, 1950).

The effect of all these factors is to make labor a quasi-fixed input in agriculture. Because workers are constantly leaving the sector, occasional-fixity would not be expected. Such a condition is conceivable, however. In this case, a base acquisition wage higher than the base salvage wage, as in Figure 2.8, would lead to slower expansions than contractions. (The case of net acquisition is so unlikely as to make the counter-case irrelevant.)

Machinery and Buildings. These purchased durables represent, for agriculture, the classic case of quasi-fixity discussed in the literature and reviewed in the previous chapter. They might be considered, therefore, to be a major source of lagged adjustment in agricultural supply. Two factors alter this analysis, however, and will be considered in more detail in the next two chapters. First, the fact that service flows from stocks are actually more flexible than assumed so far may make machinery stocks and purchases less of an influence on machinery use, and, hence, on agriculture supply and supply adjustment. Second, credit availability may affect machinery purchases to an extent that diminishes the role of farmers' machinery stocks, thus considerably complicating the analysis of lagged adjustment. (Buildings can best be thought of as a complement to machinery, animals, or storable output. The latter case is discussed below under Farm-produced durables.)

Regarding constraints on investment, a lack of aggregate salvage markets for agricultural machinery precludes gross disinvestment. Constrained occasional-fixity does not result, however, because gross investment has never fallen nearly to zero (Tostlebe, 1957, p. 146; Table 3.2, below). (Although this may not be true for all types of machines in all areas, it is true for aggregate statistical purposes.) Even in the worst of times, mechanization has been a major force displacing labor.

Even if history were not a guide, capacity-constrained purchases, as in Figure 2.7, would seem to be the more probable case of occasional-fixity. One reason is that plant capacity expansion responses require considerably more than one year for completion. The other reason is that normal plant operation (N on Figure 3.2) is well above 50 percent of capacity (C). (For historical evidence, see Table 3.2.) With symmetrically-distributed[a] random demand (f) centered on normal capacity utilization, the capacity constraint (I*=C) would occur more often than the no-salvage constraint (I*=0). (This can be seen by the relative thickness of the two tails at these points.)

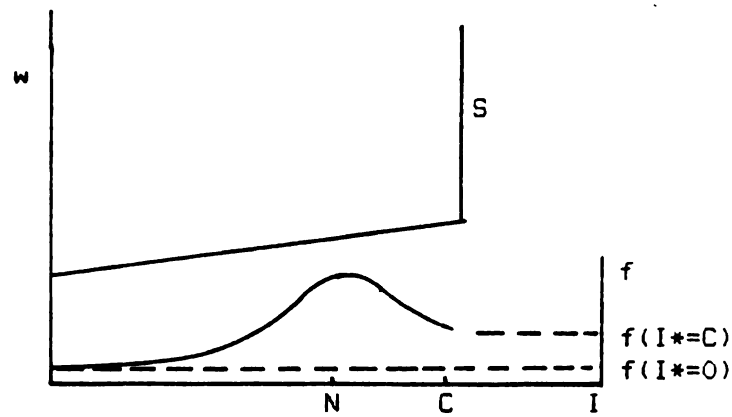

Figure 3.2. The relative likelihood of two cases of occasional-fixity given the frequency distribution of demand for I (f).

As explained in the previous chapter, the net effect would be for supply of these inputs to respond more slowly in expansion than in contraction at the high end of booms and, therefore, on average. Available capacity expenditure data (Table 3.2) show that the supplying industry itself has not experienced significant no-salvage constraints. Because imports and exports are each only about 10 percent of U.S. machinery production (USDA-ERS, 1985a), it is sufficient to consider only domestic capacity and its utilization.

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[a] This would be true with demand distributed at all symmetrically.

Table 3.2. Gross investment in farm machinery and equipment (deflated by its Producer's Price Index), 1965-84, and that industry's fourth-quarter practical capacity utilization rate, 1974-84, and new capital expenditures (deflated by CPI), 1972-82.

Year	Investment (millions of 1967 dollars)	Capacity Utilization	New Capacity (millions of 1967 dollars)
1965	3,431	-	-
1966	3,830	-	-
1967	4,171	-	-
1968	3,521	-	-
1969	3,313	-	-
1970	3,550	-	-
1971	3,348	-	-
1972	3,801	-	93
1973	5,166	-	82
1974	4,886	.86	135
1975	4,318	.78	188
1976	4,394	.66	149
1977	4,261	.65	188
1978	4,900	.58	163
1979	5,062	.58	166
1980	4,105	.62	186
1981	3,545	.48	192
1982	2,565	.31	118
1983	2,334	.38	-
1984	2,166	.42	-

Sources: USDA-ERS, 1986; USDC, 1984 and earlier issues; USDC, 1982a. No earlier comparable numbers for capacity utilization and new capacity are available, due to changes in responsibility for data collection.

Purchased non-durables. Non durables purchased by farmers include materials like fertilizers, herbicides, insecticides, and fuel. Although these inputs are variable to farmers, they come from plants whose capacity is not. Input prices, therefore, can generally be expected to respond to changing demand. For some inputs, like fuel, alternative uses make this price response low. For specialized inputs without alternative uses, like fertilizer, price response can be high. For other inputs with specialized uses but non-specialized feeder stocks or fixed plants, response would be intermediate.

As described in the previous chapter, such endogenous prices for variable inputs will reduce the price elasticity of agricultural supply. With lagged capacity adjustment in the input-supplying industries, however, lagged adjustment and greater long-run elasticity are induced in agricultural supply. (The analysis would be the same if the assets of the input industries were considered to be a part of agriculture itself.) The above conclusions regarding machinery would then also apply to these inputs.

These conclusions would hold both for quasi-fixity and occasional-fixity. Normal operating capacity greater than 50 percent of capacity would constrain input production and use more often in expansion than in contraction, thereby affecting agricultural production in the same way. (See Table 3.3.) The fact of continuous investment in these industries demonstrates a lack of no-salvage fixity (Table 3.4).

Table 3.3. Practical capacity utilization rates for the agricultural chemical industries, fourth quarter, 1974-84.

Year	Nitrogen Fertilizers	Phosphate Fertilizers	Fertilizer Mixing	Pesticides
1974	.71	.92	.49	.71
1975	.81	.76	.55	.81
1976	.82	.56	.66	.84
1977	.92	.73	.60	.69
1978	.97	.77	.75	.87
1979	.89	.92	.61	.70
1980	.88	.89	.70	.58
1981	.86	.61	.48	.58
1982	.74	.59	.52	.49
1983	.84	.87	.67	.56
1984	.84	.79	-	.61

Source: U.S. Department of Commerce, 1984 and earlier issues.

Table 3.4. New capital expenditures in the agricultural chemical industries, (millions of 1967 CPI dollars), 1972-82.

Year	Nitrogen fertilizers	Phosphate fertilizers	Fertilizer mixing	Pesticides
1972	26	53	14	32
1973	78	66	17	41
1974	105	202	24	66
1975	248	188	31	129
1976	355	132	20	110
1977	405	62	23	121
1978	154	113	25	129
1979	91	54	39	96
1980	46	130	25	87
1981	56	252	18	93
1982	50	79	12	98

Source: U.S. Department of Commerce, 1982b.

<u>Farm-produced durables</u>. Farm-produced durables are predominantly of two kinds: breeding livestock and land improvements. Breeding livestock are generally acquirable from (or salvagable to) the production of the same marketable output that they produce. Market prices may be affected thereby, but this is not of immediate consequence to the purposes of this study. Unless a whole population (and more) was desired for breeding, no constraint would bind, and this would be an extremely unlikely event.

Land improvements generally involve the application of purchased durables or their services to alter the productivity characteristics of land. Examples include clearing, draining, irrigating, and fencing. The effect is to make improved land behave like a specialized durable. Because the supply of purchased durables would be capacity-constrained, expansions could be slowed relative to contractions. Although salvage markets for farm land exist, improved land could be occasionally-fixed if improvements caused base acquisition and salvage rents to differ. This topic is discussed in more detail below.

<u>Farm-produced non-durables</u>. Farm-produced non-durables, like feed and seed, are variable at given prices for individual production processes. Because of year-long production lags, however, their short-run supplies are virtually inelastic. (Storage possibilities alter this somewhat.) Because prices for these inputs are derived from demands for end products, they are, in effect, goods-in-process. Although such multi-stage production is of interest in itself (see, e.g., Chavas and Johnson, 1982; Chambers and Vasavada, 1983), it is not of particular interst to the problem at hand. Knowing that these inputs are fixed in the short run allows ignoring them for present

purposes.

Land. Land is the most problematic input category, because, although total area is fixed, usable area and productivity can vary greatly. Because this variation is accompanied by use of inputs that are durable, depreciable, and bound to the soil (fertilizer residues, irrigation and drainage improvements, fencing and windbreaks, etc.), land might behave like a quasi-fixed input. On the other hand, some empirical results indicate that land is a freely variable input in crop production (Karp, Fawson, and Shumway, 1985), probably due to alternate uses like grazing and timber production.

Whether fixed, quasi-fixed, or variable, it is shifts in the supply response of land that interests us here. These hinge on behavior of land in the vicinity of I*=0. (Although capacity-constrained purchases of durable improvements may limit land use expansion, this is merely as a complement, as with machinery; in neither case is land fixed in itself.) This case depends on the effect of durable improvements on the difference between base acquisition and salvage prices, as mentioned above. For now we will state that this effect is basically neutral, as will be discussed below under The Supply of Exported Grains.

Inputs in combination. As discussed in the previous chapter and alluded to in the previous paragraph, supply elasticities of agricultural inputs affect one another's levels of use. (This is evident from both the input price response (w_i) and fixity (D_v and D_r) terms in the coefficient matrices on page 24.) These interrelationships are affected as well by characteristics of the technical production process (the original a and F_{vv} terms). Because reliable measurement of these technical relations depends on proper identification of the other components of the agricultural supply system (and because all these relations change through time), it is not clear that we really know much about these terms. Some specific representative observations can, however, be made.

If, for example, tractors and tractor drivers are complements in production, increasing the use of one factor raises the marginal product of the other (i.e., their F_{vv} term is positive). With the quantities of other inputs held constant, this implies that an exogenous price decrease for either factor would lead to an increased use of both. An endogenous input price limits this effect, however, by decreasing the own-price response of own-quantity and, thereby, the other-quantity's marginal product. The more severe the quasi-fixity of any factor, the more severe the resulting quasi-fixity of its complements, even to their own exogenous price changes and even if they themselves are perfectly variable. The fixity of an input is the extreme case of limiting the price response of its complements, but the result would not be to eliminate it. Complementarity, by the way, is the most common type of relationship between inputs (Hicks, 1946, pp. 94-98).

If, for another example, cultivating machinery and herbicides were substitutes, increased use of one would lower the marginal product of the other (a negative F_{vv} term). With other inputs constant, a decreased price for one increases its use and lowers that of the other. In this case, endogenous prices accentuate these effects, with fixity again the extreme case. (As one input becomes less responsive to exogenous changes, its substitutes become more responsive.)

The actual measuring of these effects becomes more complex when other quantities can vary, but the theoretic work of this paper makes it possible to structure the econometric estimation of these relationships, among others. For a good example of such work, see Hsu (1984).

Summary. On average, then, the use of the inputs described above is more likely to be constrained in expansion than in contraction. All inputs are either neutral with respect to occasional-fixity or more prone to capacity constraints. None are more likely to be subject to the no-salvage constraint.

Among the apparently neutral factors are labor, breeding stock, farm-produced non-durables, and land. Labor is always quasi-fixed and salvaging (through, if occasionally-fixed, it would be expansion-constraining). Breeding stock is quasi-fixed and unlikely to be constrained. Farm-produced non-durables are fixed for our short-run purposes. Land is a special case, shown below to be neutral. For the most part, these are farm produced factors.

The more occasionally capacity-constrained inputs are the purchased factors. Machinery and buildings are quasi-fixed. Purchased durables fixed to land become quasi-fixed. Purchased non-durables are from fixed plant and equipment. All of these inputs are possibly occasionally subject to capacity constraints. They can be expected to dominate the neutral factors, thereby making their complements more sluggish to expand in use than to contract. Although use of substitutes will become more responsive as that of constrained factors becomes less responsive, the net effect on output must be to become less responsive.

The conclusion that expansions are likely to occur more slowly than contractions is supported by empirical results reported in Woods et al. (1981, p. 17). Of the many empirical tests of irreversibility attempted in that paper, one is compatible with the theoretic findings in this study's previous chapter (as justified in more detail in the following chapter). That equation uses a "shifter" for each coefficient in a regression of aggregate agricultural input use on: 1) that measure, lagged, and 2) the lagged aggregate output-to-input price ratio. The study covered the U.S. from 1948 to 1977. (Note, however, that the price ratio is the inverse of that which was judged to be appropriate in the previous chapter.) Simultaneity problems were avoided by using last period's input prices, and by segmenting the period according to rising and falling price ratios rather than rising and falling input use. (The latter technique can only be used when there is only one price variable.) The results are shown in Table 3.5.

Table 3.5. Regression on input use of lagged prices and inputs.

	Intercept	$(P/W)_{t-1}$	Inputs_{t-1}
Coefficient**	27.885	.038	.681
(s.e.)*	(13.80)	(.026)	(.155)
Shifter***	-16.353	-.014	.187
(s.e.)*	(22.94)	(.039)	(.257)

R^2 = .825 Durbin-h = 1.213 (reject hypothesis of serial correlation at alpha = .05)

* Standard error of estimates.
** Coefficients for periods of falling price ratios.
*** Add-on to coefficients in periods of rising price ratios.

Implications for Agricultural Output Supply

It should now be possible to draw some conclusions about agricultural output supply based on the above conclusions regarding agricultural input supply. This will be done first by establishing a theoretic basis in long-run agriculture, second by introducing unconstrained quasi-fixity, and third by introducing input occasional-fixity. The section will conclude with a discussion of cobweb-like cycles.

Long-run supply. It would be helpful to establish a concept of long-run supply to serve as a basis for short-run supply analysis. The most obvious initial base is the horizontal long-run curve with all factors variable. Whether or not fixed factors exist in agriculture in the long run, this model is not sufficient for present purposes. Because of the consideration of endogenous (upward-sloping) input prices and opportunity costs in the production of joint outputs, it would not be useful to assume the prices of all inputs and other outputs constant for the aggregate industry. To show both short- and long-run effects together, the supply of an output will be shown as an (inverse) function of its price, assuming fixed exogenous other-price factors but variable endogenous other-price effects. Such an upward-sloping long-run supply curve is shown in Figure 3.3.

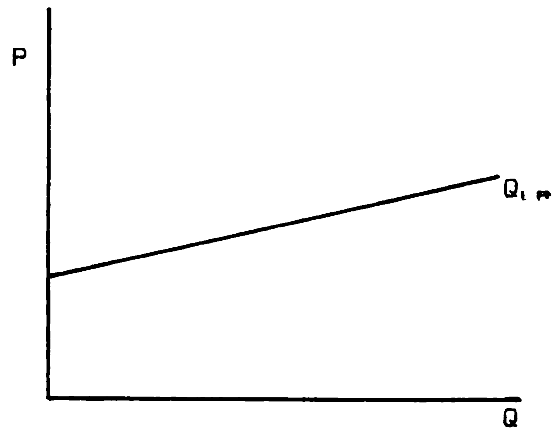

Figure 3.3. Long-run output supply given endogenous prices of inputs and other outputs.

<u>Supply with quasi-fixity</u>. In the theoretical model developed in the previous chapter, a linear short-run supply curve with linear long-run supply and linear input adjustment costs was derived. Short-run supply would then be a steeper intersection of the long-run supply curve, as shown in Figure 3.4. The position of the short-run curve on the long-run curve would be an increasing function of input stocks left over from the previous period. Movement of the short-run curve along the long-run curve from one period to the next is a linear function of the deviation of price in the first period from that of the intersection of the two curves in that period (equilibrium). Equilibrium is the limit of the adjustment process given price. With linear input supply curves adjustment to equilibrium would be of equal speed regardless of the direction of adjustment.

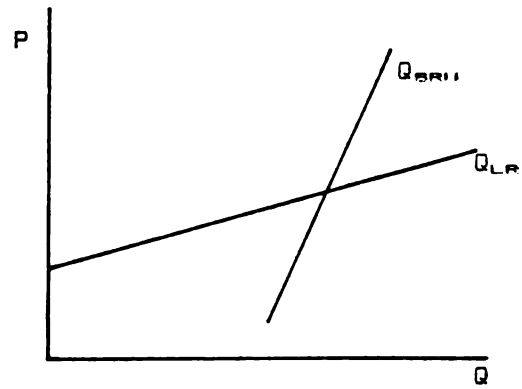

Figure 3.4. Long-run (Q_{LR}) and short-run (Q_{SRU}) output supply with unconstrained input quasi-fixity.

<u>Supply with occasional-fixity</u>. With input occasional-fixity, as described in the previous section, movement along the quasi-fixed short-run supply curve can be constrained. As more inputs become fixed with larger departures from equilibrium, supply becomes increasingly constrained, as shown by the sigmoid curve (Q_{SRC}) in Figure 3.5. Note that, in keeping with the assumption of more binding capacity constraints in expansions than no-salvage constraints in contractions, the curve "turns up" nearer to equilibrium than it "turns down." Similarly, the short-run curve will shift out more slowly along the long-run curve (for a given departure of price from equilibrium) than it will shift in, again reflecting asymmetric constraints on quasi-fixity.

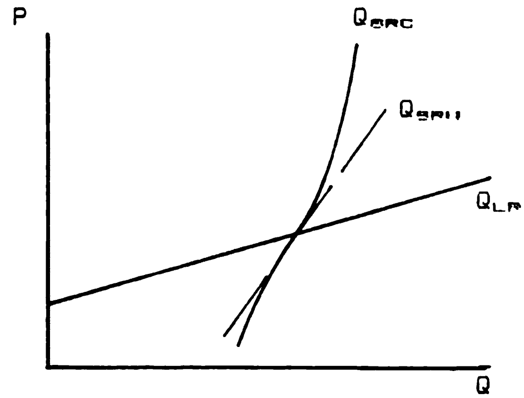

Figure 3.5. Constrained short-run supply with input occasional-fixity.

Implications for cyclicality. With the cobweb assumption of expected price equal to last period's price, the constrained short-run curves just developed have interesting implications for agricultural cycles. Because demand for agricultural inputs is generally thought to be inelastic, it is entirely possible that the demand curve is steeper than the supply curve at equilibrium, as shown in Figure 3.6. In this neighborhood, therefore, a cobweb is liable to be explosive, although convergent to a stable cycle as prices move away from equilibrium. This possibility, cited by Waugh (1964) is known as a "limit cycle" (Baumol, 1959, pp. 273-277). It would be further dampened by adjusting shifts in the short-run supply curve or by rational price expectations, but it would not necessarily be eliminated. This is an interesting observation, because it helps to explain the existence of agriculture cycles (even after long experience and supposed learning), and also explains some regularity in their amplitude. Notably, Waugh believed "that the lagged-output curves for most commodities are shaped somewhat like the one shown in Figure [3.6]" (1964, p. 749). Conclusions about limit cycles are not affected by the fact that he was referring to the sigmoid shape rather than irreversibility.

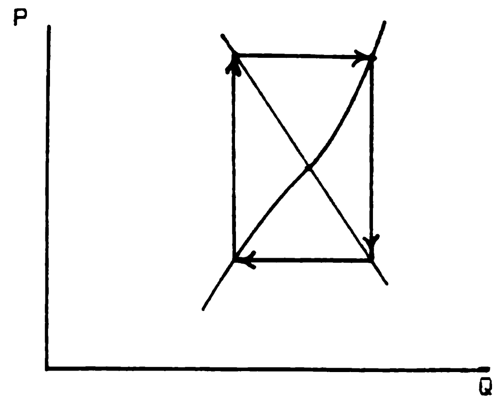

Figure 3.6. Limit cycles with input occasional-fixity.

<u>The Supply of Cash Grains</u>

The theory presented in the previous chapter and the observations of this chapter set the stage for discussing the supply of cash grains and establishing a link between theory and econometric specification in this section. Supply analyses for numerous countries would be necessary to accomplish the broad task of examining world price and trade prospects under various policy regimes. This section focuses on the United States as an example of how these examinations can begin. Specific points about other nations will be covered in the next chapter on <u>Empirical Methods</u>.

The multi-output analysis outlined above could be applied to U.S. agriculture as a whole. If a part of the sector could be seperated from the rest without losing much information, the analysis could also be applied to that subsector. Cash grains meet this criterion: they are grown jointly and are essentially non-joint with the rest of agriculture. Therefore, our theory can be applied to estimating their supply.

Wheat, feed grains, and soybeans (the last not a grain) are the crops of interest. They are generally grown in the same parts of the country (the Corn Belt and the Plains) and they share extensive margins of cultivation. Many of the same durable inputs are used for more than one of these crops, and their different temporal demands facilitate this joint use. As a result, many firms grow more than one of these crops. (Risk reduction may also help explain crop diversification, but risk is not dealt with here.) These characteristics suggest the existence of a joint technology, as attested to by the common presence of each other's cross-price terms in supply estimation. (See, e.g., the MSU Agriculture Model.)

The limitation of joint production to include only these crops (i.e., separability) can also be defended. Substitution with other crops is too slight to measure with national data. Although some inputs may be shared with other crops, the degree of such sharing is generally small enough to ignore.

One group of products, forage crops, may be an exception to this rule. They are grown in the same regions as the cash grains and use some of the same durable inputs. Furthermore, forage crops are often used in rotation with exported grains, although the increased use of chemical fertilizers and pesticides has diminished this practice. For these reasons, wheat, feed grains, soybeans, and forage crops will be considered the joint technology for supply analysis.

The inclusion of forage crops in the joint technology raises the important issue of land conversion costs. These include extraordinary land preparation costs and opportunity costs of scrapped forage production. More durable land improvement costs that may accompany land use changes are also pertinent, as mentioned above. These issues determine the reversibility of land use decisions, and thereby affect the reversibility of crop supply. They are the focus of the remainder of this section.

For the purposes of this analysis, the total supply of land to the subsector is considered fixed. In other words, the effects of non-subsector land use values on current production decisions will be ignored. This approach is particularly safe if it can be assumed that other land uses impinge primarily on forage, because the supply of forage is not of direct concern. The focus of this study is grains and soybeans, and the only relevant other land use effects are assumed to be those of forage price and presence on these land uses. The land use decision, then, is the allocation of the fixed land base between alternate subsector crops.

For analyzing this decision, the same graphs will be used as for other inputs. In this case, gross investment (I) will be considered to be an increase in a non-forage crop use (L). The depreciation rate on land is assumed to be zero, so:

$$I = L - (1-d)L_{t-1} = L - L_{t-1}$$

This terminology is consistent with definitions used for other inputs. (Depreciable land improvements will be considered below.)

For alternate land uses without conversion costs, the graphical analysis is quite simple (see Figure 3.7). The marginal value of land for, say, corn (MV_c) is the demand curve for more corn land in the right-hand quadrant and the supply curve of more forage land in the left-hand quadrant. The marginal value of land for forage (MV_F), on the other hand, shows the reverse: net land supply in the right-hand quadrant and net land demand on the left. The curves slope as they do (decreasing marginal returns) due to specialized quasi-fixed factors. If land is of non-uniform quality and the better land is used for corn, both curves would be lower on the left-hand end than if land were uniform.

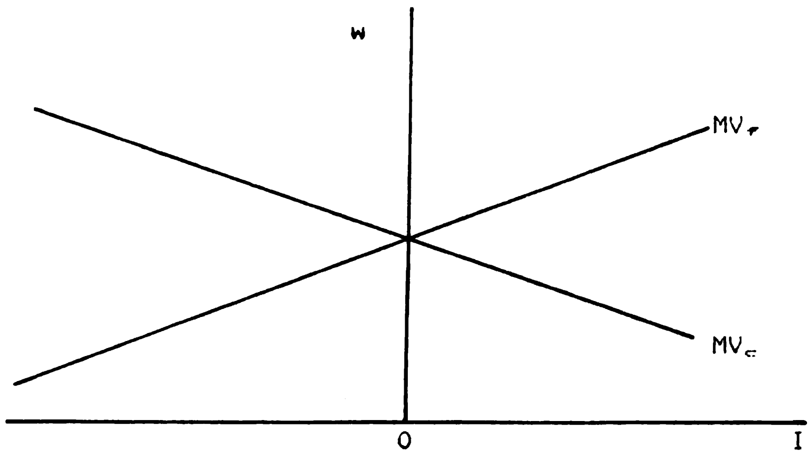

Figure 3.7. Land use equilibrium without conversion costs (w = the price of land).

The intersection of the marginal value curves in Figure 3.7 shows land use in equilibrium (no net change). If the price of corn were to rise, its marginal value curve would shift to the right (MV_C' in Figure 3.8), and land would shift into corn use. With the same corn price in the next period and all quasi-fixed inputs in equilibrium, a new land equilibrium (like Figure 3.7, but with a higher land price) would result. If quasi-fixed factors took longer to adjust, gradually smaller additions to corn land would continue as the system converges to equilibrium. If the price of corn had fallen instead of risen, this same analysis would simply have been reversed, with the speed of adjustment unchanged.

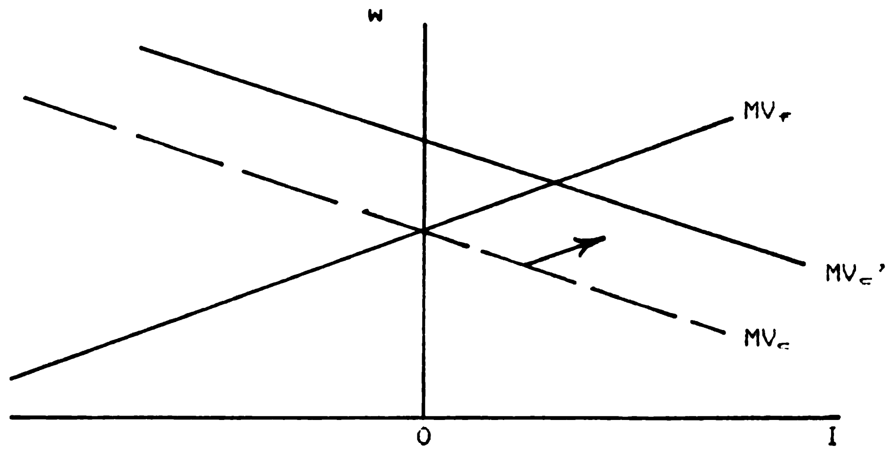

Figure 3.8. Land use shift to corn without conversion costs.

This is the case of an input with a salvage market with price flexibility equal to that of the acquisition market and equal base salvage and acquisition prices (unconstrained quasi-fixity). This analysis is sufficient for land use changes between wheat, feed grains, and soybeans, for which there are no significant conversion costs. With conversion costs, however, the analysis becomes more complex. In Figure 3.9, conversion costs are added to the marginal value of forage curve in the right-hand quadrant to derive the supply curve of new corn land. (There are no conversion costs for new forage land.)

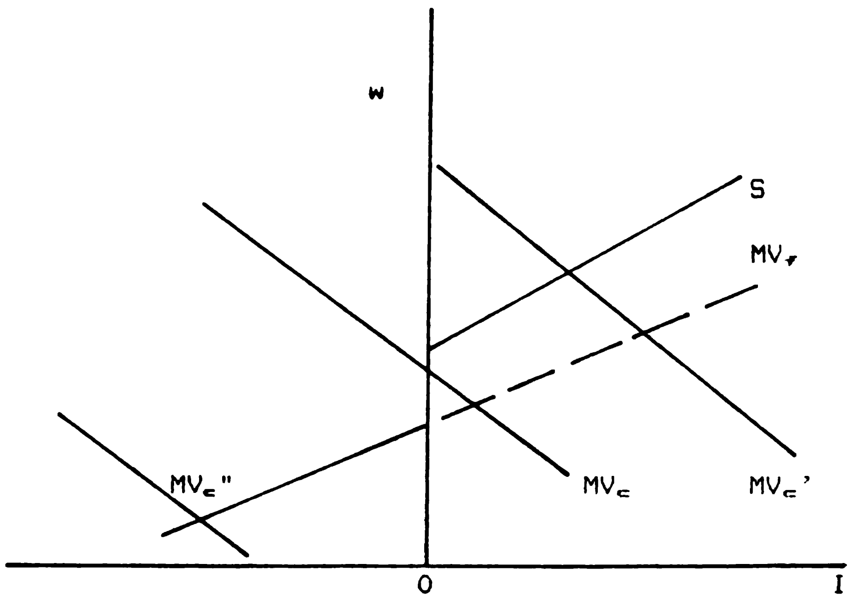

Figure 3.9. Land use shifts with conversion costs.

In this case, corn-price changes in the neighborhood of MV$_c$ will produce no change in land use. Corn price changes resulting in MV$_c$' (or MV$_c$") will produce additions to (or subtractions from) corn land with the same marginal sensitivity to corn price. This is the case of corn land with a salvage market with base acquisition price greater than base salvage price and equal price flexibilities in the two markets.

The net result of this analysis is that, unless land use changes are strongly uni-directional, the net effect of conversion-cost-based occasional-fixity is neutral. With land use conversion going back and forth, as they have in the United States, conversion costs would at times constrain expansions and at other times constrain contractions. Although the actual effect at particular times might be identified, the average effect, as stated in the section on agricultural inputs, would be neutral.

As mentioned above, land use improvements are also pertinent to this analysis, because they are durable, are fixed to the land, and affect land productivity. If such improvements raise the marginal productivity of land for one use more than for the other, the above analysis is altered by inserting durable "kinks" in the marginal product curve. Their durability means that land use changes can move such kinks off the vertical axis, as in Figure 3.10. Because of the reasons cited above, such kinks would tend to have a neutral effect unless land use changes were strongly uni-directional. Depreciation of improvements would tend to make the kinks shrink through time. More divisibility of improvements would tend to make them not appear as kinks at all.

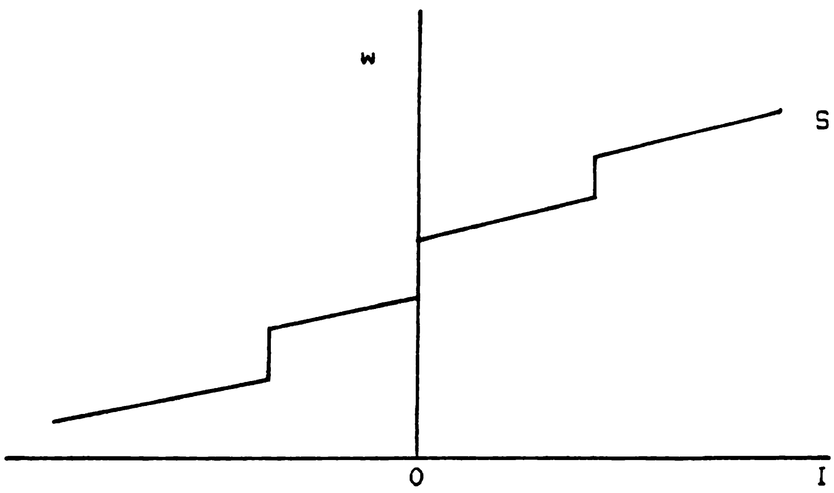

Figure 3.10. The effect of durable land improvements on land supply.

<u>Other Factors Affecting Supply</u>

In addition to the items mentioned above, other factors affect the supply of exported grains. These include export infrastructure, input imports, credit, government policies, and technical change.

In addition to the effects of durable inputs to farming, new fixed infrastructural investments are often cited as causes of irreversible export supply. For a combined production/export system responding to port prices, this would be the case of occasionally-fixed inputs (communication, processing, transportation, and port facilities) as discussed in the previous chapter. Identifying the system in this way could lead to no-salvage constraints (on these facilities) as well as to capacity constraints. Since periods of such constraints might be identifiable, segmentation of the data set to allow for them might be advisable. In any event, new lower-variable-cost infrastructure would then pass on higher prices to the farm; the analysis of farm-level supply response to farm-level prices, however, would not be affected. Complete analysis of export supply, therefore, must distinguish between these two levels of analysis.

Import possibilities for inputs could change the shape of input supply curves. If imports are a continuous permanent part of the input market (e.g., potassium from Canada), they would create no problems. If new sources enter the market as domestic input capacity is reached, however, supply curves could have additional kinks and new slopes. These would suggest a need for additional coefficient shifters in the analysis. Obviously, changing policy with respect to these imports could have similar effects.

Farm credit availability has a major effect on durable input purchases. In addition to the effects of prices and market interest rates, farm income strongly influences investment due to imperfect capital markets and a high degree of internal financing (Johnson, 1947; Tostlebe, 1957). In effect, constricted capital flows cause a separate, endogenous interest rate to prevail in farming. One approach might be to consider cash balances and capital gains to be factors of production that influence adjustment costs, but this could be quite complex. In any event, government policies with respect to income, credit, and insurance must be kept in mind.

Numerous other government policies also affect agricultural supply. To the extent that these policies work directly on prices, no special analysis is required; the use of prices in the analysis is sufficient. Land set-aside requirements and diversion programs, however, work directly on supply. Variables representing these policies have been useful in empirical work (see, e.g., Houck and Ryan, 1972; Wailes, 1983). To the extent that these policy variables are over-simplified, omitted, and autocorrelated, their effects will bias the parameter estimates for lagged endogenous variables (Griliches, 1967, pp. 33-34).

Technical change that increases the efficiency of certain inputs will tend to change the relative demand for inputs and the supply of outputs. To the extent that input mixes differ by output, the supply of some outputs will increase more than that of others (some of which may fall). It is standard to represent such changes with time trends, and that approach could be useful here. To the extent that other variables (especially lagged endogenous variables) embody these trends, seperate representation may not be necessary.

CHAPTER FOUR

ECONOMETRIC METHODS

Introduction

Now that the problem for study has been defined, a body of applicable theory identified, and a sense for its application to the problem established, it is possible to specify techniques for measuring parameters and testing hypotheses econometrically. Major hypotheses to be tested include:

H1. For wheat, feed grains, and soybeans in the United States, short-run and long-run supply responses differ.

H2. For these crops, supply response is constrained more by input capacity in expansions than by lack of salvage markets for durable inputs in contractions.

These hypotheses were examined somewhat informally in the previous chapter. The purpose of this chapter is to examine methods for testing these hypotheses more formally. These methods might also be applied to measure other foreign and domestic supply response for projecting the effects of alternative U.S. policy proposals.

To test these hypotheses, it has been theorized above that supply of each of these crops can be approximated by a linear function of their own prices, input prices, and quantities of durables used in the previous period:

$$Q = f(P, W, L_{t-1})$$

According to the theory, all prices can be normalized by the price of a numeraire: forage. (Another alternative, normalization by the Consumer's Price Index, is discussed below.)

To generate useful econometric specifications, it will be necessary to couch this relation more precisely according to statistical principles for the examination of available data. That will be done in this chapter by the application of a priori knowledge and the design of minor hypothesis tests. These minor tests will be used to sort out appropriate forms and techniques for testing the major hypotheses.

The chapter begins with a section on each of the above four variable vectors, including discussion of relevant policy and structural change where appropriate. Then, after a section on the role of credit, debt loads, and income, opportunities for efficiency gains via cross-equation restrictions will be explored. The chapter concludes with a review of approaches to handling the need for coefficient shifters, and a methodological note.

Dependent Variables

Although the language of this study has been couched in terms of supply, it is not clear which supply variables are most important. If export supply is of concern, the role of export facilities (in addition to farm production) must also be considered. This would be possible for a country (e.g., Argentina) in which there are no significant stocks and consumption is sufficiently predetermined; it would simply be a case of a more comprehensive production analysis. In the U.S., where considerable stocks are held and grain feeding rates are endogenous, the problem is much more difficult; although farm production is predetermined, stockholding and consumption are determined simultaneously with prices. Such a model would be too complex for this study.

Even if looking only at farm-gate supply, the proper choice of dependent variables is not straightforward. Because such a large component of crop supply variation is caused by random weather-determined yield variation, it has become standard in supply estimation to use planted acreage to represent intended production. (See, e.g., Nerlove, 1958b, pp. 66-68; Behrman, 1968, pp. 151-154.) Assuming predetermined growth of expected random yield, quantity supplied is proportional to planted acreage and no information is lost. This assumption has been challenged by Houck and Gallagher (1976), who found U.S. corn yields to be responsive to a corn-to-nitrogen price ratio from 1951 to 1971. This relationship apparently disappeared for the period 1972 to 1980 (Menz and Pardey, 1983), and was never found for any of ten regions of Kentucky, 1960 to 1979 (Reed and Riggins, 1982). Perhaps because such relationships are even harder to find for other crops and other yield components, the assumption of predetermined yield growth is still quite common (e.g., the MSU Agricultural Model; Lee and Helmberger, 1985, p. 195).

One approach to supply analysis with planted acreage estimation is to define supply as acreage multiplied by yield. This ignores, however, that yield is normally expressed in terms of acres harvested, and that the harvested-to-planted acreage ratio is not constant. Not only has this ratio varied considerably; it can be thought of as determined by current price and yield. The facts that these latter two variables are related and that harvested acreage and price are determined simultaneously complicates the empirical estimation of these relations. For present purposes, therefore, this study will focus only on planted acreage and yield as measures of supply.

Before leaving the topic of yield, two important considerations remain. The first is that yield growth represents a technical change that should affect the response of acreage to price. The general topic of technical change is covered below under Lagged Endogenous Variables, but it should be mentioned here that, because yield growth has not been constant (see Menz and Pardey, 1983), such change may not be adequately modeled by simple time trends. Second, because the unavailability of planted acreage data in many countries necessitates the use of harvested area data instead, some of the above-mentioned caveats of using such data should then be born in mind.

There should be no confusion that acreage planted by crop is input demand rather than output supply; nothing in the theory of Chapter Two suggests that the joint-production model is capable of generating the allocation of input demands to specific outputs. (Also see Shumway, Pope, and Nash, 1984.) Because the subsector under consideration is assumed to face fixed land supply, its only land demand equation would be for the determination of land rent. It should be noted that forage acreage is the remainder of total acreage after accounting for acreage planted to other crops. If these equations are estimated simultaneously, the forage equation must be left out to impose the restriction of a fixed land base.

As implied by the theory, variable and quasi-fixed input use and price equations can also be estimated to provide additional evidence about input supply elasticities and reversibilities. If cross-equation restrictions can be imposed with supply equations, estimates of all equations can be made more efficient. (See Cross-equation Restrictions below.) If restrictions cannot be imposed, the independently estimated equations can still yield valuable results, and might even reveal effects not detectable in supply estimation.

This raises another important point about input use. Both input use and output supply equations are assumed to incorporate information about input supply. In the theory chapter, input supply relations were assumed to be stationary because the theoretical analysis was intended to show how equilibrium is determined in one period. When time series data are used in estimation, however, this stationarity assumption may be inadequate. Trend shifts in otherwise-stationary input supply curves present no special problems, but shifts based on short-run capacity utilization, for example, can introduce complications. One approach to the solution of this problem might be to also estimate explicit input supply functions, inculding their own short- and long-run components. This approach is discussed below on page 70, and is relevant to the section on Coefficient Shifting.

Finally, because U.S. acreage set-aside and diversion programs (including the 1983 PIK program) have been shown to be effective (e.g., Houck and Ryan, 1972), acreage "supplied" to these programs (or separate participant and non-participant planted acreage equations) might also be estimated. The alternative followed in this study is to include seperate price-like policy variables in the standard acreage-planted equations (see Crop Prices, below). Too much information is lost by simply ignoring the programs (see Lagged Endogenous Variables, below).

Crop Prices

Appropriate output prices to use for this exercise include the non-forage crop prices normalized (divided) by the price of the numeraire (forage). This normalization deflates prices, accounts for the price of an alternate output (without using another degree of freedom), and is consistent with the above theory. In a case where forage is not an alternative crop, of course, another numeraire must be identified.

As an alternative approach to the normalization of crop prices, the joint technology under consideration could be thought of as including the rest of the total economy as the numeraire good. The result of this approach would be to use a general price level indicator, such as the Consumer's Price Index, as the numeraire price for normalization. This approach provides theoretical justification for the common practice of estimating supply and demand functions of discounted prices. Such a justification makes sense if, in fact, important input and output prices have been excluded from an analysis due to lack of data or problems of multicollinearity and degrees of freedom, especially if the price index used is a reasonable measure of price changes for these goods. If these goods provide a major share of costs or revenues, as does labor in our case, this approach should be preferred.

So far, the term "forage" has been used somewhat indefinitely. In fact, "forage" is being used to stand for a number of different outputs including hay, pasture, and range. It is assumed for the purpose of this study that these outputs are close enough substitutes in production to be considered one output and close enough substitutes in consumption for one price, that of hay, to represent them all. In other cases, pasture rental or beef price data may be more readily available.

Similarly, feed grains (corn, sorghum, barley, and oats) are quite ready substitutes in consumption, somewhat less so in production. Because of the collinearity of feed prices (simple correlations of discounted prices range from .82 to .96 for the period 1955-83), it will generally be advisable to use the price of only one feed grain, usually that of corn, the most commonly traded. (See McKinzie, 1983.) Because acreages of other feed grains in the United States are relatively small, little damage is done by aggregating all feed grain acreages into one measure as well. This will also facilitate the imposition of symmetry conditions between supply equations when appropriate.

Because of the time required for growing crops, expected prices at times of input purchase and use are the relevant determinants of supply response. These expected prices, however, are not observed. In their place, prices received for the previous year's crop are often used. Alternatives include the use of futures prices or, for example, posted Wheat Board prices in Canada. (U.S. loan rates, for that matter, could also be considered as expected prices or determinants of expected prices.)

Another common model of price expectations impose an infinite geometric lag on past prices to derive "adaptive expectations" for the future (Nerlove, 1958b). In reduced form, this model is similar to a partial-adjustment model in one-period lagged price and output terms, except that econometric error terms would be expected to be serially correlated. A combined partial-adjustment/adaptive-expectations model, which reduces to a form with two-years of lags in quantities (Nerlove, 1958b, p. 64), would consume too many degrees of freedom to be used here. In any event, anticipating Muth (1961), the adaptive-expectations approach was disclaimed by Nerlove (1958c, p. 724) in favor of the partial-adjustment approach.

None of these models takes advantage of forecasted supply information directly, as would a rational expectations approach (Begg, 1982), although futures price would be expected to include such considerations. In spite of the usefulness of this approach in some cases (e.g., Eckstein, 1984), the more involved modeling procedures have not produced significantly different results in others (e.g., Karp, Fawson, and Shumway, 1985). This is perhaps as should be expected given the similarity of rational expectations reduced forms to those of other distributed lag models (Tomek, 1985, p. 906).

As a result of these considerations of expectations, last-period's price is used in this study. Policy prices are incorporated into program variables, which are minimized in number to avoid problems of collinearity and degrees of freedom.

For the analysis of farm supply, farm-level prices are obviously most appropriate. In other cases, world or port prices may have to suffice, with the implicit assumption of constant marketing margins. In this case, either official or black market exchange rates may be required to convert prices to the same terms as numeraire prices.

As an alternative to the use of crop prices, some researchers have used gross margins per acre as supply determinants (e.g., Salathe, Price, and Gadson, 1982). This approach combines information on yields, input prices, and technical change to restrict coefficient relations and save degrees of freedom. Unfortunately, it runs the risk of simultaneity problems by its inclusion of endogenous input price and use information. The use of gross returns per acre avoids this problem for inputs and for yield changes when treated as a trend.

Finally, it should be mentioned that the use of single price expectations in a dynamic model implicitly assumes the stationarity of current expectations over relevant time horizons. Although a rational expectations approach could alter this, the marginal benefit of such a model would not justify its cost.

Input Prices

The heart of this study's concern with input prices is related to their endogeneity. This is both the major source of its models' dynamics and the primary cause of problems of estimation. These problems result from the simultaneity associated with endogeneity. (Expectations are not a major problem with inputs, because farmers generally know prices when they make production decisions and order and purchase inputs.) Prices are endogenous because, though often set by manufacturers at the beginning of the season, they are set with "rational expectations"; in other words, manufacturers have the same information as farmers, and forecase demand accordingly. Endogeneity also occurs because these prices can respond to demand somewhat during the purchase season.

In the theoretical model, endogenous input price effects were "reduced into" the coefficient matrix. To implement this model econometrically, only exogenous input price shifters would be used on the right-hand side. This approach has four advantages:

1. The model can be estimated using ordinary least squares (at least as considered so far).
2. The coefficients of output prices are <u>mutatis mutandis</u> with respect to input prices, that is, they show the response of supply to output price changes given induced changes in input prices. Unless one was interested in modeling a whole production system, there are obvious advantages; after all, of what use are <u>ceteris paribus</u> coefficients for policy analysis when the option of fixing input prices does not exist? (A more general case for this position is presented by Leamer, 1978, p. 208.)
3. The effects of exogenous input price shifters, such as their respective input prices, can be identified separately.
4. These latter variables can be left out without biasing output price coefficients (if orthogonal to them). This is helpful because input price data often will not be available. If these data add little information anyway, degrees of freedom can be saved.

A second approach would be to simply use input prices as if they were predetermined in ordinary least squares. The gains in terms of low-cost estimations would be offset by inconsistent estimates, but especially if the latter were not greatly in error, estimates could later be improved via two-stage least squares. This approach is particularly attractive when the system to be estimated is not well specified at the outset (Intriligator, 1978, p. 419).

A third approach would be to model input price directly. For one advantage, this would provide a basis for specifying instrumental variables for the first-stage estimates of input prices in two-stage least squares regressions of input demand. In addition, input price regressions can contribute to the efficiency of input demand estimators via generalized least squares consideration of cross-equation error correlations. (See Cross-equation Restrictions, below.) Finally, this approach allows for the direct examination of lagged adjustment in input supply capacity, which is, for all practical purposes, just another part of lagged adjustment in agricultural production. (For non-durables, this is the same "first-order" quasi-fixity as provided by durables whose supply is less than perfectly elastic; for durables, lagged capacity adjustment introduces a "second-order" form of quasi-fixity into agricultural production.) This is the approach taken in this study.

An important question arises as to whether and how to include the price of time (interest rates) in the analysis. If interest costs vary, the present value of (and hence demand for) durables is affected. This is shown in the theory chapter by the presence of i in the B term on page 17. If B is part of the coefficient matrix, then that matrix is clearly not constant (although this complication is frequently ignored, e.g., by Karp, Fawson, and Shumway, 1985); annualizing durable prices (w) by dividing by B does not solve the problem if i is erroneously assumed constant. One approach to this problem is to calculate an annual user cost assuming expected interest and depreciation rates. This approach is imperfect, however, since the endogenous component of durable prices must remain in the coefficient matrix anyway. Another approach would be simply to retain the B^{-1} term in estimating equations in a rather ad hoc way, and leave it in if it proves to be statistically significant, a particularly good strategy if durable use equations are also estimated. The effect of these approaches on the imposition of symmetry conditions is addressed below under Cross-equation Restrictions.

Lagged Endogenous Variables

As shown in the theory chapter, lagged input quantities could be important determinants of agricultural supply in a dynamic context. Not only are they the base stock to which new durables are added, but by establishing one end of the gap between current and desired stocks, they also affect the level of new input prices and purchases. The coefficients derived in Chapter Two (and to be estimated) include both of these effects. (If depreciation rates were not known or undepreciated lagged stocks used, the coefficients would also include deductions for depreciation.)

To provide for comparison of durable stocks across time and to adequately represent technical change in input industries, both prices and quantities of inputs must be stated in terms of their service-yielding capacities (e.g., horse-power of tractors). (For detailed discussions of this point, see Griliches, 1963, and Jorgenson and Griliches, 1967.) If, in addition, technical change in farming itself changes the demands for various inputs, it would be reflected in output supply and input demand shifts. If such shifts were fairly constant over time (in absolute terms), they could be represented by simple time trends. Such terms, however, would tend to be highly collinear with terms representing percentage growth in input use. Because these latter terms would be a part of measured coefficients of lagged input quantities, simple trend terms would be highly collinear with input quantities. As a result, the addition of trend terms to estimating equations would show little statistical significance, so it might be most useful to ignore such terms and accept their inclusion in the coefficients of lagged input quantities. Both approaches can, of course, be tried and tested; time might even prove to be the more significant variable.

The U.S. Department of Agriculture maintains domestic input stock data series, but such series may not be available for other countries. Given this fact and the common use of the partial-adjustment model in lagged output quantities (Askari and Cummings, 1976), it could be helpful to use lagged output quantities as proxies for lagged input quantities. This comparison is predicated on the assumption that the use of lagged input variables is the preferred alternative. This assumption is based on the fact that a lagged output vector cannot be derived directly from a lagged input vector (at least not without the additional information of a lagged expected output price vector). This is because any given combination of inputs could produce many different combinations of outputs and any given combination of outputs could have been produced by many different combinations of inputs.

As it turns out, however, there may be good reasons for including lagged output quantities as legitimate regressors in their own right.

One justificaiton would be the assumption of the adaptative expectations model described above (under Crop Prices). Although that notion is not accepted for this study, others may be applicable. For one, technical change that is very crop specific may show up more clearly in the effect of lagged output than in that of lagged input. Second, the complementarity of sequential cropping that leads to crop rotation would only be expected to appear as a function of lagged output quantities (Eckstein, 1985). Third, as a sort of combination of these two effects, trends toward double-cropping or inter-cropping (such as with wheat and soybeans in the U.S.) would be revealed in these terms. There may be reasons to include both lagged input and output quantities as regressors. Collinearity between the two could force a choice of one, however; its coefficients would then be recognized as including the effects of the other.

Regardless of which lagged endogenous regressors are used, they will tend to pick up the effects of serially correlated excluded regressors (Griliches, 1967, pp. 33-34). Because the included coefficients will be biased (upward for positive serial correlation in the excluded variable), their standard errors biased down, and the standard error of the regression too low, the partial adjustment specification will generally look better than it would with a proper specification. Perhaps the most obvious candidates for such omission already mentioned are variables representing government policies and programs in the U.S., but any serially correlated omitted variable that should be included would have the same effect. This should serve as a general caveat to the use of lagged endogenous variables as regressors, and may help to explain the wide use of the partial adjustment model in econometric work.

Credit, Debt, and Income

Little mention has been made so far of credit availability and the effects of imperfect capital markets on investment and production. As evidenced by current distress among U.S. farmers, however, these are important and complex topics. (For a more complete treatment, see, e.g., Cochrane, 1958; Hathaway, 1963.)

The pure interest rate effects of credit availability are addressed above under Input Prices. Because of imperfect capital markets, however, the effective interest rate in farming is, for all practical purposes, endogenous.

Capital market imperfections may be based partly on resistance to flow of funds in and out of farm debt markets, but it is more fundamentally caused by the virtual absence of external equity financing (Johnson, 1947, pp. 65-66). The total funds available for asset acquisition and crop production, then, are determined by a desire to maintain moderate debt-to-equity ratios (Weston and Brigham, 1975).

A number of factors affect debt-to-equity ratios. Income flow changes, whether from price or policy shifts, affect the level of cash on hand. When such variables affect perceived land values, asset and equity holdings change. Finally, unanticipated inflation rate changes alter the relative value of existing debt.

Since a composite cost of capital is both endogenous and unavailable as an historical data series, any attempt to include these considerations in explanatory variables will require another approach. Possible predetermined proxy variables include the previous period's income, capital gains, and year-end debt-to-equity ratio. The lag period of these variables would seem to be appropriate as determinants of current investment.

Shifts in policy with respect to credit markets and insurance could also be expected to have effects on investment and production, but they will not be considered in this study.

Cross-equation Restrictions

The theory developed in Chapter Two provides a basis for specifying output supply and input use equations for econometric estimation. It also provides a basis for relating coefficients in one equation to those of others and may thereby justify cross-equation restrictions for estimation. Such restrictions, if true, are a basis for a more effective use of information in producing statistically efficient parameter estimates. In addition to this minimum-variance-of-parameter-estimate sense of efficiency (Pindyck and Rubinfeld, 1981, p. 28), this section considers the benefits of such restrictions in relation to their costs.

Before proceeding to cross-equation restrictions, it should be emphasized that certain "zero" restrictions have already been imposed on our estimating forms. By deriving linear supply and demand equations from a quadratic production function, we have implicitly assumed the adequacy of these first- and second-order approximations. As emphasized by Mortenson (1973), Treadway (1974), and Epstein (1981), however, this assumption is rather restrictive in terms of assumed forms of adjustment costs. Although this form is generally defended by Gould (1968), it represents a considerably stronger simplification than does, for example, a second-order approximation of a static production function. Although a more flexible specification may be preferred, the costs in terms of degrees of freedom probably do not justify such an approach (Epstein and Denny, 1983).

The most obvious source of useful cross-equation restrictions is knowledge of the symmetry of the original F_{YY} matrix (p. 10). Once transformed to account for dynamic considerations, however, this matrix can lose some of its symmetry. In the absence of internal adjustment costs, it can be shown that cross-crop-price effects on crop supply are still equal regardless of how input prices are expressed (see Appendix C). Input prices must be converted to annual user prices, however, for the effects of crop prices on input use to equal those of input prices on crop supply, and for cross-input price effects on input use to be equal. Symmetry still will not hold, however, if the second-order approximation is inadequate or if variations in the input supply relations embodied in the coefficient matrix are insufficiently accounted for.

For somewhat obvious reasons, error terms are likely to be contemporaneously correlated between estimating equations. If all estimated equations include the same regressors as theory suggests they should, no additional information can be gained from this fact (Pindyck and Rubinfeld, 1981, p. 334). Under other circumstances, this condition would suggest the possibility of improving coefficient estimates by the use of generalized least squares and Zellner estimation. If multicollinearity leads to the imposition of zero restrictions that limit the list of regressors, for example, Zellner estimation or three-stage least squares could be used to produce more efficient parameter estimates.

Coefficient Shifting

Given the methods just described for measuring production response, the groundwork is laid for testing reversibility hypotheses. According to theory, output irreversibility exists when input occasional-fixity is more common for either supply expansions or contractions. Because no way has been found to endogenize the fact of fixity and because some way must be found to relate supply movements to fixity, specifications for reversibility hypothesis tests must still be derived.

The simplest approach, as suggested by the discussion of theory, is to compare average rates of price response in periods of expansion versus periods of contraction. Although each average would include periods of different extents of input fixity, at least this partitioning would indicate which direction of supply shift is more likely to produce fixity. Because this is the basic reversibility question, this direct test might be the most meaningful.

The major problem with this approach with a multi-output technology is that it is not clear what constitutes a supply expansion or contraction. Each crop could be dealt with individually--essentially a test for the fixity of specialized inputs--but this would ignore the effect of shifts in the production of substitute crops. Especially because the common acreage measure of supply provides a clear basis for aggregation, shifts in total supply would be used to define periods of expansion and contraction as they relate to unspecialized inputs. A combination of these two methods could also be applied, but the cost in terms of degrees of freedom would be high, since all coefficients must shift for each combination of situations.

Alternative approaches to indexing fixity center on examining input supply directly. For rough approximation, periods of expansion or contraction can be identified in terms of input aggregates. This approach has the advantage of readily available data series in the U.S. Although these inputs cannot be identified in terms of crop use, it is not necessarily use in the subsector of concern that determines fixity anyway.

If more detailed information about input industries is available, direct information about capacity utilization could be used to identify periods of input fixity. Although this approach offers the advantage of using direct information on sources of fixity, degrees of freedom could be consumed quickly if there are too many combinations of cases for different input industries. On the other hand, if periods of expansion of input industries are clear enough, strong support could be provided for fairly simply partition of the period under investigation. Care must be exercised, however, because (as mentioned above) domestic input supply might not be the relevant level for examination; if inputs are imported in significant quantities, foreign producers must also be studied. Furthermore, capacity utilization figures are characteristically unreliable.

All of the approaches discussed above hinge on the notion of segmenting the sample period for the application of dummy variables defining coefficient shifters in ordinary least squares regression. More complex approaches are possible if consideration is given to the point made in the previous chapter that the extent of input fixity is proportional to the magnitude of output supply changes. To incorporate the implication that short-run supply is sigmoid, two techniques are possible. The first would be simply to add non-linear price terms as regressors to produce the desired functional form. Ordinary least squares could still be used, but it would cost additional degrees of freedom and probable collinearity. The second technique would be to impose a restriction that causes input prices (and, hence, linear coefficients) to change proportionately to shifts in supply. This would save degrees of freedom, but the resulting highly non-linear specification would require costly iterative estimation techniques that might not even yield stable parameter estimates.

Finally, it should be pointed out that, as stated in Chapter Two, none of these approaches solves the simultaneity problem of using the observation of D-matrix-type variables to segment the sample period. No way has been found so far to solve the resulting problem of biased estimators.

Methodological Note

It is common to use theory to structure econometric specifications. The extent and form of such structuring, however, varies. At one extreme, a simple belief that some variables affect others provides the basis for ordinary least squares estimation. At the other extreme, variable choices, functional forms, and appropriate estimators are derived from economic theory, statistical principles, and a set of assumptions about the processes that generated the data.

The first approach is predicated on the belief that it is a low-cost way to apply prior knowledge to statistical estimates, that theoretical restrictions are generally arbitrary and are harmful if untrue, and that complex estimation procedures usually offer little advantage over ordinary least squares and may make estimates worse if inappropriate. The second approach assumes that prior knowledge includes some axioms and structure of economic behavior whose contribution to estimation can be tested and used if appropriate.

This study takes an intermediate position between these two. It assumes that hypotheses about economic behavior can be examined to see how they influence results, but that such examinations cannot tell much by themselves. In this view, legitimate hypotheses are so numerous and complex that none can be tested apart from a background of untested maintained hypotheses that influence outcomes in unknown ways. Because only a limited set of combinations of hypotheses can be tested (and because this set itself is frequently large), choices between competing hypotheses are generally inconclusive and often predetermined by prior beliefs. As a result, the researcher's judgement and experience are a major and inseparable part of research conclusions, the acceptance of which is conditional to researcher's preconceptions and to other theoretical and empirical evidence. A more complex statement of a similar outlook is found in Leamer (1978).

The practical significance of this position is that many of the results in the next chapter are presented somewhat tentatively. They were obtained from extensive "specification searches" (the title of Leamer's book), which, though informed by prior hypotheses, were not strictly limited by them. Summary and test statistics are considered to be measures of "fit," not firm indicators of statistical significance. The data analysis, then, represents an attempt to see whether the data can fit the theory, not whether certain hypotheses are "falsified." Finally, the sensitivity of important results to equation specification and the influence of other evidence and theoretical convictions on conclusions are discussed in the following chapter as explicitly as is practicable.

In spite of these caveats, the standard language of statistical significance is still used in Chapter Five. A parameter estimate at least twice as big as its standard error is called "significant," and "significance levels" of .05 and .01 refer to this ratio and a corresponding ratio of three, respectively. t-ratios between 2 and 5 are called "quite" significant, and those above 5 are called "very" or "highly" significant. Those between 1 and 2 are called "fairly" significant, although some between 1 and 1.5 are considered "not high." Those below 1 are consididreed "low," "rather low," or "not very significant," with those below .5 generally considered insignificant. This terminology is adopted for convenience only, and does not reflect an assertion regarding the probability of Type I error.

CHAPTER FIVE

ECONOMETRIC RESULTS

In this chapter, data, econometric specifications, and regression results are reported, and preliminary specific conclusions are drawn about the hypotheses and methods examined in the earlier chapters. In general, the approach taken is to determine whether the world is simple enough and the data definitive enough to yield useful econometric results regarding these hypotheses. Specifically, various specifications are tested to detect dynamic effects and input supply constraints (the major hypotheses outlined at the beginning of Chapter Four). This exercise will also help to determine whether the methods described in the previous chapter are capable of yielding useful results in other applications.

By and large, the results reported below are not very definitive regarding the major hypotheses. This may be because the hypotheses are not true, or may be the result of complex adjustment processes, difficulty in modeling policy effects, and collinearity between independent variables. In addition, specification problems mentioned in the previous chapter and other problems discussed below probably took a considerable toll.

In summary, certain results provide some support for the notion of lagged adjustment, particularly with respect to machinery production capacity. There was little evidence of occasional fixity, except for possible resistance to expansion of planted acreage, which could be caused by constrained fertilizer supplies. If there are additional problems of irreversibility, they are either so complex or so minor (or both) as to be quite unmeasurable given the difficulties mentioned above.

More extensive general conclusions and the possible usefulness of this mode of analaysis for other applications are addressed (along with other topics) in the final chapter. The remainder of this chapter is devoted to examining specific results of regressions on output and the prices of and demands for farm machinery, fertilizers, pesticides, and fuel; a final section focuses on the joint estimation of equations.

The output analysis below is based on the set of crops discussed in the previous chapters. The input analyses, however, are performed for agriculture as a whole, due to data, econometric, and theoretical considerations. Ready data availability did not permit otherwise, although detailed data might be acquirable from the USDA. Econometrically, the use of the individual crop prices did not produce significant effects (possibly due in part to collinearity), so the USDA all-crop price index was used instead. Finally, the afore-mentioned problem of stability in the coefficient matrix caused by endogenous prices of durables was alleviated by normalizing all prices by the Consumers' Price Index as discussed in Chapter Four. Data availability also constrained the input analyses to a calendar-year, rather than crop-year, basis.

The regression results reported in this chapter are for the following dependent and independent variables. (Not all independent variables shown for an equation are necessarily included in any one regression.) In addition, a time trend and an intercept shifter were included in most regressions.

Total acres planted = f (corn and wheat diversion variables, wheat allotment, machinery carry-in)

Machinery and equipment price index = f (own lagged value, lagged steel price, lagged crop price, fertilizer price, wheat allotment, lagged machinery purchases)

Machinery and equipment purchases = f (own user price, lagged crop price, fertilizer price, wheat allotment, debt capacity, own lagged value, machinery carry-in)

Fertilizer price index = f (lagged natural gas price, lagged crop price, machinery user price, corn diversion variable)

Fertilizer pruchases = f (own lagged value, own price, lagged crop price, machinery user price, corn and wheat diversion variables, machinery carry-in)

Pesticide price index = f (own lagged value, lagged crop price)

Pesticide purchases = f (own price, lagged crop price, machinery carry-in)

Fuel price index = f (crude oil price, lagged crop price, wheat allotment, machinery carry-in)

Fuel purchases = f (own price, lagged crop price, wheat allotment, machinery carry-in)

Output

Most of the analysis of output was focused on total U.S. acreage planted to feed grains, soybeans, and wheat (see Figure 5.1). Acreage planted to these individual crops was also examined. In addition, some attention was paid to crop yields and to quantities produced (yields times harvested acreage). More detailed data descriptions and sources are provided in Appendix D.

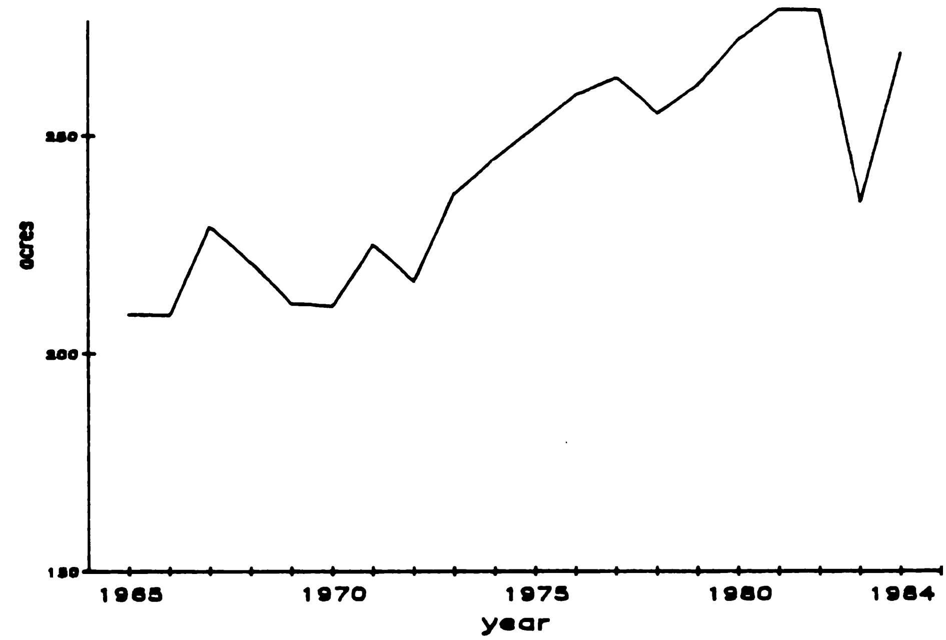

Figure 5.1. Acreage planted to studied crops in the U.S., crop years 1965-84.

The period 1965-1984 was chosen for the analysis because of the availability of data for most variables for the period and because of major changes in the terms of government programs prior to 1965.

Independent variables used. Output prices for planted acres were expressed in terms of expected gross returns per acre (i.e., expected price times expected yield), and were normalized by the same values for hay and by the Consumer's Price Index. Expected prices were taken to be prices for the previous year's crop prior to planting this year's crop; expected yields were calculated as averages of the previous five years' yields adjusted for yield growth trends. (This approach implicitly assumes constant planted-to-harvested-acreage ratios, the value of which would be a component of estimated coefficients.) These variables worked well to explain individual crop choices, but had

little measurable effect on total acreage. The USDA price index for all crops (discounted by hay price and the CPI) was also tried with little success. As a result, no returns variables were retained in total acreage specifications.

Policy variables were used in a number of ways. First, corn and wheat gross returns per program acre were calculated as above, but with adjustments for program payments and acreage set-asides and diversions. These variables were used in conjunction with average (of minimum and maximum) diversion rates to guage the programs' acreage reducing effects. Second, the effects of both variables for each crop were combined by multiplying them together to conserve degrees of freedom. Third, this second approach was modified by dividing by market gross returns per acre; the result was the average diversion rate times the ratio of program-to-market returns. Finally, the wheat allotment was also used. (Most work to develop these approaches was done by John N. Ferris of Michigan State University.)

A number of input price variables were used in the analysis of planted acreage, but generally poor results (wrong signs and collinearity with other variables) led to their exclusion. This decision was supported by the resulting relief from simultaneity concerns stemming from input price endogeneity. Coefficients of the remaining independent variables, therefore, should be considered as _mutatis mutandis_, as discussed in Chapter Four. The input variables used are addressed in the corresponding input sections of this chapter.

Dynamic adjustment variables used in the analysis included the January stock of machinery and equipment ("machinery carry-in") and the debt capacity of farmers. (Both variables--which apply to all of agriculture, not just the subsector under consideration--are described more fully in the machinery section.) The effect of debt capacity on new purchases of machinery was too slight to lead to a detectable effect on acreage planted, so it was dropped from consideration.

A trend variable is included in most relations estimated; it is justified as a proxy for technical change, and it generally tends to improve fits. Lagged acreage variables were tried in certain specifications (see page 73); they did not improve fits well enough to compensate for their generally ad hoc nature, so results of their use are not reported here.

Finally, to test the hypothesis of occasional fixity, "shift" variables were included. These variables serve as proxies for the D matrices (page 24) in time series to represent occasional-fixity as it changes through time. As the theory chapter suggests (page 32), these shifters should account for all conditions of occasional-fixity for all coefficients estimated. To keep them simple enough to be useful, however, only zero/one dummy intercept shifters were used. Three forms were tried. The first focused on a prior belief that the years 1973 and 1974 were strongly predetremined to be years of expansion by increased prices in 1972 and 1973 and diversion relaxation in 1973 and suspension in 1974; a seperate dummy variable was used for each year. The other two forms were ad hoc (and endogenously determined): significant changes (more than four million acres) in total acreage planted to the six crops were taken to indicate the possibility of land-use-related fixity. The second form included negative one for years of contraction, zero for years of little change, and one for years of expansion. The third form dropped the negative values for years of contraction. These latter two forms are shown in Table 5.1.

Table 5.1. Dummy variable coefficient shifter forms representing the possibility of acreage-related fixity, and the total and change in planted acreage (in millions) of feed grains, soybeans, and wheat from which the shifters were derived, 1965-84.

Year	Total acreage	Change in acreage	+/- shifter	+ Shifter
1965	209.9	+ 1.7	0	0
1966	208.6	- 0.4	0	0
1967	229.0	+20.4	1	1
1968	220.9	- 8.1	-1	0
1969	211.4	- 9.5	-1	0
1970	210.6	- 0.8	0	0
1971	224.9	+14.3	1	1
1972	216.5	- 8.4	-1	0
1973	236.7	+20.2	1	1
1974	244.7	+ 8.0	1	1
1975	252.1	+ 7.4	1	1
1976	259.3	+ 7.2	1	1
1977	263.3	+ 4.0	1	1
1978	255.0	- 8.3	-1	0
1979	261.6	+ 6.6	1	1
1980	272.0	+10.4	1	1
1981	279.0	+ 7.0	1	1
1982	278.5	- 0.5	0	0
1983	234.6	-43.9	-1	0
1984	268.8	+34.2	1	1

Regressions reported. Because it was neither desirable nor possible to investigate all possible combinations of the above variables, only the combinations that made the most sense were estimated. Similarly, only those judged to be the most important of those estimated are reported here.

Generally, the most meaningful results to report are regressions on total acreage in the six crops. Results for individual crop acreages were rather predictable and lead to no useful information regarding production dynamics. Yield and quantities-produced regressions on normalized crop prices and other variables did not produce useful results; this may underline the advantage of focusing attention on variables that are relatively easy to model and understand.

Policy variables used tended to be dominated by the average diversion rate. The choice of policy variable retained, therefore, is that in which the average diversion rate is multiplied by the ratio of program-to-market returns. This approach made it possible to use returns information without consuming additional degrees of freedom or dealing with normalization questions.

Of the shift variables, results for only the expansion shift variable (the last column of Table 5.1) are reported here. Results for the expansion/contraction variable were clearly inferior in terms of its own t-statistic and effects on other coefficient estimates. (Because this variable includes the expansion variable, the comparison can be considered a test of a nested model.) Although the dummy variables for 1973 and 1974 were often quite statistically significant, their values were quite sensitive to changes in specification.

Regression results. Relevant regression results are shown in Table 5.2. These results show the effect of the lagged adjustment variable (machinery carry-in) and the acreage expansion constraint on the response of total acreage planted to the policy variables.

Equation 2.1 presents the basic model without lagged adjustment but with the expansion constraint. The coefficients of the diversion variables represent millions of acres not planted per 100 percent of diversion. Corn diversion is significant at the 1 percent level, wheat at 5 percent.

Table 5.2. Results of OLS regressions on total acreage of the six study crops (millions of acres), 1965-84.

Variable	Equation number: 2.1	2.2	2.3	2.4	2.5
Constant	89.1	33.8	24.1	149.4	173.0
	(27.3)	(21.3)	(29.4)	(45.3)	(9.8)
Corn diversion	-91.2	-61.9	-64.2	-98.0	-102.9
	(19.7)	(19.4)	(20.5)	(19.1)	(16.4)
Wheat diversion	-28.7	-46.7	-50.5	-7.0	1.3
	(12.4)	(12.4)	(14.8)	(17.8)	(8.7)
Wheat allotment	.341			.511	.584
	(.127)			(.160)	(.079)
Machinery carry-in			-.045	.153	.199
			(.091)	(.094)	(.037)
Time	2.08	3.07	3.38	0.55	
	(0.43)	(0.27)	(0.68)	(1.03)	
Expansion shifter	-8.16	-6.36	-6.99	-6.93	-6.72
	(3.63)	(4.24)	(4.53)	(3.52)	(3.40)
Adjusted R^2	.967	.953	.950	.970	.972
Durbin-Watson	1.79	1.85	1.77	2.47	2.60

Mean of dependent variable = 241.8 ; standard deviation = 24.6
Figures in parentheses are standard errors of estimates.

Note that, because the feed grain base is not even twice that of wheat (and some of the feed grain diversion is not perfectly correlated to that of corn), the much larger coefficient for the corn diversion implies a more effective diversion program for feed grains. On the other hand, the significant (at 5 percent) wheat allotment coefficient is also part of the wheat program, a part which would appear to be about 34 percent "effective" (since the allotment and planted acres are scaled in the same units). The time trend catch-all is quite significant. So is the expansion shift variable, which indicates an average "cost" of eight million acres associated with an acreage expansion.

The estimated value of the shift coefficient is quite robust to the specifications shown in Table 5.2, as it was to virtually all specifications examined. Only in equations without the wheat allotment is its significance level less than 5 percent. The implications of this significance, however, are not immediately clear. It could be associated either with the costs of breaking new ground or with input occasional-fixity. The fact that the shift variable that allows for contractionary land fixity showed no significance, however, suggests that the resistance to expansion is grounded in increasingly higher input costs. Unfortunately, no other strong evidence for this particular explanation was found. In any event, the amount of the adjustment cost--eight million acres out of an average of 242 million--is rather small.

Before moving on to consider lagged adjustment based on machinery stocks, one more aspect of the acreage control programs should be considered. Although the allotment coefficient is quite significant and of believable magnitude, it is not evident exactly how or why the allotment variable should have any effect. For the period of operation of the wheat program, the allotment serves primarily as the calculated base to which diversion rates would apply. It is not clear how the allotment would operate to control plantings on its own. When excluded from the regression, as in Equation 2.2, the coefficients of the diversion variables take on values much more proportional to their acreage bases. This fairly large change in these coefficients is not totally surprising given the .66 simple correlation of the diversion variables. The allotment, however, is only slightly correlated with each of them (.17 with corn and -.05 with wheat). (The Durbin-Watson statistic, by the way, takes on its only conclusive value in the table, supporting rejection of the hypothesis of serially correlated residuals at the 5 percent significance level.) No judgement is offered as to which is the proper specification, a decision which is quite important to the hypothesis of a machinery-stock-based lagged adjustment effect.

With machinery carry-in added to this second specification (see Equation 2.3), virtually nothing changes, a tribute to the low significance, small value, and wrong sign of the coefficient. When added to the first specification (as in Equation 2.4), however, the wheat diversion coefficient shrinks, the allotment effect grows, and the time trend almost disappears. The 1.62 t-statistic on the machinery coefficient, its proper sign, and the high correlations of both the allotment (.77) and machinery (.90) with trend suggest eliminating the now low-significance trend variable. The result, Equation 2.5, indeed raises the significance level of the machinery variable to less than 1 percent. (It also costs the wheat diversion the rest of its effect, and raises that of the corn diversion and the wheat allotment). Note that these latter two specifications render the Durbin-Watson statistic firmly inclusive at the 5 percent significance level.

Some support for the correctness of specifications 2.4 and 2.5 springs from the estimated value of the machinery coefficient. Since the means of the dependent and independent variables are nearly equal, the coefficient values (.15 and .20) are the estimated elasticities of acreage with respect to machinery carry-in. As one would hope, these values are reasonably close to the share of machinery costs in total production costs of these crops (USDA-ERS, 1985c). Two factors which would qualify this observation tend to be offsetting. First, the estimate should be lower than the cost share because there is probably some elasticity of yield to machinery use. Second, the estimate should be higher than the cost share because machinery carry-in will induce higher use-levels of other inputs.

Conclusions. The lagged-adjusment effect of machinery carry-in may have some effect on the dynamics of planting. This conclusion, however, is sensitive to the representation of the effects of acreage control programs. The expansion shifter robustly indicates the presence of some small constraint on expansion, which is more likely to be based in input supply fixity. Together, these measures provide some support for the hypothesis that dynamic adjustment of supply is constrained somewhat more in expansion than in contraction.

Farm Machinery and Equipment

Machinery market characteristics indeed apear to be a potential source of lagged adjustment in agriculture, but not necessarily for the reasons anticipated. One source of dynamics may be in lagged adjustment of machinery supply, a second-order effect (see page 70) that is probably quite minor. The endogeneity of machinery price seems quite firmly established, but real machinery price variation is small. Finally, the measured effect of machinery carry-in on new purchases is insignificant, a fact which could make lagged effects larger than theorized, unless machinery use intensity varies enough to compensate.

Farm machinery quantities used are gross investment and January 1 stocks ("carry-in") of tractors and other machinery and equipment, deflated by the Producers' Price Index for farm machinery and equipment (which was used as the price variable). The annual user price was calculated as the sum of interest and depreciation rates times machinery price adjusted for tax policy changes (see Appendix D).

Price. Machinery prices in aggregate varied little with respect to the CPI over the period studied: the coefficient of variation of deflated price was .049 (see also Figure 5.2). The measured determinants of price are shown in Table 5.3. The results reported were quite robust to the specification used, expect that additional variables increased standard errors of estimates somewhat.

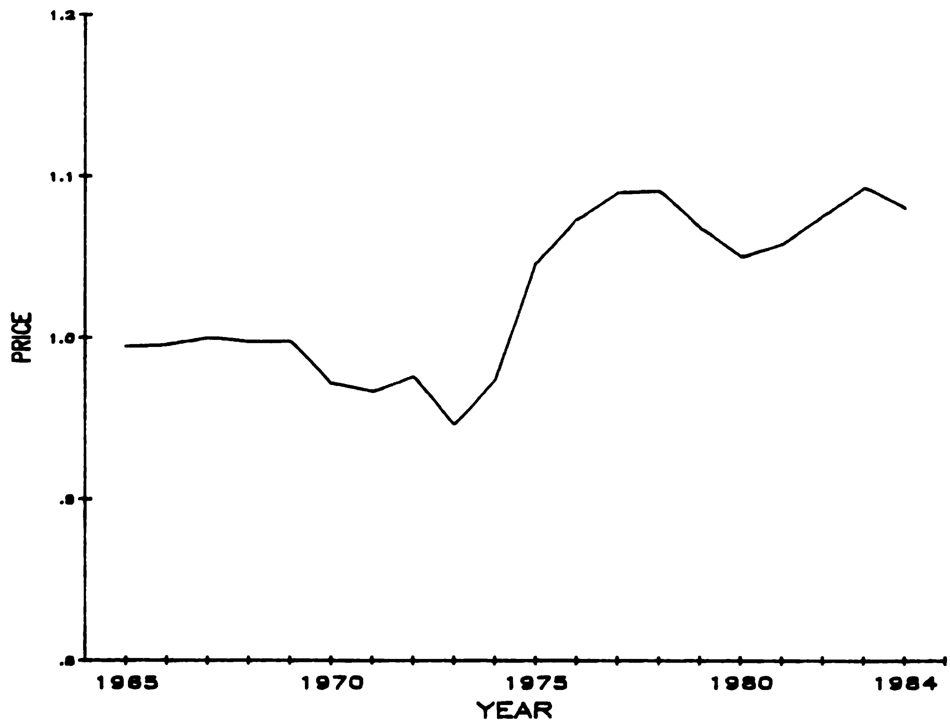

Figure 5.2. Normalized price of farm machinery and equipment, (1967=1.00), 1965-84.

Table 5.3. Results of regressions on the normalized price of farm machinery and equipment (1967=1.00), 1965-1984.

Variable	OLS	IV	IV price flexibiity
Constant	.088 (.164)	.108 (.170)	-
$Price_{t-1}$	.540 (.186)	.514 (.194)	-
Steel $price_{t-1}$	.103 (.092)	.115 (.096)	.13
Crop $price_{t-1}$	.093 (.032)	.101 (.036)	.23
Fertilizer price	-.064 (.055)	-.079 (.063)	-.11
Wheat allotment	.00063 (.00044)	.00072 (.00048)	.044
Machinery $purchases_{t-1}$	-.00088 (.00054)	-.00090 (.00054)	-.034
Time	.0021 (.0012)	.0020 (.0012)	-
Expansion shifter	-.0118 (.0061)	-.0118 (.0061)	-
Standard error of the regression	.011	.011	
Durbin-Watson	2.073	2.175	

Mean of dependent variable = 1.027; standard deviation = .050
Figures in parentheses are standard errors of estimates.

Results from both ordinary least squares (adjusted R^2 = .952) and instrumental variables are shown. The two results are quite similar. The latter technique was necessary because of the inclusion of endogenous fertilizer price. Actual two-stage least squares was not used because of the large number of predetermined variables in the system studied. Instead, the list of instruments included: (1) the policy variables; (2) the interest, depreciation, and tax components of the user price of machinery; (3) the predetermined variables in the equation; and (4) the predetermined variables in the equations of the endogenous variables. (Justification for this selection rule is provided in Appendix E.) The instrumental variables results are taken to be the proper estimator of the machinery price equation.

The equations estimated are for the price of farm machinery and equipment. The quite significant coefficient of last period's price in the regressions is taken to indicate a lagged endogenous effect of machinery supply. In other words, capacity and the price-dependent supply curve adjusts in lags to last period's price. The possible interpretation that this measured effect actually results from the high serial correlation of a highly significant steel price is rejected on the basis of the considerably more significant coefficient of lagged own-price when both variables are included in the regression (as shown). In addition, the more unfavorable Durbin-Watson statistic (1.49 versus 2.17) and the higher standard error of the regression (.014 versus .011) that resulted from excluding the lagged price of machinery are taken to indicate the superiority of the reported regression.

The short-run supply curve is shown to be shifted by last period's price of steel, a major input to farm machinery. The elasticity (or "flexibility") of this measure is .13, a value that should be comparable to the share of steel in farm machinery manufacturing costs. Neither this effect, not that of time, is very statistically significant. The latter measure represents the sum of technological change in the farm machinery industry (normally producing a negative effect on price), the trend in other machinery input prices, the machinery-intensifying trend of technological change in farming, and the excluded trend in other demand shifters.

The remaining variables in the price equations are farm machinery demand shifters. The direct use of these predetermined (and one endogenous) instruments was necessitated by the fact that price has such a strong effect on purchases that the use of purchases (or even its estimated value) in the price equation consistently produced negative coefficients. The resulting demand shifters in the price equation are not exactly the same as those in the demand equation. There is nothing objectionable in this if, as is likely:

(1) machinery prices are set at the beginning of the season;

(2) prices are set in response to factors known at the time;

(3) these factors imperfectly match those that actually affect farmers' decision; and

(4) these prices are somewhat inflexible with respect to actual later developments.

These comments also apply to the other input analyses.

The estimates for crop and fertilizer price effects and the wheat allotment should be self-explanatory. The lagged machinery purchases were expected to have the depressing effect of recently purchased stocks on demand. Interestingly, total machinery stocks were not a significant factor, as will be shown below.

The expansion shifter is fairly significant statistically. The negative value of the coefficient indicates a resistance to rising demand for machinery, _ceteris paribus_, when acreage planted is expanding. Such a finding would result from expansions being constrained by some factor other than machinery demand. This finding, however, is not supported by the results of the estimated demand function.

Demand. Farm machinery and equipment investment was estimated as a function of the annual user price of machinery, the demand determinants used in the price equation, and debt capacity (see Appendix D). Because of the endogeneity of the prices of fertilizer and machinery, instrumental variables estimation was used. The list of instruments was derived according to the policy stated for machinery prices, and was identical to that list as a result. As shown for prices, results differed little from those for ordinary least squares (which produced an adjusted R^2 of .732). Only the instrumental variables results are shown in Table 5.4. The first equation shown in the table is accepted as the proper specification. The second equation demonstrates the very low economic and statistical significance of including the machinery carry-in variable.

The coefficients of prices and the wheat allotment in the first regressiom are self-explanatory, although their demand elasticities might be considered unexpectedly large. The influence of debt capacity is a non-standard sort of dynamic effect, as discussed in the previous chapter (pages 68-69). The course by which its effects would be played out is difficult to grasp. Although its statistical significance is

Table 5.4. Results of instrumental variables regressions on farm machinery and equipment purchases (billions of 1967 dollars), 1965-84.

Independent variable	Equation 4.1	Equation 4.1 elasticities	Equation 4.2
Constant	61.8 (38.9)	-	62.3 (81.0)
User price	-427. (206.)	-1.49	-386. (201.)
Crop price$_{t-1}$	34.5 (17.7)	1.97	25.3 (15.7)
Fertilizer price	-52.3 (26.5)	-1.88	-37.8 (23.6)
Wheat allotment	.314 (.274)	.56	.209 (.256)
Debt capacity	94.5 (63.7)	-*	85.9 (88.2)
Purchases$_{t-1}$	-.516 (.521)	-.52	-.441 (.592)
Machinery carry-in		-	.008 (.168)
Time	.435 (.413)	-	.373 (1.45)
Expansion shifter	-.699 (2.80)	-	-.350 (3.15)
Standard error of the regression	4.53		4.66
Durbin-Watson	2.53		2.39

Mean of dependent variable = 38.3; standard deviation = 8.59
Figures in parentheses are standard errors of estimates.
*For the reason that no elasticity is reported, see Appendix D.

not high, it may be that this effect tended to dominate that of machinery carry-in over the period, as is frequently discussed in explanations for farmers' current economic woes. As mentioned under Prices, above, only last year's purchases tended to discourage new purchases, and then at the low trade-off rate of about one-half.

The effect of time in the regression would support the concept of progressive capital intensification. The low, insignificant coefficient of the expansion shifter belies the interpretation of the price effect offered above, as mentioned there. With exception of this effect and that of debt capacity (which was not significant in the price equation), the demand variables generally bear the same proportion to one another in the price and demand equations. This fact would tend to support the conclusion that their significance in the two equations is, in fact, as demand shifters.

Note that machinery stock equals machinery carry-in plus machinery purchases. The results of estimating a machinery stock equation (not shown), therefore, are exactly the same as those of the second purchases equation, except that the coefficient of carry-in is greater (.990 versus .732). Graphs of the fitted and actual values of both purchases and stocks are shown in Figure 5.3.

Fertilizer

In addition to machinery (with variable-cost expense shares of 26, 37, and 39 percent for corn, wheat, and soybeans, respectively), fertilizer is the other major purchased input for the subsector under consideration, with variable-cost shares of 38, 32, and 14 percent (USDA-ERS, 1985c).

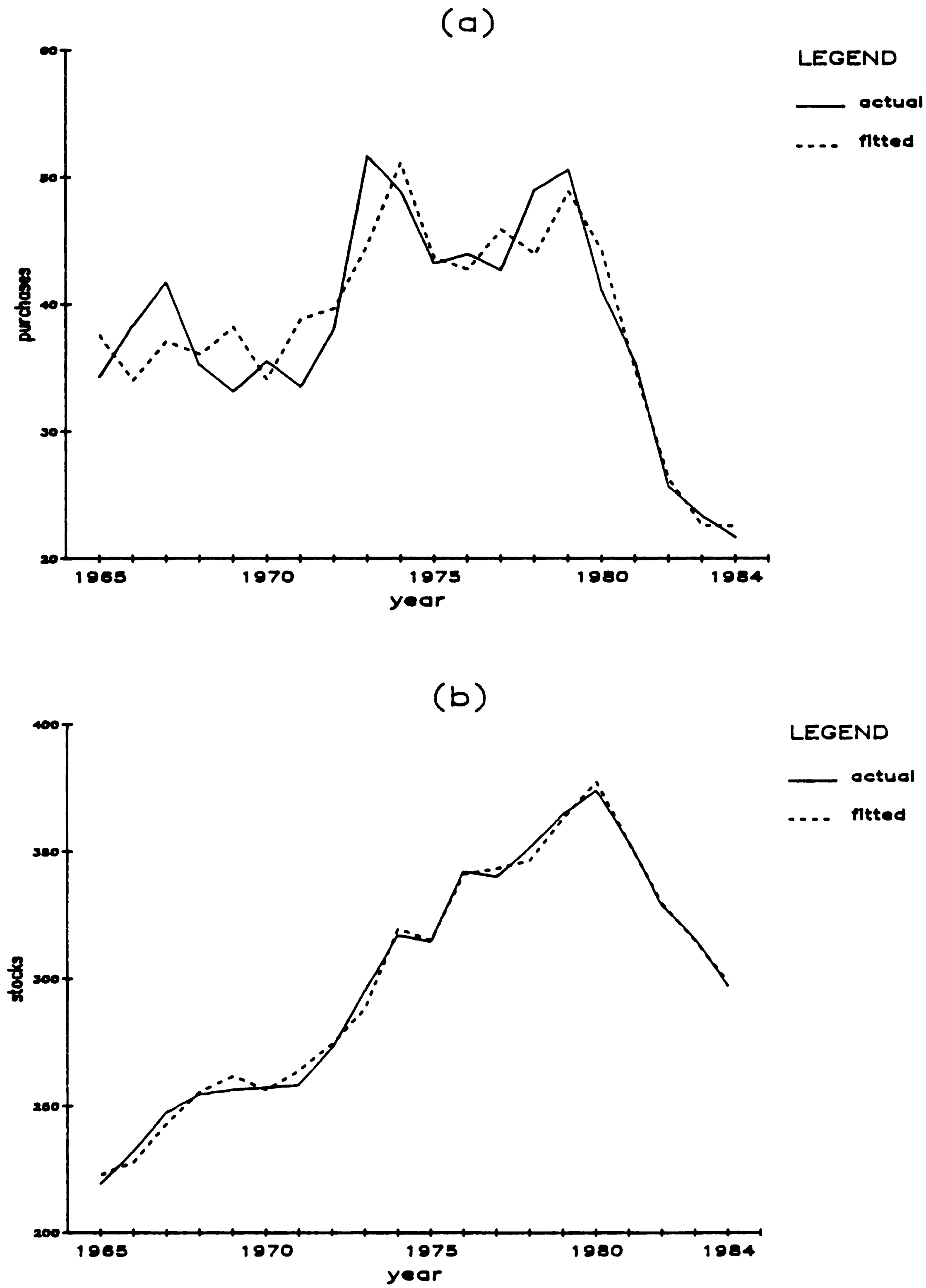

Figure 5.3. Farm machinery and equipment purchases (a) and stocks (b), fitted and actual, 1965-84.

Fertilizer price is determined largely by expected crop prices, with a simple correlation coefficient (when normalized by the CPI) of .925 (see Figure 5.4). No evidence was found of lagged adjustment in fertilizer capacity, however. There may be a tendency for fertilizer supply to be constrained in acreage expansions, but this factor is confounded by other effects and is too small to be definitively measurable.

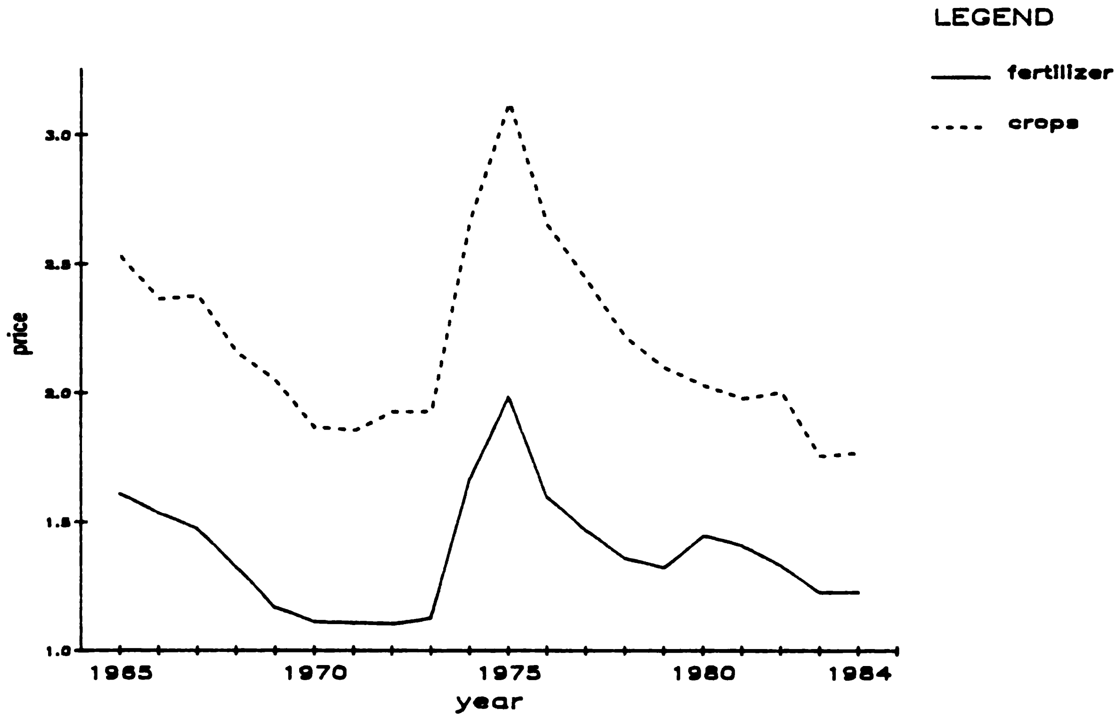

Figure 5.4. Normalized prices of crops (lagged, 1967 = 2.38) and fertilizer (1967 = 1.47), 1965-84.

<u>Price</u>. In addition to the highly significant crop price (with a price flexibility of 1.05), the normalized price of fertilizer is significantly affected by the lagged price of natural gas (price flexibility of .227), the user price of machinery (.187), and time. The negative coefficient of time is taken to represent a long-run fall in the real price of fertilizer due to efficiency gains in its

Table 5.5 Results of instrumental variables regressions on normalized fertilizer price (1967 = 1.47), 1965-84.

Independent variable	Equation number 5.1	5.2	5.3
Constant	1.29	1.22	1.22
	(0.46)	(0.48)	(0.41)
Natural gas price$_{t-1}$	.182	.182	.182
	(.034)	(.034)	(.033)
Crop price$_{t-1}$	.655	.662	.622
	(.039)	(.041)	(.035)
Machinery user price	-1.96	-1.93	-1.92
	(0.80)	(0.81)	(0.77)
Time	-0.19	-0.18	-0.18
	(.006)	(.006)	(.005)
Corn diversion	-.088	-.003	
	(.121)	(.178)	
Expansion shifter		.027	.027
		(.039)	(.026)
Standard error of the regression	.0465	.0474	.0457
Durbin-Watson	1.74	1.82	1.82

Mean of dependent variable = 1.378; standard deviation = .228
Figures in parentheses are standard errors of estimates.
The elasticities reported in the text are for Equation 5.2.

manufacture. All of these measures are quite insensitive to the specification changes shown in Table 5.5, as well as to others tried.

The equations shown in the table were estimated with instrumental variables because of the endogeneity of machinery price. The selection of instruments followed the same policy for both fertilizer price and demand as for machinery. The OLS estimates, with adjusted R^2's around .96, were virtually identical to those shown.

The equations reported in Table 5.5 are intended to examine the hypothesis that fertilizer supply may have been capacity-constrained in acreage expansions during the period. This is done by testing the sensitivity of the standard error of the coefficient of the expansion shifter to the presence of the corn diversion variable, with which it has a simple correlation of -.82. Only the corn diversion has been included in Equation 5.1. It is of rather low statistical significance, but of correct sign and reasonable magnitude. It was the most significant policy variable in the fertilizer price regressions.

When the expansion shifter is added (in Equation 5.2), the magnitude and significance of corn diversion virtually disappear. The expansion shifter is of rather low significance, but its magnitude and sign suggest that fertilizer capacity could be responsible for constraining planted acreage (and presumably yields as well). When the corn diversion variable is dropped in Equation 5.3, the expansion shifter becomes somewhat more significant, but is still not highly so.

Demand. In Equation 6.1 (Table 5.6), the demand for fertilizer is estimated as a function of own price (elasticity of -.791), the prices of crops (.500) and machines (-.576), diversion rates, machinery carry-in (.178), time, and the expansion shifter. In addition, lagged

Table 5.6. Results of instrumental variables regressions on fertilizer purchases (expenditures divided by price, 1910-14=100), 1965-84.

Independent variable	Equation number 6.1	6.2	6.3	6.4
Constant	-6.49	-2.33	-9.86	-5.53
	(8.03)	(8.10)	(6.05)	(5.80)
$Purchases_{t-1}$	-.317		-.319	
	(.179)		(.176)	
Price	-12.1	-11.2	-12.7	-11.8
	(3.3)	(3.4)	(3.1)	(3.3)
Crop $price_{t-1}$	4.82	4.52	5.07	4.76
	(2.11)	(2.27)	(3.12)	(2.19)
Machinery user price	-90.9	-66.9	-99.5	-74.9
	(21.7)	(18.4)	(17.1)	(11.9)
Corn diversion	-6.16	-4.03	-6.11	-3.96
	(3.51)	(3.62)	(3.46)	(3.56)
Wheat diversion	-3.72	-2.40	-5.07	-3.68
	(3.18)	(3.29)	(2.37)	(2.37)
Machinery carry-in	.014	.014		
	(.022)	(.024)		
Time	.679	.474	.789	.586
	(.229)	(.206)	(.135)	(.062)
Expansion shifter	-.460	.243	-.697	.022
	(.859)	(.822)	(.766)	(.715)
Standard error of the regression	.816	.882	.804	.867
Durbin-Watson	2.84	2.67	2.90	2.73

Mean of dependent variable = 21.14; standard deviation = 3.79
Figures in parentheses are standard errors of estimates.

fertilizer expenditures are included, with a fairly significant elasticity of -.309. The negative value, if true, could represent the effect of last year's residues on this year's demand, but the measure obtained seems a bit large.

Note that the coefficient of the expansion shifter is of low statistical significance. A zero coefficient would be compatible with the hypothesis of a fertilizer supply constraint, since the higher price of fertilizer would serve to balance supply and demand. A constraint imposed by another output would produce a negative coefficient on the shifter, but it would also make the shifter coefficient in the price equation negative, the opposite of what was observed. These findings, then, provide some weak support for the hypothesis that fertilizer capacity has constrained crop supply in expansions.

The conclusion is not challenged by dropping the somewhat questionable lagged purchases variable in Equation 6.2. Little else changes enough to assist much in choosing between the two specificaitons. In neither equation are the demand shifter coefficients of comparable proportion to those in the fertilizer price equation, although the machinery price coefficient moves in the right direction in Equation 6.2. The lower value of -66.9 is also closer to the fertilizer price coefficient of -52.3 in the preferred machinery demand equation; since the two would be equal under the symmetry condition, some support is provided thereby for favoring Equation 6.2 as a preferred specification.

Neither the conclusion just stated nor that regarding the expansion shifter is challenged by excluding the rather low-significance machinery carry-in variable as in Equations 6.3 and 6.4. The expansion shifter becomes larger in Equation 6.3, but its still low significance does not support concluding that an input fixity exists elsewhere. When lagged purchases is dropped in Equation 6.4, this coefficient falls to very near to zero. Again, the value of the machinery coefficient is more believable without lagged purchases. In both pairs of equations, the inconclusive (at 5 percent) Durbin-Watson statistic is more favorable without lagged purchases.

The jump in the value and significance of time resulting from the exclusion of machinery carry-in can be thought of in two ways. Statistically, the two are highly correlated. Economically, the marginal productivity of fertilizer has been increased by genetic improvement of crops through time and by the lowered cost of spreading fertilizer. With machinery carry-in included, time measures only the first effect; when it is excluded, time represents both.

Finally, the relative size of the diversion coefficients argues for the validity of the first two specifications. Because fertilizer use per acre is roughly three times as great for corn as for wheat (USDA, ERS, ECIFS, 1982, Costs of Production), the roughly two-to-one ratio of these coefficients in these equations is more expected than the one-to-one ratio in the latter two equations.

The use of fertilizer over the sample period is shown in Figure 5.5.

Pesticides

The last two categories of inputs considered, pesticides and fuel, represent 14, 6, and 31 and 14, 22, and 20 percent, respectively, of the variable expenses of corn, wheat, and soybean production (USDA-ERS,

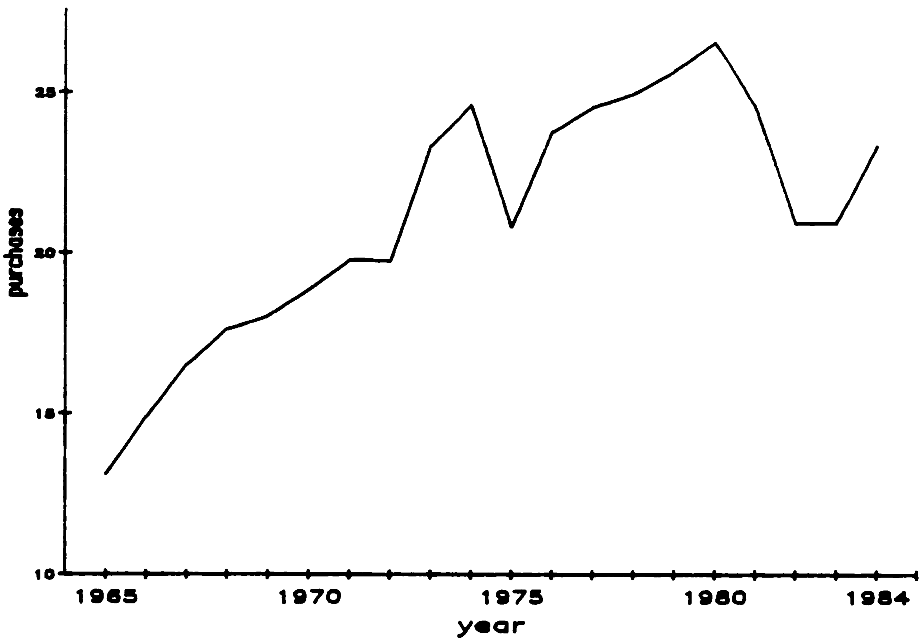

Figure 5.5. Fertilizer purchases (expenditures divided by price, 1910-14 = 100), 1965-84.

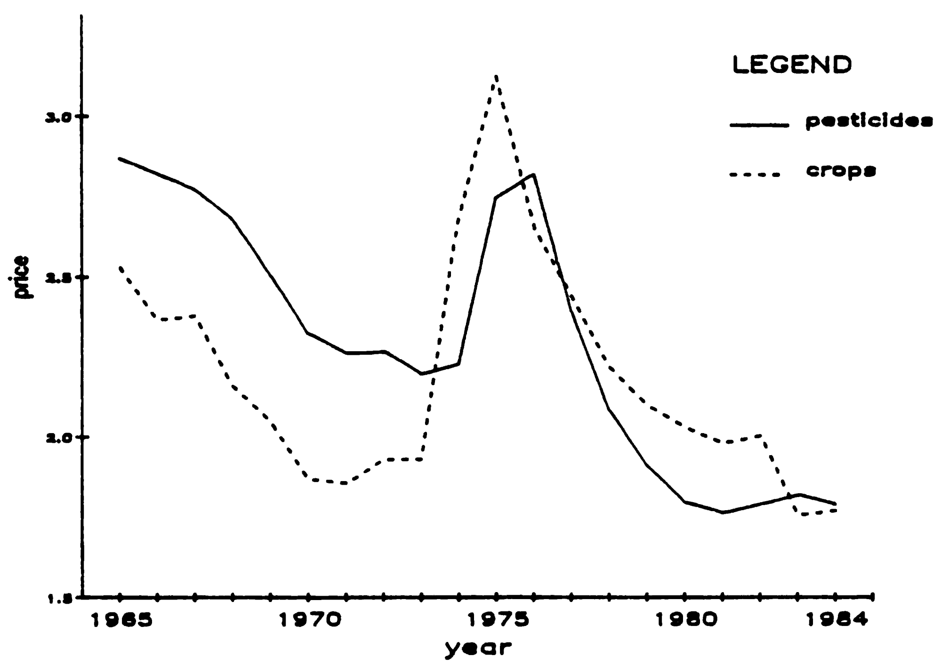

Figure 5.6. Normalized prices of crops (lagged, 1967 = 2.38) and pesticides (1967 = 2.77), 1965-84.

1985c). For neither input are results as satisfying as for machinery and fertilizer.

Pesticide price is strongly endogenous and, in addition to falling steadily in real terms, may have a lagged endogenous capacity effect. The growth in pesticide use appears to be caused by the persistant fall in price. No evidence of resource occasional-fixity was found in the analysis of this input.

Price. The normalized price of pesticides has fallen persistently through time, except during the response to high crop prices in the mid-1970s, as is evident in Figure 5.6.

Statistical measures of this relationship are shown in Table 5.7,

Table 5.7. Results of regressions on real pesticide price, 1965-84.

Independent variable	Equation 7.1	Equation 7.2
Constant	4.54 (0.61)	2.17 (0.90)
Pesticide price$_{t-1}$		.427 (.136)
Crop price$_{t-1}$	.527 (.109)	.414 (.095)
elasticity	.504	.396
Time	-.045 (.007)	-.024 (.009)
Expansion shifter	-.036 (.077)	-.026 (.061)
Adjusted R^2	.854	.906
Durbin-Watson	1.38	1.50

Mean of dependent variable = 2.29; standard deviation = .40
Figures in parentheses are standard errors of estimates.

in which the coefficients of crop price and time are very statistically significant. In Equation 7.2, lagged pesticide price is added to the simple specification of Equation 7.1 to test the hypothesis of lagged adjustment in pesticide supply capacity. In statistical terms, the significance of this variable would appear to support the hypothesis. The high correlation of this variable with time, however, leaves the question somewhat in doubt. The inclusion of no other variable improved regression results; hence, the admissibility of the ordinary least squares estimator.

The expansion shifter is quite insignificant statistically in each regression. Its magnitude is also not large. The negative sign would support the idea of expansion fixity in some other input, but this result is not supported by the demand estimation results.

<u>Demand</u>. Results for pesticide demand estimation are fairly sensitive to the specification used. (Instrumental variables are used in each case.) Equation 8.1 in Table 5.8 includes a time trend which dominates the effect of all other variables. When time is excluded, as in Equation 8.2, price coefficients become quite significant and of reasonable magnitude. The estimated own price elasticity of demand at the means is -3.13. The elasticity with respect to crop price is 0.90.

In the last three regressions, the coefficient of time is constrained to equal 0.10 in recognition of the fact that the cost of applying pesticides has probably fallen through time, but not as much as implied by the unconstrained coefficient in Equation 8.1. The constrained value represents a growth in demand of about 2 percent per year over the period. This constraint lowers the estimated own-price elasticity to 2.27 (probably a more reasonable figure), and that of

Table 5.8. Results of regressions on pesticide purchases (expenditures divided by price, 1910-14 = 100), 1965-84.

Independent variable	Equation number 8.1	8.2	8.3	8.4	8.5
Constant	-17.5	16.8	6.9	6.9	5.1
	(17.9)	(1.4)	(1.0)	(1.0)	(3.8)
Price	-.301	-7.13	-5.16	-5.07	-4.50
	(3.62)	(0.92)	(0.70)	(0.67)	(1.62)
Crop price$_{t-1}$	-1.11	2.13	1.19	1.12	.79
	(1.85)	(1.00)	(0.76)	(0.74)	(1.21)
Time	.345		.100	.100	.100
	(.179)		-*	-*	-*
Expansion shifter	.154	.075	.098	.118	.077
	(.367)	(.462)	(.350)	(.344)	(.326)
Machinery carry-in					.005
					(.010)
Standard error of the regression	.683	.866	.656	.650	.628
Durbin-Watson	1.18	1.81	1.92	1.91	1.92

Mean of dependent variable = 5.21; standard deviation = 2.33
Figures in parentheses are standard errors of estimates.
*The time coefficient in Equations 8.3, 8.4, and 8.5 is imposed by restricted regression.
Equations 8.4 and 8.5 use lagged price as an instrument.

crop price to .50.

All of the regressions use the policy mentioned in previous sections to select instruments for estimated own price. In the first three regressions, these instruments exclude lagged own-price, as if Equation 7.1 were the proper price specification. The last two regressions included lagged price, as if Equation 7.2 were more appropriate. As Equations 8.3 and 8.4 show, the effects of changing this assumption are minor.

Equation 8.5 shows the effect of including machinery carry-in. Standard errors generally are increased, but no major changes occur. If this variable were taken to represent the effect of lower pesticide application costs, the restricted time variable could be omitted. Because nothing suprising results, this specification is not reported.

Finally, the coefficient of the expansion shifter is fairly insensitive to all these changes, especially considering its low statistical significance. No particular meaning is seen in this result, however, because, as mentioned above, its sign is not consistent with any hypothesis of input fixity when considered in combination with the results for pesticide price.

Fuel

Regressions on fuel price and use yield no particularly strong or surprising results. Fuel price is strongly determined by crude oil price, and may be influenced by demand variables. The expansion shifter exhibits no significant effects. For trends in price and use, see Figure 5.7.

Price. The price of agricultural fuels is highly determined by

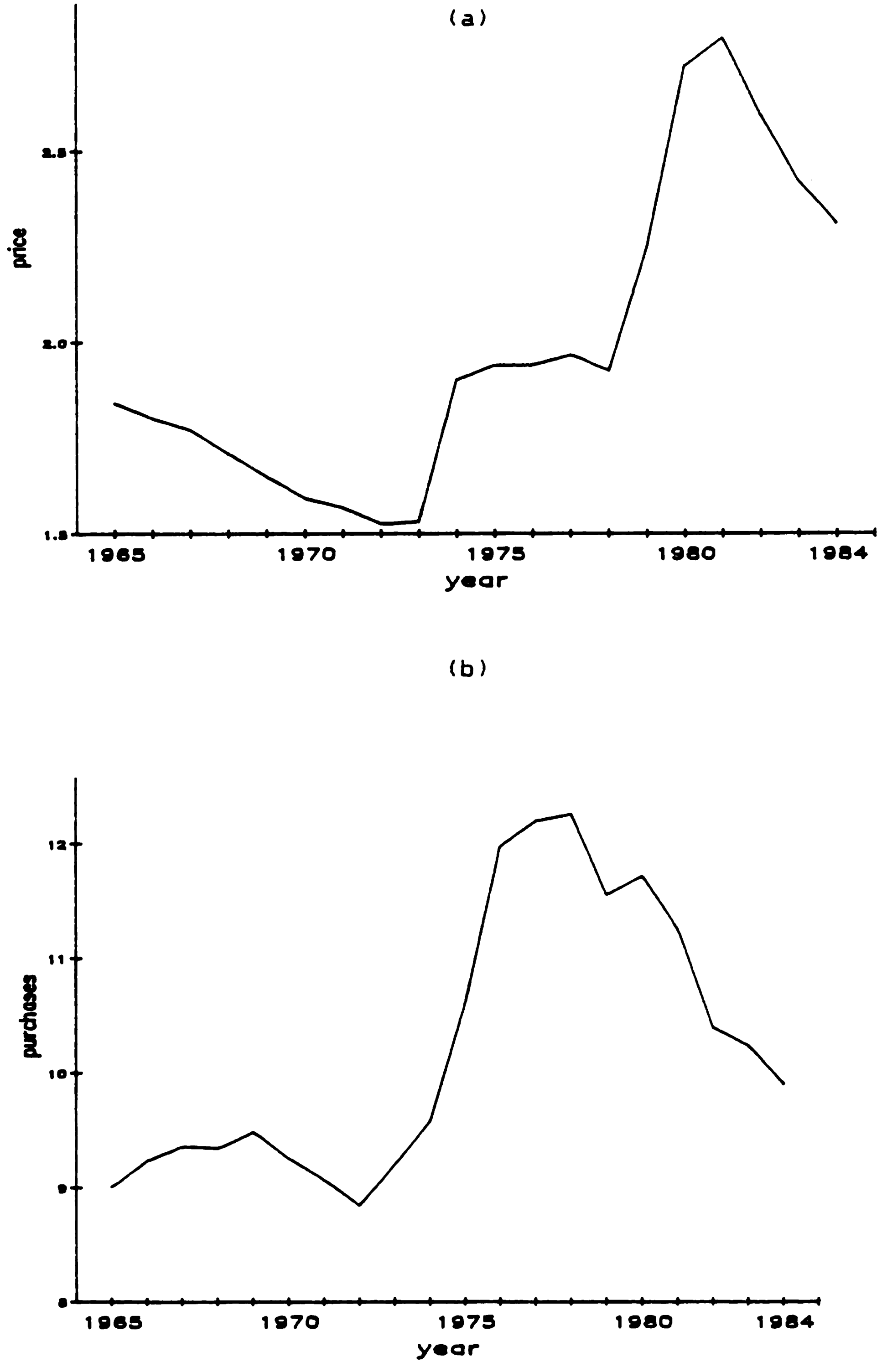

Figure 5.7. Normalized price of fuel (a, 1967 = 1.77) and fuel purchases (b, 1910-14 = 100), 1965-84.

crude oil price. The elasticity of .419 should represent the share of crude oil costs in fuel price. The price of fuel may be affected by agricultural fuel demand, reflecting a less-than-perfectly elastic supply of fuel processing and delivery services. Although there is no evidence of this in the crop price coefficient, wheat allotment and machinery carry-in effects are significant at the .05 level. It should be born in mind, however, that both of these variables have strong trend components.

The quite significant negative coefficient of time is taken to indicate increasing efficiency of the fuel processing and delivery system. The coefficient of the expansion shifter is of minimal economic or statistical significance; the positive sign of the coefficient has no clear economic meaning. Because of the lack of endogenous variables, the price equation was estimated with ordinary least squares. No additional variables yielded useful results in other specifications.

Demand. The fuel purchases equation is estimated in essentially the same form as the fuel price equation. The replacement of crude oil price with the endogenous fuel price required the use of instrumental variables estimation. The choice of the list of instruments followed by the same policy as mentioned above.

As expected, the estimated fuel price elasticity of demand is quite low. Crop price now has a measurable and reasonable estimated effect, though of fairly low statistical significance. The relative magnitudes of the wheat allotment and machinery carry-in effects have shifted, probably due in part to their high correlation. The negative sign of the time coefficient is taken to indicate the increased fuel

Table 5.9. Results of regressions on discounted fuel price and fuel purchases (expenditures divided by price, 1910-14 = 100), 1965-84.

Independent variable	Price coefficients	Price flexibilities	Purchases coefficients	Purchases elasticities
Constant	2.74 (0.61)		11.07 (4.28)	
Crude oil price	.556 (.092)	.419		
Fuel price			-1.40 (1.06)	-.272
Crop price$_{t-1}$	-.036 (.067)	-	.508 (.440)	.109
Wheat allotment	.0072 (.0030)	.227	.035 (.026)	.215
Machinery carry-in	.0036 (.0013)	.475	.047 (.011)	1.19
Time	-.039 (.011)		-.180 (.084)	
Expansion shifter	.0057 (.0439)		-.215 (.289)	
Durbin-Watson	2.01		1.26	
Mean of dependent variable	1.99		10.22	
Standard deviation of dependent variable	.397		1.19	

Figures in parentheses are standard errors of estimates.

efficiency of agricultural machinery and equipment.

The negative sign on the expansion shifter could be consistent with the hypothesis of a supply constraint for another input, but it is of low significance both statistically and in terms of its magnitude.

Cross-Equation Restrictions

A cross-equation restriction for improving the efficiency of parameter estimates was imposed and tested. It involved the symmetry of cross-price effects (as discussed in Chapters Two and Four and Appendix C). Only one symmetry condition existed--equality of machinery user and fertilizer price effects on each other's demands. This condition was tested using instrumental variables and two-stage least squares estimates, for both of which the null hypothesis of symmetry could not be rejected at even the .20 level of significance. Three-stage least squares (3SLS) estimates resulted in a higher t-statistic, but its significance is unclear given the small sample used. Details of the results obtained are presented in Appendix F.

The use of 3SLS improves the asymptotic efficiency of estimates through Zellner's technique of accounting for the correlation of error terms between seemingly unrelated regressions. The resulting addition of generalized least squares to two-stage least squares (Intriligator, 1978, p. 403) reduced the estimated standard errors of parameter estimates somewhat, but no estimated coefficient changed radically. In a sense, then, the results discussed in this chapter were strengthened, but (due to the small sample size) it is unclear how much or how reliably. Details of the use of this procedure are reported in Appendix F.

CHAPTER SIX

CONCLUSIONS AND IMPLICATIONS

This chapter serves five functions in terminating this study. Each is addressed in a seperate section.

First, general conclusions are drawn about the dynamics of cash grain production in the United States. The previous chapters provide the base in theory, informal knowledge, methods, and data analysis for the period 1965-84 on which these conclusions rest.

Second, the potential and form for extension of this work to application in other cases are described. Most such cases involve a different scope or geographical subject, but uses for other time periods and economic sectors are also mentioned.

Third, strengths and weaknesses of the analysis are discussed to qualify the conclusions and assist in designing future applications.

Fourth, policy implications of the conclusions for United States farm price and income support programs are outlined.

Finally, suggestions are made for improvements in theory, data, econometric techniques, and other analytic approaches that could benefit future research along the lines of this study. Ideas for clarifying the need for and use of such studies are also proposed.

General Conclusions Regarding U.S. Agriculture

For the most part, such dynamics as exist in the U.S. cash grain sector appear to result form the classic forms of quasi-fixity (see page 11) discussed in the literature of economics. They cause some lagged adjustment in input use and a fairly small lag in acreage adjustment. Yield lagged-adjustment may also occur, adding somewhat to the total adjustment effect in production. These findings are essentially compatible with those of Karp, Fawson, and Shumway (1985), who detected minor quasi-fixity in U.S. agricultural production as a whole. For the cash grain sector in aggregate, planted acreage appears to be so strongly affected by program variables that crop price effects are not detectable.

The source of this quasi-fixity is seen to be related primarily to endogenous prices for durable inputs. In the case of the obvious durables, farm machinery and equipment, the virtual independence of purchases from existing stock represents an extreme case of another source of lagged adjustment. Two factors, however, may mitigate this effect: first, the low variability of machinery price leads to a low degree of quasi-fixity induced by its endogeneity; second, flexibility of stock use rates may reduce output effects. On the other hand, second-order quasi-fixity (see page 70) resulting from lagged adjustment in machinery supply capacity adds a more complex dynamic force to the analysis. In addition, probable lagged adjustment in credit availability (a complementary input) is another likely source of quasi-fixity.

Although fertilizer prices are highly endogenous, the non-durability of the input and a failure to detect lagged adjustment in supply capacity suggest no source of quasi-fixity. On the other hand, the possibility of fertilizer residues acting as durable stocks reintroduces a potential lagged effect, made greater by probable influences on both acreage and yields.

Pesticide price is also quite endogenous and may exhibit lagged capacity adjustment in supply. Because pesticides are non-durable, this lagged effect would be a first-order quasi-fixity. If pesticides also have a fertilizer-like multi-period lagged effect on crop production, this first-order effect would make capacity a second-order effect. Although fertilizer may be a more important input, the relative magnitude of fertilizer and pesticide dynamic effects is difficult to determine. The faster growth of pesticide use may justify a shift in focus for future studies.

Although fuel prices show evidence of endogeneity, no lagged adjustment effect originating from this input was detected.

Labor is a significant input that was not studied econometrically. Prior knowledge, beliefs, and theory suggest, however, that labor is quasi-fixed and leaving agriculture on a continuing basis.

Results with respect to occasional-fixity were not overwhelming. A small effect was detected for acreage planted, but the nature of the effect would imply that it does not originate in land-related costs, per se. (Again, this is keeping with the findings of Karp, Fawson, Shumway.) Some weak evidence suggests that this effect could have originated in constrained fertilizer supply.

In summary, quasi-fixity adjustment effects in U.S. cash grain production are not large, although the tendency for labor to be under constant pressure to leave is persistent. Occasional constraints on inputs have an even smaller role. Their effect, if any, is to make production expand, on average, more slowly than it contracts. The most significant characterization of the dynamics of U.S. cash grain production, therefore, is simply that of an industry whose labor productivity grows faster than does demand for its products.

Extensions to Other Cases

Since a original motivation for this study was to develop a method for examining the dynamic crop supply of our major grain export competitors, attention will now turn to possible applications to other cases. The question of reversibility of these supply relations will be a special focus. First, similarities and differences between the U.S. and other areas will be examined. Then a number of potentially important differences will be discussed in terms of their likelihood of occurrence, their significance for supply, and the implications for analysis. A final section will address applications to other periods in the U.S. and to other sectors of the economy.

Similarities and differences. Aggregate farm-level analysis--the level of the empirical analysis of this study--seems to be much the same everywhere. Production trends are dominated by labor-saving mechanization, biological improvements, and increased purchases of non-durables. Specific patterns obviously vary considerably from place to place and time to time, as when labor demand is increased via infra-structural development or when labor displacement is decreased as by the agricultural policies of Japan. If anything, however, these exceptions demonstrate the rule: efforts to mitigate labor displacement are necessitated by the persistence of the problem. As a result, farm-level differences are not seen as a major threat to the generality of the analysis applied in this study.

On the other hand, significant variation can exist in the environments in which farming develops. Discussions of specific environmental factors comprise the remainder of this section. Such factors include: alternate land uses; the development of input industries, processing capacity, and infrastructure; credit markets; other policy changes; and the introduction of new technologies.

Alternate land uses. Major differences can exist in the regional characteristics of land added to crop production. In addition to irrigation of arid lands (addressed below), new lands used for grain production can come from forest or brushland, or from perennial crops of greater value than hay or pasture (such as coffee or sugarcane). As a result, land conversion costs could be more significant elsewhere than they appear to be in the U.S. In addition, the long-lived and cyclic nature of foregone crops make their addition to an analysis quite complex. In the case of timber, the variability in the value of salvaged material creates even more difficulties.

In this study, the loss of land to urban development has been ignored; in other cases, this alternate land use may be too important to be overlooked. Similarly, extensive land reform might make cropping patterns change so severely that reform itself might be considered to be an alternate land use factor (Shabman, 1985, p. 1031).

New input capacity, processing, and infrastructure. As explained above, opportunities always exist to draw the boundaries of the sector under consideration to fit the needs of the study. In individual countries, development of input and processing capacity and infrastructure may fall within these boundaries. New fertilizer plants have sprung up around the world in recent years, many countries have entered the ranks of farm machinery producers, and large, publicly-funded irrigation projects, processing plants, and export facilities have long been part of agricultural development programs. When such changes are "lumpy" relative to existing capacity and economically isolated from available foreign substitutes, they can emerge as occasionally-fixed factors of production. While such changes simply produce price changes at the farm level, the analysis becomes more complex for the agricultural system as a whole. Furthermore, stock-holding behavior might also have to be considered as part of the system under study, including the effects of storage capacity and public policy.

Credit. The ability to purchase inputs, especially durables, is affected by the availability of credit. Such effects have been shown to be important in the U.S.; they are likely to be even more so where credit markets are less developed. This is especially true when government policies restructure patterns of credit availability. While not a fixity, per se, such changes can drastically alter patterns of input use. In some cases, different credit policy regimes might produce a whole new pattern of purchases and production. Although often mitigated by social factors at the village level, the possibility for such effects must be considered when credit markets change significantly.

Other policy changes. Like the physical and credit policy tools mentioned above, a number of other government actions have major effects on agricultural production. Such actions include policies with respect to input and output prices, money supply, exchange rates, taxes, communications, migration, and population. When these policies shift sharply, fixity-like changes in supply parameters can result. As discussed below, such changes must be handled on a case-by-case basis. When change occurs gradually, time-trend representations may be sufficient. Otherwise, more definitive techniques may be required.

<u>Technological change</u>. Technological change is often cited as a source of irreversibility in supply (e.g., Tomek and Robinson, 1981, p. 86). Once gained, new knowlegde is assumed to never disappear. (A more sophisticated view recognizes that some forms of knowledge, such as biological improvements, are subject to depreciation and require additional investments to keep supply curves from shifting back.) If taken as a time trend, of course, the index of technological change does not ever change its direction of movement; even so, the velocity of this movement might change in reality, causing problems for econometric analysis.

Non-continuous effects of technical innovations can sometimes be represented by diffusion indices. The lagged effects of further learning are more complex to model. Although such changes may theoretically resemble fixity, important differences exist. Accounting for uneven technological change again requires special treatment on a case-by-case basis.

<u>Treating the special cases</u>. Most of the factors discussed above are strongly influenced by public policy. Although policy measures often respond to prices and other economic signals, the actions of a government (like those of any other single actor) are uneven and lumpy. Such sporadic change cannot always be represented by the methods that apply to the aggregate behavior of many individuals. In these cases, prior knowledge regarding different conditions is necessary. To save degrees of freedom, different rates of change or various factors must at times be combined into single indices, much as was done with the coefficient shifter in Chapter Five. Care must be taken to determine

if these indices represent simple intercept shifters, or whether more complex coefficient shifting is involved.

Examples from U.S. agricultural history and other industries. A longer view of the history of agriculture in the United States reveals the occurrence of many of the kinds of issues discussed above. Structural changes like railroad development and hybrid seed are similar in all countries. (This is why many studies focus on short enough periods for such factors to be considered stable.) The same measures, of course, must be taken to deal with them, depending on the level and purpose of a particular analysis.

In general, the analyses presented in this study might be applied to the study of other sectors both within and outside of agriculture. Among non-agricultural industries, steel, auto, textiles, chemicals, and electronics seem to offer either sufficient instability or product life-cycle effects for examinations of dynamic factors to yield interesting results. Perhaps more general, factors discussed in this study might be extended to intersectoral or aggregate macroeconomic models to improve the conceptualization and measurement of lagged economic adjustment.

Strengths and Weaknesses of the Analysis

As in the examples just shown, there are many qualifications and complicating factors that make the analysis presented in this study somewhat less straightforward than we might like. Although most of these issues have been addressed in earlier chapters, a list of the strengths and weaknesses of the analysis is collected here.

Strengths. Perhaps the major strength of this analysis is in explicitly laying out the theory of dynamic aggregate output supply and input demand for a sector of an economy facing endogenous input prices. Although this has been done in the past, the addition of the consideration of lagged adjustment in the input industries and possible constraints on input supply are novel. These additions do more than just extend the theory; they also impose consistency and clarity on the discussion of important issues in agricultural supply and policy analysis and bound the process of examining data to test for correspondence of theory to actual events. By specifying the effects of certain conditions on the relationships between variables, these developments assist in drawing conclusions from assumptions and data. The testing of hypotheses is facilitated thereby, whether or not formal econometric estimation is pursued or possible.

Weaknesses. The weaknesses of the approach taken in this study include:

(1) the dificulty of representing commodity and other policies and modeling their effects;

(2) the difficulty of representing uneven technological change;

(3) the unobservability of expectations, especially regarding future crop prices;

(4) possible errors in assuming price-taking behavior on the part of input suppliers;

(5) failure to deal adequately with some inputs, particularly labor;

(6) other short-cuts in system identification; and

(7) numerous other simplifications.

Most of these problems are most costly to econometric work. To the extent that they impose more general limits on our ability to infer conclusions from observations, they also restrict less formal methods. There is nothing particularly unique about this list of weaknesses, however, and they may be no more extensive for this study than for others. Possibilities for getting around these weaknesses are suggested in the last section of this chapter, but they may be limitations of the subject matter that simply must be lived with. In any event, comparison of the costs and benefits of further refinements is also discussed below.

Policy Implications

As discussed in Chapter One, inelastic supply is often cited as a justification for government programs to stabilize agricultural markets. Presumably, beliefs about the precise nature of supply inelasticity have been relevant to the formulation of specific policies. To the extent that this study may change perceptions about the nature of agricultural supply, it might be useful to examine implications for the design of policy instruments. Specifically, the significance of beliefs about supply irreversibility is addressed below.

Whether or not the two are casually related, previous discussions about the irreversibility of agricultural supply have occurred at the same time that U.S. commodity policies have served to create a floor for some agricultural prices. One might suspect other causes for this policy design, but previous ideas about irreversibility would not appear to fall reasonably among them. If irreversibility were characterized by inputs fixed in farming, price floors would hold up incomes, but they would not help the problem of constrained dynamic adjustment.

If inputs were thought to enter farming more easily than they leave, dynamic adjustment would be better facilitated by providing price ceilings. By keeping prices from rising too high, situations would be less likely to occur in which a surge of new inputs are later found to be fixed in excess use.

Ironically, if the thesis of this study (that inputs are more likely to be fixed out of agriculture than fixed in) is accepted, the existing policy design is rational. Price floors help to prevent a situation in which input use falls so low that later response to high prices becomes constrained by input supply capacity. Dynamic adjustment is thereby facilitated. In any event, neither case of occasional-fixity seems to be important in fact, so the policy significance of this analysis is small.

Perhaps a more significant implication of this analysis derives from the income-supporting effects of current policy design. To the extent that target prices transfer income to farmers at rates even higher than those associated with the supply-stimulating effects of target prices and loan rates, resources for purchasing additional inputs are provided. This may be particularly important for purchases of farm machinery and equipment, which have been shown to be affected by farmers' asset positions and which may even be quite independent of current machinery holdings.

Although it could be argued that such purchases would not be affected by income given any level of price signals, two factors counter this claim. First, at higher income levels, the farmer's leisure/labor trade-off will shift toward labor-saving mechanization. Second, if farmers perceive themselves to be in competition for the control of surrounding land to enable them to survive in an environment of growing economies of scale, higher incomes could cause them to act preemptively by purchasing land and large machinery beyond current levels of profit maximation as insurance policies for futher employment. Although the first factor would lead to voluntary labor-saving with little effect on output, the second factor would lead to "excess" competition creating even greater labor displacement than otherwise. Ironically, by passing income through to excessive machinery purchases and higher land prices, the income-raising effects of income supports would be diverted from farm consumption; there still would be income benefits for machinery manufacturers and dealers, and for farmers who had planned to sell out anyway.

As a final note, the "cannibalism" encouraged by this second factor is part of Willard Cochrane's "Treadmill" (1958). This early formulation of Cochrane's thesis also included an element of machinery-embodied technological change (pp. 99-100) that made matters even worse. In a later formulation (Cochrane, 1979, Ch. 19), however, this element is missing. (A more general treatment is found in Tomek and Robinson, 1981, p. 86.) Although no mention of the lost element is made, there may be good reasons for reducing its emphasis. First, machinery-embodied technological change may be minor. Second, the elasticity of substitution between labor and machinery may be so great that the technical change represented by mechanization is merely a strong substitution response to changing prices which does not produce significant savings in total factor cost per unit of output.

Suggestions for Further Work

The theory of this study indicates a likelihood that farm production of the crops considered expands more slowly than it contracts. Econometric results provide weak support for this finding. If desired, more conclusive results might be generated with improved theory, data, and econometric techniques, or with other approaches to the problem and better prior information. In addition, the need for and usefulness of such analyses should be clarified to guide the choice of future attempts at improvement and application.

Theory. The theoretical analysis for this study was performed using fairly simple discrete dynamics. Perhaps because of the relative difficulty of discrete analysis, this approach seems to be less developed than continuous analysis. Further basic development of discrete dynamic theory would appear to be of some value.

In addition, numerous aspects of applied dynamic optimization theory deserve attention. For one thing, standards for normalization when input supply is part of the system studied are vague; a general price level indicator is one approach, but it is not clear whether better options exist. Second, it is unclear how input supply capacity changes should be handled; lagged supply was used in this study, but this procedure was also shown to be rather ad hoc. Third, the adequacy of the quadratic (or other second-order) approximation for dynamic processes has been called into question (Epstsin and Denny, 1981), as has the validity of this whole mode of analysis in the presence of allocable joint inputs (Shumway, Pope, and Nash, 1984).

The annual user cost of durables is difficult to define when the opportunity cost of capital is endogenous, and the adequacy of the assumption of constant rates of depreciation should be examined. In addition, credit availibility, a source of potentially major dynamic effects, could probably be incorporated more formally and explicitly into theoretical models, as could the role of policy variables as independent variables.

Data. More definitive results regarding the dynamics of cash grain production might be derived from input data more specific to this sector. (Such data could probably be obtained from USDA.) Conclusions would not necessarily change, but their standard errors might be reduced.

Approaches to reducing levels of aggregation could also include working at the regional level. Disaggregation of crop supply and input purchase functions might be easier at this level. Attempts to model other land uses would be desired, but are perhaps too difficult to produce useful results. The labor input deserves seperate attention; results for specific equipment inputs, like irrigation, might also yield interesting findings. Data on double- and inter-cropping would clarify information about land as an input.

Econometric techniques. More work is probably needed on the theory of cross-equation restrictions in dynamics under different circumstances, especially as they are tied to different assumptions about the underlying functional forms of production functions and adjustment costs. Particular attention should be applied to the role of endogenous input prices with lagged adjustment of input supply, and to the joint estimation of input price and demand equations. It is not clear how the use of instrumental variables in these situations affects restrictions, nor is the meaning of Zellner estimation when zero restrictions are imposed.

Other approaches and improved priors. Even with improvements of the types listed above, there may be fairly firm limits to our ability to extract information from available time series data, especially with changes in technology and policy regimes. These limits might be avoided by gathering cost data from farm surveys and deriving production responses with mathematical programming, but care must be exercised to avoid fallacies of composition in aggregating results to the sectoral level. Land conversion cost data might be the most valuable acquisition from this approach. Finally, simulations using results for a complete system could serve to test the reasonableness of estimates, to examine the dynamic effects of findings, and to suggest foci for future research. Regardless of empirical approaches, however, well-thought-out theory is the ultimate source of useful priors.

Clarifying goals. Finally, many different paths could be followed in pursuing these proposed improvements. As with any study, the use of and need for an analysis should be clarified to guide future model choice, development, and application. It is incumbent that policy makers be as clear as possible about priors and uncertainties to help frame questions for researchers. It is likewise necesary for researchers to specify the reliability of findings and be explicit about options available for analyses. The value of future developments will depend on the care exercised in their selection.

APPENDICES

APPENDIX A

MODELS OF DEPRECIATION

For the purposes of this study, it is assumed that depreciation is a constant proportion of the stock value of an asset class per period. This geometric-decay (GD) pattern may seem contrary to the finding that the one-hoss-shay model of depreciation (OHS) is more accurate (Penson, Hughes, and Nelson, 1977; Penson, Romain, and Hughes, 1981). The two models are not necessarily at odds, however, because GD represents the value of an asset before maintenance and OHS represents its value after.

The service-yielding capacity of an asset given GD and a OHS-type model derived (by Penson, Hughes, and Nelson, 1977) from engineering data (ED) are both shown as functions of age in Figure A. The difference between the two, the barred area, is also shown.

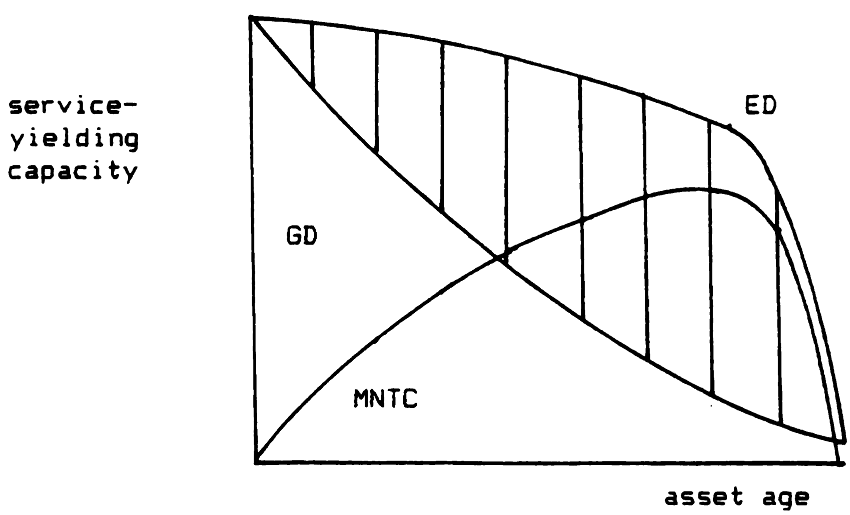

Figure A.1. Models of depreciation: geometric decay (GD), engineering data (ED), and their difference (MNTC), (adapted from Penson, Hughes, and Nelson, 1977, p. 324).

Note that the shape of this difference (MNTC) represents a typical form of current annual expenses for repairs and maintenance: it rises gradually as more major repairs and overhauls are required, until such expenditures no longer pay and the asset is allowed to expire.

Although the ED curve may reflect the services derived from durables given the addition of current inputs, the GD model better reflects the service-yielding ability left over from the previous year. Thus the two models are compatible, and GD is the more relevant for the purposes of this study.

APPENDIX B

DERIVATION OF SUPPLY/DEMAND FUNCTIONS WITH OCCASIONAL INPUT FIXITY

As described on pages 23 to 29, the case of occasionally-fixed inputs can lead to irreversible output supply and input demand relations. The derivation of the relations shown on page 24 is described below.

Three sets of equations are necessary to account for all cases of occasional input fixity. The first two are the first-order conditions already described:

$$F_Q = -p$$

$$BF_L = w_n + w_s I$$

The third is the shadow price of fixed factors:

$$w_x = BF_L$$

This is merely the reverse of the second set above, making w_x rather than L endogenous when L is predetermined.

To account for the fact that any input could be sometimes fixed and sometimes variable, a full complement of equations (one equation for each input) exists for each of the last two sets of equations. Because only one condition can apply for each input at one time, we can multiply each of these sets by a dummy matrix that indicates which equations are "turned on":

$$D_v BF_L = D_v(w_K + w_t I)$$

$$D_f \; w_K = D_f BF_L$$

in which $D_v + D_f$ is the identity matrix.

Because "turned-off" equations are zero, adding together these two sets of equations produces one set in which each equation is either a first-order condition (if that input is variable) or an endogenous price expression (if the input is fixed):

$$D_v BF_L + D_f w_K = D_v(w_K + w_t I) + D_f BF_L$$

By solving this set of equations simultaneously with the output first-order conditions, a handy way for representing supply and demand relations with occasional fixity can be derived as follows. Begin with:

$$(F_Q' \; (D_v BF_L + D_f w_K)')' = (-p' \; (D_v(w_K + w_t I) + D_f BF_L)')'$$

Collect F_L terms on the left:

$$(F_Q' \; ((D_v - D_f)BF_L + D_f w_K)')' = (-p' \; D_v(w_K + w_t I)')'$$

The diagonal square matrices B and $(D_v - D_f)$ can be reversed, and again assuming a quadratic technology for expanding the partial derivatives (this time with non-separable internal adjustment costs, F_{QI} and F_{LI}, added on for exposition):

$$((a_q+F_{QQ}Q+F_{QL}L+F_{QI}I)' \ (B(D_v-D_r)(a_l+F_{LQ}Q+F_{LL}L+F_{LI}I)+D_r w_k)')' =$$

$$(-p' \ D_v(w_k+w_l I)')'$$

Results are unchanged by inserting D_v+D_r to account for endogenous versus predetermined L, and D_v when $I \neq 0$, on the left-hand side:

$$\begin{pmatrix} a_q+F_{QQ}Q+F_{QL}(D_v+D_r)L+F_{QI}D_v I \\ B(D_v-D_r)(a_l+F_{LQ}Q+F_{LL}(D_v+D_r)L+F_{LI}D_v I)+D_r w_k \end{pmatrix} = \begin{pmatrix} -p \\ D_v(w_k+w_l I) \end{pmatrix}$$

Then, after expanding all I's ($I = L-(1-d)L_{t-1}$):

$$\begin{pmatrix} a_q+F_{QQ}Q+F_{QL}(D_v+D_r)L+F_{QI}D_v(L-(1-d)L_{t-1}) \\ B(D_v-D_r)(a_l+F_{LQ}Q+F_{LL}(D_v+D_r)L+F_{LI}D_v(L-(1-d)L_{t-1}))+D_r w_k \end{pmatrix} =$$

$$\begin{pmatrix} -p \\ D_v(w_k+w_l(L-(1-d)L_{t-1})) \end{pmatrix}$$

and noting that when $D_r=1$, $I=0$, so $D_r L=d_r(1-d)L_{t-1}$, we collect all endogenous L terms on the left-hand side and all intercept and L_{t-1} terms on the right-hand side:

$$\begin{pmatrix} F_{QQ}Q+ \quad (F_{QL}+F_{QI}) \quad D_v L \\ B(D_v-D_r)F_{LQ}Q+(B(\mathbf{D_v-D_r})(F_{LL}+F_{LI})-w_l)D_v L+D_r w_k \end{pmatrix} =$$

$$\begin{pmatrix} -p \\ D_v w_k \end{pmatrix} - \begin{pmatrix} a_q \\ B(D_v-D_r)a_l \end{pmatrix} - \begin{pmatrix} F_{QL}D_r-F_{QI}D_v \\ B(\mathbf{D_v-D_r})(F_{LL}D_r-F_{LI}D_v) \end{pmatrix} (1-d)L_{t-1}$$

Because $D_v D_v=D_v$ and $D_v D_r=0$, the **bold** D_v-D_r terms can be dropped and the sign on $F_{LL}D_r$ changes. Then, factoring the endogenous variable matrix from the left-hand side yields:

$$\begin{pmatrix} F_{QQ} & (F_{QL}+F_{QI}) & D_v \\ B(D_v-D_f)F_{LQ} & (B(F_{LL}+F_{LI})-w_I)D_v+D_f & \end{pmatrix} \begin{pmatrix} Q \\ D_vL+D_fw_K \end{pmatrix} =$$

$$\begin{pmatrix} -p \\ D_vw_m \end{pmatrix} - \begin{pmatrix} a_Q \\ B(D_v-D_f)a_I \end{pmatrix} - \begin{pmatrix} F_{QL}D_f-F_{QI}D_v \\ B((-F_{LL})D_f-F_{LI}D_v) \end{pmatrix} (1-d)L_{t-1}$$

(This factoring works because $D_vD_v=D_v$, $D_fD_f=D_f$, and $D_vD_f=0$.) Multiplying both sides by the inverse of the left-hand side coefficient matrix results in the system of output supply, input demand, and fixed-factor shadow price relations shown on page 24. The convenience of this form of expression is the ability to see how results change with changing D_v and D_f, as explained on pages 23 to 29.

APPENDIX C

COEFFICIENT MATRIX SYMMETRY FOR IMPOSING ECONOMETRIC CROSS-EQUATION RESTRICTIONS

It is shown in Chapter Two and Appendix B that the coefficient matrix of exogenous short-run output and input price effects on output supply and input use with input quasi-fixity and possible internal adjustment costs is:

$$\begin{pmatrix} F_{QQ} & F_{QL}+F_{QI} \\ BF_{LQ} & B(F_{LL}+F_{LI})-w_i \end{pmatrix}^{-1}$$

Taking the inverse by partitioning (Ayres, 1962, p. 57), the southeast submatrix is:

$$[B(F_{LL}+F_{LI})-w_i-BF_{LQ}F_{QQ}^{-1}(F_{QL}+F_{QI})]^{-1} = (BG^{-1})^{-1} = GB^{-1}$$

B alone causes asymmetry, but factor out B^{-1} and call the remaining submatrix G. Even with B^{-1} factored out (i.e., using annual input user costs), the effect of F_{LI} and F_{QI}, which are generally not symmetric (Mortenson, 1973), is to destroy the symmetry of G. If F_{LI} is, by chance, null, diagonal, or otherwise symmetric and F_{QI} is null, G would be symmetric because its inverse would be symmetric (Ayres, p. 58). (G^{-1} would be symmetric because $B^{-1}w_i$ is diagonal, F_{LL} and F_{QQ}^{-1} are symmetric, and $F_{LQ}=F_{QL}'$.) This implies equivalent input cross-price effects on input use if and only if F_{LI} is symmetric, F_{QI} is null, and prices are expressed in terms of annual user costs ($B^{-1}w_n$).

Similarly, cross-price effects of output a and input b are equal under and only under the same conditions. This is true because the southwest and northwest submatrices of the original inverted matrix, which are, respectively:

$$-GB^{-1}BF_{LQ}F_{QQ}^{-1}$$

and:

$$-F_{QQ}^{-1}(F_{QL}+F_{QI})GB^{-1}$$

are each other's transposes under and only under these conditions (since using $B^{-1}w_K$ removes all B terms).

Finally, the northwest submatrix is symmetric if and only if there are no F_{QI} adjustment costs and no assymmetric F_{LI} adjustment costs, regardless of how input prices are expressed. This is because its term:

$$F_{QQ}^{-1}+F_{QQ}^{-1}(F_{QL}+F_{QI})GB^{-1}BF_{LQ}F_{QQ}^{-1}$$

has B^{-1} and B terms that cancel each other out. Hence, the equality of crop cross-price effects depends only on adjustment costs.

APPENDIX D

VARIABLE DEFINITION AND DATA SOURCES

The variables used in the econometric analyses of Chapter 5 are, in order of appearance:

Acres planted to the six study crops = the sum of acres planted to barley, corn, oats, sorghum, soybeans, and wheat (double-cropped acres counted twice).

Source: numerous USDA publications.

Yields per harvested acre - in bushels.

Source: numerous USDA publications.

Expected yield = mean of five previous years, plus three times the average annual yield increase over the study period.

Crop price = prices-received index, all crops (1910-14 = 100).

Source: Agricultural Statistics.

Diversion variables = mean of minimum and maximum program diversion and set-aside rates, times the ratio of program to non-program gross returns per planted acre.

Gross returns = sum of crop returns and government payments.

Source: Ferris, 1986.

Machinery and equipment purchases, depreciation, and January 1 stocks (carry-in).

Source: USDA-ERS, 1986.

Machinery and equipment price - Producer Price Index 11-1, agricultural machinery and equipment. (For stocks, mean of December and January indices.)

Source: USDL-BLS.

Steel price = Producer Price Index 10-1, iron and steel.

Source: USDL-BLS.

User price of machinery and equipment = BA(1-TX)PKC in which:

BA = (DR+d)/(1+DR)

in which:

DR = Federal Intermediate Credit Bank interest rate (USDC-BEA, Survey of Current Business), less last year's rate of change of the CPI.

d = mean depreciation rate over the study period = .1243 (standard deviation = .0025).

TX = a measure of tax preference due to investment tax credits and accelerated depreciation (Mumin, 1985).

PKC = machinery and equipment price (above), normalized by the CPI.

Debt capacity = ASS(.1622-DAR)/PK in which:

ASS = values of assets (excluding farm households) held by farmers, January 1.

DAR = debt-to-asset ratio of farmers, January 1.

.1622 = mean DAR, 1965-81 (standard deviation = .0054), taken to be a norm.

PK = machinery and equipment price (above).

Source: USDA-ERS, 1986.

Fertilizer purchases = fertilizer expenses (USDA-ERS, 1986) divided by fertilizer prices-paid index (below).

Fertilizer price = fertilizer prices-paid index (1910-14 = 100).

Source: Agricultural Statistics.

Pesticide purchases = pesticide expenses (USDA-ERS, 1986) divided by pesticide prices-paid index (below).

Pesticide price = agricultural chemicals prices-paid index (1910-14 = 100).

Source: Agricultural Statistics.

Fuel purchases = petroleum fuels and oils expenses (USDA-ERS, 1986) divided by fuels prices-paid index (below).

Fuel price = fuels and energy prices-paid index (1910-14 = 100).

Source: Agricultural Statistics.

Crude oil price = Producer Price Index 5-61, crude petroleum.

Source: USDL-BLS.

APPENDIX E

POLICY FOR THE SELECTION OF INDEPENDENT VARIABLES

Although the final number (19) of predetermined variables in the system of equations in this study was fewer than the number of observations (20), actual two-stage least squares was not used. Technically, two-stage least squares could have been employed by using all 19 instruments in the first-stage determination of the estimated values of endogenous independent variables. These values would have been so close to the actual values, however, as to make second-stage estimates virtually identical to ordinary least squares results. The obvious but often-overlooked question (an exception is Intrilligator, 1978, p. 392) would then have been, "has two-staged least squares actually eliminated the inconsistency introduced by using endogenous variables as regressors?"

The policy reported in Chapter Five (p. 96) was chosen because it was decided that this was not the case. This decision was based on the following logic:

(1) The variables used as instruments have been shown to have (or can be reasonably assumed to have) significant influences on the relevant endogenous variable.

(2) Although all predetermined variables in the system affect all endogenous variables in theory, the effects of the other predetermined variables on the relevant endogenous variable have not been measurable.

(3) Although on average and in the limit, these other variables can add more information, their ability to explain variation in the endogenous variable in any given small sample will be over-shadowed by spurious correlations with first-stage error terms resulting from the more limited choice of instruments.

(4) As a result, the use of all possible instruments simply restores correlation between the estimated values of endogenous variables and second-stage error terms.

(5) The resulting spuriously-restored bias would outweigh any gain from the use of additional true information, producing estimates that would be worse than those produced under the chosen policy.

Although this position has not been shown to be valid either mathematically or in Monte Carlo simulations, it is presented here as a reasonable and pragmatic solution to an otherwise ignored problem. This is in keeping with the Methodological Note at the end of Chapter Four, and is compatible with the criteria established by McCarthy (1971). It is very close to the "structurally-ordered instrumental variables" approach recommended by Fisher (1965) and used frequently in large econometric models (Pindyck and Rubinfeld, 1981, p. 330). It should be pointed out, however, that this policy could not be followed in the use of 3SLS (see Appendix F), because this estimator requires the use of the same instruments for all endogenous variables. For this reason, this system estimator is not strictly comparable to the results reported in Chapter Five.

APPENDIX F

RESULTS OF REGRESSIONS WITH CROSS-EQUATION RESTRICTIONS

Tests of the symmetry of the effects of fertilizer and machinery prices on each other's demands were mentioned in Chapter Five (p. 116). These tests were performed on instrumental variables (IV), two-stage least squares (2SLS), and three-stage least squares (3SLS) estimates by calculating t-statistics as the difference of the two coefficient estimates in the unrestricted specification divided by the standard error of the difference. (The standard error is equal to the square root of the sum of the variances of the two estimates less twice their covariance in 3SLS.) Results for the regressions that are most inclusive of independent variables are shown in Table F.1. (Other coefficient estimates were not materially affected by the imposed restriction in 3SLS.)

Table F.1. Results of tests of the symmetry condition.

Statistical result	Estimator		
	IV	2SLS	3SLS
Coefficient of fertilizer price effect on machinery demand	-50.6 (27.6)	-45.7 (24.0)	-43.4 (15.5)
Coefficient of machinery price effect on fertilizer demand	-90.9 (21.7)	-85.0 (21.3)	-91.1 (10.6)
Difference	40.3	39.3	47.7
Covariance	-	-	13.1
Standard error	(35.1)	(32.1)	(18.1)
t-statistic	1.15	1.22	2.64

Three-stage least squares estimates are asympototically efficient relative to IV and 2SLS. This improvement is slight in small sample sizes, however (Thiel, 1971, p. 528), and specification errors diffused throughout the equation system may actually produce worse estimates (Intriligator, 1978, p. 420). Non-iterative 3SLS suffers from the same problems discussed in Appendix E with respect to 2SLS; a Fisher-like SOIV 3SLS option to avoid this problem was not available in the statistical package used (Hall, 1983), and the iterative 3SLS alternative (Brundy and Jorgenson, 1971) was judged to be too expensive given the problems mentioned above. A similar (Hausman, 1975) solution, FIML, would have also been costly; it could not actually even be estimated due to a greater number of variables in the system than observations (Sargan, 1975, appendix).

The results of non-iterative 3SLS were not markedly different from those for IV or 2SLS. Table F.2 shows these estimates for the acreage planted equation, which varied more in results than most other equations. Although 3SLS standard errors are lower than for IV and 2SLS, the reliability of this apparent efficiency in small samples is unknown.

Table F.2. Results of acres planted regressions using three different estimators.

Independent variable	Estimator IV	2SLS	3SLS
Constant	149.4	149.5	113.9
	(45.3)	(45.3)	(28.3)
Corn diversion	-98.0	-99.2	-93.3
	(19.1)	(19.1)	(12.4)
Wheat diversion	-7.0	-7.1	-19.0
	(17.8)	(17.8)	(10.8)
Wheat allotment	.511	.511	.349
	(.160)	(.160)	(.098)
Machinery carry-in	.153	.151	.090
	(.094)	(.094)	(.061)
Time	.55	.56	1.41
	(1.03)	(1.03)	(0.64)
Expansion shifter	-6.93	-7.31	-8.04
	(3.52)	(3.54)	(2.62)
Standard error of the regression	4.26	4.26	3.59
Durbin-Watson	2.47	2.46	2.18

Mean of dependent variable = 241.8; standard deviation = 24.6
Figures in parentheses are standard errors of estimates.

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