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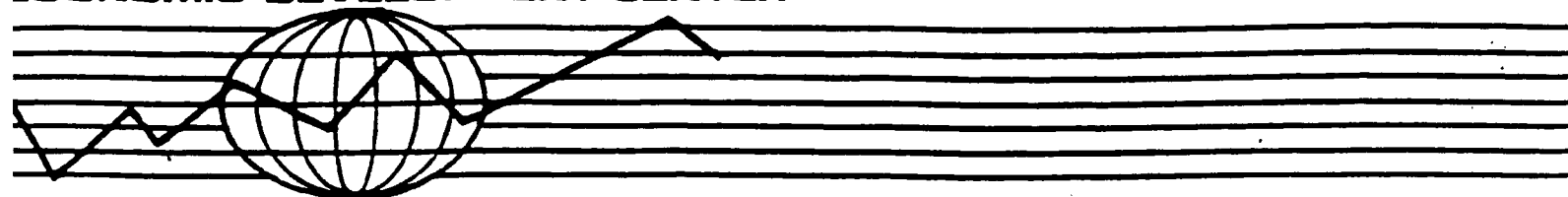
GENERAL EQUILIBRIUM ANALYSIS OF SUPPLY AND FACTOR RETURNS IN U.S. AGRICULTURE, 1949-91

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Abstract

General equilibrium - open economy trade theory and time series data on the US agricultural sector are used to provide insights into the structure of agricultural supply, factor returns and linkages to the rest of the economy. Output expansion and changes in factor rental rates depend on relative factor intensities. Theoretically consistent price elasticities of supply and factor rental rates are also obtained. The effect of the rest of the economy, particularly the increase in price of services, is found to have relatively large negative impacts on agriculture. The static effects on growth of supply and factor rental rates tend to be dominated by rate effects which are shown to have strong positive effects on returns to family labor.

J.E.L. classification numbers: O13, O30, Q11

I. Introduction

This paper focuses on the structure of US agricultural supply, factor returns and linkages to the rest of the economy. Previous studies (see Capalbo, 1988 for a survey) of factor productivity and supply response, using time series data, have tended to ignore agriculture's linkages with the rest of the economy with which it must compete for resources. In a general equilibrium - open economy framework, the productivity of resources specific to agriculture, such as land,

are affected by events that increase the use of economy wide resources in other sectors of the economy. For instance, changes in the domestic terms of trade have favored the service sector by almost doubling its share of GDP, and increasing the labor share of GDP from 59 percent to 65 percent, over the period 1948-92.[1] Since labor is not traded internationally, these changes force agriculture to substitute other factors, thus altering sub-sectoral demand for sector specific resources. These adjustments affect factor productivity in agriculture differentially, depending on relative factor intensities in each sub-sector.

In this paper, agricultural supply, factor returns and linkages to the rest of the economy are modelled in a general equilibrium - open economy framework using time series data for the period 1948-91.[2] For this purpose, we develop a <u>sectoral GDP function</u>, following Diewert (1980) and Woodland (1982), and exploit its envelope properties along the lines of Kohli (1994). In addition, a distinction is made between the 'static effects' and 'rate effects' of growth in agricultural supply and factor returns. Changes in economy wide and sectoral output prices, and endowments are generally short-run effects and hence, referred to as 'static effects' whereas the longer-run effects of technological change are referred to as 'rate effects'.

Results show that the relative factor intensities (Rybczynski like effects) are all positive suggesting that an increase in endowments of sector specific inputs causes all sectors to expand. However, as relative factor intensities vary among sectors, some outputs expand more than others. The factor return responses to output prices (Stolper-Samuelson like effects) reflect the relative factor intensities. Own price supply elasticities are all positive and relatively small, while cross price effects suggest competition for specific resources, contrary to other studies (Ball, 1988 and Luh and Stefanou, 1993).[3] The effect of the rest of the economy, particularly

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[1] National Income and Product Accounts, BEA, US Commerce Department.

[2] Data from Ball et al. (1994).

[3] In their dynamic adjustment cost model, Luh and Stefanou (1993) find that own price supply elasticities are negative in both the intermediate and long-run, an implausible result. Non-parametric methods are typically partial equilibrium in nature and tend to provide relatively large bounds on supply and factor demand elasticities (Chavas and Cox, 1995).

increases in the price of services has had a relatively large negative impact on the supply and returns to specific factors in agriculture, while that of the industrial sector is opposite, but small. In general rate effects (technological change) outweigh static effects. The contribution from rate effects to agricultural output supply is fairly common knowledge, however, its relatively large contribution to sector specific factor returns has, until now, not been emphasized.

The paper is organized as follows. The next section outlines the theoretical framework followed by a brief description of data in Section III. The empirical framework is presented in Section IV. Section V is divided into 6 sub-sections where the first four discuss the results holding constant changes from the rest of the economy. The other two sub-sections deal with general equilibrium responses. Summary remarks conclude the paper.

II. Model

Consider the two element vector of outputs (vectors) y_j, $j=$ Agriculture (A) and Non-agriculture (N) and three inputs (v_A, v_N, v_E) where input vector v_j, $j = A, N$ is specific to sector 'j' and v_E is a vector of economy wide factors which can be allocated among sectors. Following Woodland (1982), define the economy wide GDP function as:

$$G(p_A, p_N, \bar{v}_A, \bar{v}_N, \bar{v}_E) \equiv \max_{\chi} \{p_A Y_A(v_A, v_E^A) + p_N Y_N(v_N, v_E^N)\} \tag{1}$$

where,

$$\chi = \{(v_A, v_N, v_E^A, v_E^N) : v_A \leq \bar{v}_A, v_N \leq \bar{v}_N, v_E^A + v_E^A \leq \bar{v}_E\} \tag{2}$$

and Y_A and Y_N are 'vintage' production functions which exhibit constant returns to scale at the firm level (Diewert, 1980). Note that the Lagrangian multipliers of this (constrained) maximization problem $(\lambda_A, \lambda_N, \lambda_E)$ are the shadow prices for the three categories of inputs. The envelope properties of $G(p_A, p_N, \bar{v}_A, \bar{v}_N, \bar{v}_E)$ (Woodland, 1982) imply the net output supply function, for

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$j = A, N$

$$\frac{\partial G}{\partial p_j} = y_j(p_A, p_N, \overline{v}_A, \overline{v}_N, \overline{v}_E) \tag{3}$$

and the factor rental rate or inverse demand function, for $i = A, N, E$

$$\frac{\partial G}{\partial v_i} = \lambda_i(p_A, p_N, \overline{v}_A, \overline{v}_N, \overline{v}_E). \tag{4}$$

Equations (3) and (4) provide supply response to inputs (Rybczynski like effects) and factor rental rate response to output prices (Stolper-Samuelson like effects).[4]

Given λ_E from the solutions to the problem in (1), redefine it as:

$$\max\{(p_A Y_A(v_A, v_E^A) + p_N Y_N(v_N, v_E^N) - \sum_j \lambda_E v_E^j : v_A \le \overline{v}_A, v_N \le \overline{v}_N\}. \tag{5}$$

Proposition 1 [5] *The solution to problem (5) is given by:*

$$G(p_A, p_N, \overline{v}_A, \overline{v}_N, \overline{v}_E) \equiv g_A(p_A, \lambda_E, \overline{v}_A) + g_N(p_N, \lambda_E, \overline{v}_N) + \lambda_E \overline{v}_E. \tag{6}$$

The envelope properties of (1) imply the function

$$\lambda_E = \lambda_E(p_A, p_N, \overline{v}_A, \overline{v}_N, \overline{v}_E) \tag{7}$$

which is homogeneous of degree one in prices and zero in factor endowments. In the empirical model, labor is treated as the economy wide resource which is assumed to be non-traded in international markets. In this case, (7) is used as an instrumental or reduced form equation. The underlying economy implied by (1) can be viewed as being in a short run Walrasian equilibrium. At any point in time, the supply of factor endowments can be taken as given although their supply may be variable in the long run. $g_j(\cdot)$ is a 'sectoral GDP' function which, under certain regularity conditions, completely characterizes the underlying technology set (following Diewert,

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[4]We refer to these as 'like' effects, since Rybczynski and Stolper-Samuelson theorems do not necessarily apply to the general case (Woodland, 1982).

[5]See Appendix I for proof.

1974). This product function is homogeneous of degree one in each of (p_j, λ_E) and (v_j), and has the same envelope properties as the economy wide GDP function. Functions g_j and λ_E provide the basis for our parametric analysis of the responses of supply and factor returns in sector j.

At time 't' it follows that,

$$GDP_A^t \equiv g_A^t(p_A, \lambda_E, \bar{v}_A) \equiv \sum_{k=1}^{K} p_{A,k}^t y_{A,k}^t - \lambda_E^t . v_E^{At} \equiv \sum_{l=1}^{L} w_{A,l}^t \bar{v}_{A,l}^t \tag{8}$$

where returns to specific factors are represented by w^t. We assume that g_A^t can be represented by a translog functional form. See Appendix II for explicit specification of the translog 'sectoral GDP' function along with accompanying restrictions related to its homogeneity and symmetry properties.

The envelope properties of g_A^t applied to the translog form imply the output share equations, for $k = 1, .. K$

$$S_k^t = \alpha_k^t + \sum_{r=1}^{K} \alpha_{k,r} \ln p_{A,r}^t + \gamma_{E,k} \ln \lambda_E^t + \sum_{s=1}^{L} \beta_{k,s} \ln v_{A,s}^t \tag{9}$$

and the input share equations, for $l = 1, .. M$

$$S_l^t = \beta_l^t + \sum_{s=1}^{L} \beta_{A,s} \ln v_{A,s}^t + \gamma_{E,l} \ln \lambda_E^t + \sum_{r=1}^{K} \ln p_{A,r}^t \tag{10}$$

The time dependent constant terms (α_k^t, β_l^t) in the above equations (9) and (10) are replaced by $(\alpha_k^0 + \alpha_k^1 t, \beta_l^0 + \beta_l^1 t)$, where '$t$' denotes a trend variable 'time'. Note that the derivative with respect to the price of hired labor is the negative share of hired labor (since λ_E^t is endogenous). This implies that the output shares and the share of hired labor sum to unity, as do the shares of sector specific inputs. The response of supplies and factors rental rates to changes in output prices and levels of primary inputs can be computed from the parameter estimates of equations (9) and (10) (Takayama, 1985 p.147-149). These are referred to as '*static effects*'. In addition, following Kohli (1994), define the semi-elasticities of supply of outputs and returns to factors with respect to the time index as:

$$\epsilon_{kt} = \frac{\partial \ln y_k}{\partial t}; \epsilon_{lt} = \frac{\partial \ln w_l}{\partial t} \tag{11}$$

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These semi-elasticities indicate the effects of the passage of time (as a surrogate for technical change) on output supplies and factor returns which, we refer to as '*rate effects*'. For the case of our translog sectoral GDP function, these semi-elasticities translate into:

$$\epsilon_{kt} = \frac{\alpha_k^1}{S_k} + \frac{\partial \ln g_A}{\partial t}; \epsilon_{lt} = \frac{\beta_l^1}{S_l} + \frac{\partial \ln g_A}{\partial t} \tag{12}$$

We make use of a discrete measure to approximate $\frac{\partial \ln g_A}{\partial t}$, as suggested by Jorgenson (1986), and evaluate these elasticities at average shares.

Since, in equilibrium, factor rental rates equal the marginal value product of the corresponding factor, rental rate responses to changes in the static and rate effects can be viewed as determinants of factor productivity. Static effects have a once and for all effect on the growth in factor returns, while rate effects are long run growth effects.

III. Data

Data on US agriculture for the period 1949-91 are obtained from Ball et al. (1994), and aggregated into four outputs and five inputs. The output categories are meat animals, rest of livestock referred to as dairy, grain (food and feed grains), and crops (other than grains). The input categories are family labor, hired labor, real property, capital, and materials. Prices and quantities for outputs are derived as Tornqvist indices. Price indices reflect market prices exclusive of commodity programs. Over the period 1949-91, the share of grain and crops in agriculture's GDP increased marginally, and at the expense of the livestock sectors (meat and dairy). Grains account for an average share of 18 per cent of GDP. The average share of crops in agriculture's GDP is relatively large (31 percent) and stable, experiencing an annual growth rate of only 0.3 percent while the grains grew at an annual rate of 1.1 percent. The meat and dairy sectors account for 27 and 24 percent of GDP, respectively. On average, the share of dairy has fallen more rapidly than the meat sector (at rates of -0.7 and -0.4 percents, respectively).

Among the five inputs, hired labor is treated as an economy wide, non-internationally traded input while the other four are treated as specific to the agricultural sector. On average, the share

of material inputs in the total cost is the largest at 40 percent followed by the shares of family labor (21), real property (18), capital (13) and hired labor (8). The share of real property and capital have increased mostly at the expense of labor (family and hired) over the period. The share of real property has grown at an average annual rate of 6.1 percent followed by capital at 1.1 percent. The share of family and hired labor declined at annual average rates of 2.5 and 2 percent, respectively. The decline in the share of materials is relatively small (-0.4 percent per year). Thus, unlike the relatively constant share composition of agricultural output, the composition of costs have changed appreciably since 1948 with labor's share falling and real property and capital rising.

IV. Econometric model

The econometric model is based on the share equations (9) and (10) from which sectoral supply and factor rental rate elasticities with respect to output prices and input quantities (sector specific as well as economy wide) are computed. Following Jorgenson (1986), we refer to the parameters (α_k^1, β_l^1) in equations (9) and (10) as biases of technical change (productivity growth), although other factors, such as efficiency gains from process innovations, may well be captured by these parameters. For α_k^1 positive, technical change is referred to as output-augmenting. For β_l^1 positive (negative), technical change is referred to as input-using (input-saving). It should be noted that these parameters indicate 'relative' rates of augmentation of output and utilization of input since the first order parameters α_k^t, β_l^t do not provide adequate structure to identify the source technological change. The elasticities ϵ_{kt} and ϵ_{lt} express the percent change in the quantities of supply and factor rental rates with respect to the trend variable. Further, "the role of ϵ_{kt} and ϵ_{lt} is to show how some quantities may increase faster than others, and how some factors may benefit more than others from technological progress. These elasticities adequately indicate how the production and factor-price possibilities frontier shift and twist over time as a result of technological change, but they have nothing to say about the almost philosophical

question as to whether progress occurs because it is inputs which become more productive, or because it is outputs which become easier to produce" (Kohli, 1994, p.12).

As the rental rate of hired labor, λ_E^t, (equation 7) is endogenous it should be estimated along with the share equations as an instrumental equation. This equation is specified as:

$$\ln \lambda_E^t = \eta_0 + \sum_{j=1}^{3} \eta_j \ln p_j^t + \sum_{i=1}^{5} \eta_i \ln v_i^t + \eta_t t \tag{13}$$

where the variables corresponding to p_j are prices of aggregate agricultural goods, industrial goods and services. The variables v_i denote sector specific variables; land, materials and capital in agriculture, and economy wide endowments; capital in non-agriculture and aggregate labor.[6]

Equations (9) and (10) suggest that the prices of outputs (p_A^t) evolve contemporaneously. However, this is not necessarily the case since production typically involves a time lag. Accordingly, the p_A^t 's in the right as well as left hand side (as shares are functions of prices) of the equations (9) and (10) are replaced by p_A^{t-1}.

Since the shares sum to one, one output share (crops) and one input share (capital) equation are omitted from the system. Hence, the share equations of meat, dairy and grain on the output side and hired labor, family labor, materials and real property on the input side along with the equation for the rental rate of hired labor were fit to the data. The restrictions pertaining to homogeneity and symmetry properties of the sectoral GDP function were imposed on the system and used to obtain parameter estimates of the omitted equations. The unexplained variation in the dependent variables, as depicted by the residual terms $(\mu_{kt}, \mu_{lt}, \mu_t)$ for (9) and (10) and (13), respectively, were assumed to be random and normally distributed with zero mean and constant variance. However, our initial results suggest that the residuals were correlated across equations and time periods as a first order vector auto-regressive (VAR) process, which we correct for in the results reported here.[7]

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[6]The 'non-agricultural sector' constitutes both the industrial goods and services. Source of data: NIPA, BEA, US Commerce Department.

[7]See Bowden and Turkington (1982) for the estimation procedure.

The correction proceeds as follows. OLS residuals ($\mu_{kt}, \mu_{lt}, \mu_t$) obtained from the system are regressed on all μ_{kt-1}, μ_{lt-1},and μ_{t-1} to obtain the matrix of parameters for the VAR process. The dependent and independent variables are transformed using this matrix, and then estimated using three stage least squares.

V. Results

Equation (13) links the agricultural sector (share equations 9 and 10) to the rest of the economy through the competition for the economy wide resource, labor. Table 1 presents the estimates of the share equations. The econometric model appears to fit the data surprisingly well, as indicated by the high t ratios in Table 1 and the system R^2 is 92 percent. Most of the restrictions pertaining to homogeneity and symmetry properties of the sectoral GDP function are accepted by the data. For the translog sectoral GDP function to be convex in output and input prices, it has to be the case that the Hessian matrix formed by rows 1 to 5 and columns 1 to 5 of Table 1 should be positive semi-definite which implies non-negative eigen values. Our results confirm this condition.[8] Output supply and factor rental rate response to output prices, factor endowments and technological progress (time) are computed using these parameter estimates evaluated at average shares. These results appear in Table 2.

V.1 Rybczynski and Stolper-Samuelson Like Effects

Output responses to inputs appear in rows 1 to 4, columns 6 to 9 of Table 2. These elasticities sum to one due to the homogeneity (of degree one) of the supply function in sector specific inputs. The discussion on the sectoral response to hired labor through which economy wide changes affect the agricultural sector is left to Section V.3.

All the sectors use material inputs relatively intensively except dairy, whose response to family labor is relatively high (an elasticity of 0.365). Family labor appears to be relatively more

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[8]Note that the negative sign on the left hand side of the hired labor share equation (Table 1) should be passed on to the parameter estimates (right hand side) before deriving the eigen values.

important to the meat and crops sectors (0.276 and 0.216, respectively) than to the grain sector.[9] The result that the grain and crops output response to real property (which is predominantly land) are larger than the elasticities of two livestock sectors is consistent with their intensity of land use. The responses of meat and crops outputs to capital (0.096 and 0.079) are small, while that of dairy and grain outputs are fairly large and similar (0.206 and 0.203).

These Rybczynski like effects suggests that an augmentation in the availability of material inputs tends to favor the output of grain the most, followed by crops, meat and dairy outputs, respectively. In addition, meat, dairy and crops outputs remain relatively dependent on family labor. Capital appears to be relatively more important to dairy and grain outputs.

Factor rental rate's response to output prices (Stolper-Samuelson like effects) are presented in rows 6 to 9, columns 1 to 4 of Table 2. These results show that an increase in the price of meat and the price of crops tends to have, all else constant, relatively larger effects on the rental rate of materials (0.327 and 0.394, respectively) in contrast to the rental rates of other inputs. This result is consistent with the factor intensities reported above. Similarly, the returns to family labor are more responsive to an increase in the prices of meat, dairy and crops (0.348, 0.412 and 0.319, respectively) than to an increase in the price of grain. Correspondingly, note from our previous discussion that the supply response of these three outputs are relatively sensitive to the changes in the levels of family labor. Thus, as family labor departs agriculture, the returns to remaining family labor should rise (as implied by the estimated wage-family labor elasticity of -0.585) while, all else constant, downward pressures are placed on the production of these three outputs. Returns to real property tends to be relatively more responsive to the price of crops, and equally responsive to the prices of the other three outputs. The rental rate of capital appears most responsive to the price of dairy and least responsive to the price of crops.

In general, holding all else constant, the effect of output prices on factor rental rates is proportional to the relative intensity to which the factors are employed in production. An unit increase in the price of crops increases the returns to all sector specific inputs (the sum of

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[9]Recall that the crops sector does not include grains.

elements in rows 6 through 9 of column4, 1.26 %) relatively more than any other sector.

V.2 Supply Response and Factor Substitution

Previous results from fitting models of multiple agricultural outputs-inputs, but in partial equi-
librium (see Capalbo, 1988 for a survey), to time series data tend to suggest either gross com-
plementarity among outputs (Ball, 1988) or negative own price elasticities of supply, both in the
intermediate and long run (Luh and Stefanou, 1993). Analyzing the responses of supply in US
agriculture in an economy wide general equilibrium framework yields results that seem more
plausible. Small direct price elasticities than those obtained from partial equilibrium analyses
are expected as our approach takes into account of the constraints of sector specific resources
on total output (Binswanger, 1989).

Direct and cross-price supply elasticities appear in rows and columns 1 to 4 of Table 2.
These elasticities along with the elasticity in column 5 (see Section V.3) sum to zero as the
supply function is homogeneous of degree zero in output and input prices. In general, own price
elasticities are positive, but some cross price effects are large and negative suggesting strong
intra-sectoral competition for sector specific resources. The meat sector's response to its own
price is relatively inelastic (0.082). The cross price effects of grain and crops on meat are small
and positive (0.038 and 0.026, respectively) implying complementarity. Dairy output response to
its own price is also relatively inelastic (0.145). The cross price effects between meat and dairy
are negative suggesting that they compete for resources, while complemetarities exist between
the dairy and crops sectors (a positive cross price elasticity of 0.138). Grain output is relatively
more responsive to its own price (0.192) than any other sector and is a complement to the meat
sector (0.056). The crops sector's response to its own price is 0.111 and it is also a complement
to the dairy and meat sectors (0.022 and 0.106). The cross price effects between grains and
crops are large and negative implying substitutability.

Substitutability among inputs can be inferred from the elements in rows and columns 6 through
9 of Table 2. The diagonal elements of this matrix indicate that the response of all factor rental

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rates to their respective quantities is negative, as expected. Substitutability among inputs is clear from the positive signs of off-diagonal elements but there is some complementarity between material inputs and real property. This result is consistent with the complemetarity between intermediate inputs and capital (includes real property) identified by Jorgenson et al. (1987) using share elasticities from their sectoral models of production. Among factor returns, the rental rate of capital is relatively more responsive to its own input quantity (-0.887) followed by family labor (-0.585), materials (-0.392) and real property (-0.228).

V.3   The Case of the Economy Wide Resource

The elasticities corresponding to hired labor are reported in Table 2 (all elements in row 5 and column 5). As mentioned in Section II, hired labor is treated as a non-internationally traded and economy wide factor. Hence, its rental rate and the quantity used in agriculture are considered endogenous.

The elements in column 5 correspond to output and factor return responses to the changes in the rental rate of hired labor. The responses of meat, dairy and crops outputs to an increase in the rental rate of labor is negative (-0.028, -0.108 and -0.113, respectively), while the response of grain output is positive but small. The effect of changes in the rental rate of hired labor on other factor rental rates are reported in column 5, rows 6 through 9. The results suggest that capital is a complement (0.009) while, the other factors, family labor (-0.081), materials (-0.143), and real property (-0.060) are substitutes to hired labor.

The elements of row 6 represent the response of the 'quantity demanded' of hired labor to changes in agricultural prices and changes in the levels of other inputs. As the crops sector consists of some of the relatively labor-intensive horticultural crops, it is not surprising that the quantity of hired labor is relatively more responsive to their prices (0.426). The dairy sector is also identified as using hired labor relatively intensively. The response of hired labor to a unit increase in its own price (-0.778) suggests a relatively elastic labor demand response relative to other inputs.

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V.4 The Pattern of Productivity Growth

The previous discussion concerned static effects on changes in output supply and factor rental rates. In this section, we focus on rate effects. The effects of technological change, to the extent captured by the time surrogate, on supply and factor rental rates are measured up to a factor of proportionality (coefficients on a trend variable 'time' in the share equations, Table 1).

All the parameter estimates of the time variable (Table 1) in the output share equations are significant. Since the shares sum to unity these results suggest that the relative effect of efficiency gains has been to favor the production of grain and crops relative to the production of meat and dairy. Parameter estimates of the time variable in the factor share equations for family labor and materials are positive and significant at 5 % level of confidence. They suggest that, to the extent time is a surrogate for technical change, technological progress has been family labor and material using. The corresponding result is unclear for hired labor, since its estimated coefficient (0.0004) is not significantly different from zero. In addition, these results also indicate that the agricultural sector has been both real property and capital-saving but, the rate of saving of real property is relatively larger than that of capital (-0.0094 vs -0.0037).

To assess the effects of technological change on supply and factor returns, a discrete approximation of $\frac{\partial \ln g_A}{\partial t}$ is employed (Jorgenson, 1986, p.1856). Our estimate of this value is 2.29 %, a value which corresponds to an estimate obtained from a non-parametric analysis (Gopinath and Roe, 1995). Using this value, we evaluate (12) at average shares (see last column, Table 2). The rate effect on supply is the largest for crops and for grain with estimated average annual rates of growth of about 2.9 and 2.8 percent, respectively, over the sample period. Once again, holding static effects constant, the returns to family labor and materials have benefitted positively from technological change (average annual growth rates of 7.2 and 2.7 percent, respectively), while having a tendency to decrease the rates of return to real property and land. These relatively high rates of output augmentation are not surprising, as productivity growth in the US agricultural sector is found to be four times that of the non-farm economy (Jorgenson and Gollop, 1992). However, the effects of technological change on factor returns (particularly on family labor) has,

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until now, not been emphasized.

V.5 General Equilibrium Responses

The elasticities in Table 2 were computed holding the returns to hired labor, an endogenous variable, constant. We now decompose the source of changes in hired labor and compute the supply and factor return responses arising exclusively from changes in exogenous variables. To illustrate, the responses in Table 2 that was of the form:

$$\frac{\partial^2 g}{\partial p_k \partial p_r} = \frac{\partial y_k}{\partial p_r} \left| \widehat{\lambda}_E - \text{constant} \right| = \theta_{kr}; \quad \frac{\partial^2 g}{\partial v_l \partial v_s} = \frac{\partial w_l}{\partial v_s} \left| \widehat{\lambda}_E - \text{constant} \right| = \phi_{ls} \tag{14}$$

are recomputed according to,

$$\frac{\partial^2 g}{\partial p_k \partial p_r} = \frac{\partial y_k}{\partial p_r} + \frac{\partial y_k}{\partial \widehat{\lambda}_E} * \frac{\partial \widehat{\lambda}_E}{\partial p_r} = \theta^*_{kr}; \quad \frac{\partial^2 g}{\partial v_l \partial v_s} = \frac{\partial w_l}{\partial v_s} + \frac{\partial w_l}{\partial \widehat{\lambda}_E} * \frac{\partial \widehat{\lambda}_E}{\partial v_s} = \phi^*_{ls} \tag{15}$$

Effectively, these computations show how activity on other sectors of the economy influence agriculture's competitiveness for the economy wide resource, hired labor. First, it should be noted that the services sector of the US economy is labor-intensive (Gopinath and Roe, 1994). Hence, an increase in the price of services tends to bid up the rental rate of labor thereby, at the margin, raising production costs in agriculture. The results of estimating equation (13) along with the share equations (simultaneous system estimated using 3SLS) are:

$$\ln \lambda_E = -9.03^* + 0.26^* \ln p_A - 0.10 \ln p_I + 0.84^* \ln p_S - 0.12^* \ln V_A \tag{16}$$
$$+ 0.25^* \ln V_R + 0.26 \ln V_M - 0.10 \ln V_N - 0.29^* \ln V_L + 0.01^* t$$

where,[10] (p_A, p_I, p_S) denote farm, industrial and service sector output prices and $(V_A, V_R, V_M, V_N, V_L)$ denote capital, land and material inputs in agriculture, capital in non-agriculture and aggregate labor, respectively.

The results corresponding to equation (15) are presented in Table 3. Table 3 replaces the wage variable of Table 2 with the price index for industrial goods and the services sector (columns

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[10] * denotes significance at 5 % level.

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5 and 6), and the endowments of economy wide labor and non-agricultural capital (columns 11 and 12). While most of the direct and cross price, endowment elasticities are similar to those in Table 2, two results deserve special attention. The first is the responses of supply and factor returns to the changes in the price index of industrial goods and services. The other is the effects of increases in economy wide labor and non-agricultural capital.

The supply response to changes in the price of industrial goods[11] is positive for all agricultural outputs, except for grain (-0.002) which is small. The demand for hired labor in agriculture increases as the price of industrial goods rise (0.08) and the returns to most sector specific inputs are positively affected by the price of industrial goods, as expected due to the supply effects. These results further confirm the complementarities between the agricultural and industrial sectors found by Gopinath and Roe (1994). The price of services has the opposite effect. As the price of services rise, the quantity of hired labor demanded in agriculture falls (-0.88), reflecting the service sector's capacity to pull labor from agriculture, as well as to lower the rental rates of sector specific factors, such as family labor and real property.

With one exception (capital), increases in the economy wide labor and non-agricultural capital increase the returns to agriculture's sector specific resources. The supply response of agriculture to these endowments are relatively small, but the effects of labor tend to be larger than those of capital. The general equilibrium responses of supply, factor returns and quantity of hired labor with respect to time are similar to the results in Table 2, except the effect on hired labor which is much smaller (0.8 %).

V.6   Contributions to Predicted Outputs and Factor Returns

Given the estimated general equilibrium elasticities (θ^*, ϕ^*) reported in Table 3, we now use the data to measure the mean effect per annum (over the sample period, 1949-91) of the explanatory variables on the 'predicted' values of output supply, hired labor demand and factor returns. To

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[11] This sector includes, among others, all the industries that add value to primary agricultural products.

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illustrate the calculations, the proportional change in supply is given by

$$\left(\frac{dy_k}{dt}\right)\left(\frac{1}{y_k}\right) \equiv \hat{y}_k^t \equiv \sum_r \theta_{kr}^* \frac{d\ln p_{kr}^t}{dt} + \sum_s \theta_{ks}^* \frac{d\ln v_{ks}^t}{dt} + \theta_{kt}^* dt \tag{17}$$

The average of the individual RHS components $(\theta_{kr}^* \frac{d\ln p_{kr}}{dt}, \theta_{ks}^* \frac{d\ln v_{ks}}{dt}, \theta_{kt}^* dt)$ are then divided by the average predicted supply $(\hat{y}_k)$ to derive the contributions of prices, inputs and technological change to the average annual changes in 'predicted' supply, hired labor demand and factor returns. It is useful to view the results in Table 4 in two different parts, one of which is 'static effects', the other 'rate effects'. Level effects have a once and for all effect on the growth in outputs and factor returns, while rate effects are long run growth effects. Table 4 is constructed so that the total contributions (percent changes) sum to +100 (-100) if the dependent variable has increased (decreased) on average over the sample period. Positive (negative) numbers in the body of the table indicate the percent contribution of the row variable to increasing (decreasing) predicted supply, demand or factor returns.

While the supply of all outputs have grown, the average annual rate of growth in supply is largest in grains (4.05 %) followed by the crops sector (2.96 %). For the most part, rate effects on growth in supply dominate the static effects of prices and endowments. The total of static effects on supply range from -64 (dairy) to 28 (grains) percent per annum of the growth in output, holding constant the rate effects.

The diagonal elements of the matrix formed by rows 2 to 5 and columns 1 to 4 indicate that the own price contribution to the share of each output is positive with the dairy sector benefiting the most from its own price (25 percent). The off diagonal values reflect complementarities and substitutability among outputs (as reported in Section V.2) from cross price effects. Note that some of these effects dominate own price contributions. The net contribution from all prices to average annual changes in supply (sum of elements in rows 2 to 5 of columns 1 to 4) is, however, surprisingly small. The effect of other sectors (industrial and services sectors) on predicted annual average growth in supply is provided by the elements in rows 5, 6, 11, and 12 of Table 4. The larger the intensity of hired labor, the greater are the impacts of the increase in

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the price of services (dairy and crops sectors). Effectively, the increase in the price of services has pulled labor out of agriculture, while the industrial sector appears to have had little effect.

The departure of family labor had fairly large negative effects on average annual changes in supply of meat, dairy and crops, while having relatively small effects on the less family labor-intensive grain sector (rows 7 to 10 and columns 1 to 4). A high growth rate in material inputs coupled with their relatively intensive use in all the sectors is reflected in the large positive contributions from this input to augment all supplies.

The relatively small net contributions from annual changes in prices and inputs (static effects) on sectoral supplies suggest that, to the extent that time is a surrogate for technical change, 'rate effects' dominate the sum of 'static effects'. This reaffirms common wisdom that technical change has been the driving force behind the growth in supply. Clearly, the rate effects have been sufficiently large to prevent the adverse domestic terms of trade affects on agricultural supply.

The contributions to average annual changes in the returns to factors (except that of hired labor) from static and rate effects are presented in columns 6 to 9 of Table 4. The data show that hired labor demand has fallen by -0.36 % per annum. Real property is the only sector specific factor that experienced a decline in its rental rate (-0.80 %) over the period. Other factor rental rates experienced real growth, the highest of which is the family labor (11.26 %). The static effects on the average annual change in the demand for hired labor and on the change in sector specific capital rental rates tend to dominate, and be opposite to, the rate effects. Hence, the long run growth effects on increasing the annual demand for hired labor over the period has been dominated by static effects, the largest of which has been the average annual increases in the price of services. Otherwise, the rate effects dominate static effects.

To the extent that time is a surrogate for technical change, technical change appears to have been the major force behind the average annual growth in returns to family labor (11.26 %) since the static effects, particularly from prices, have been relatively small. A similar picture emerges for the growth in returns to materials. Changes in agricultural output prices had larger

positive effects on the growth in real property and capital rental rates. Still, the negative rate effects dominate the static effects for real property. The annual average rise in the real price of services has had larger negative effects on agriculture than the positive effects of changes in the price of industrial goods. With the exception of agricultural capital, increases in economy wide endowments of labor and capital have large positive effects on the demand for hired labor, but otherwise relatively small positive effects on average annual changes in the rental rates of other factors.

VI. Summary and Conclusions

General equilibrium - open economy trade theory and time series data on the US agricultural sector are used to provide insights into the structure of agricultural supply, factor returns and linkages to the rest of the economy. The effects of changes in economy wide and sectoral output prices, and endowments are referred to as 'static effects' on growth. Technological change is a 'rate effect' which persists in the long-run.

Holding hired labor's wage constant, Rybczynski like effects in agriculture are positive, suggesting that an increase in sector specific endowments causes an expansion in all sub-sectors, although relative factor intensities vary among sectors so that some expand more than others. As expected, all factor rental rates respond negatively to an increase in their respective endowments. The rental rate of real property was the most inelastic, while that of capital and hired labor tended to be more responsive to changes in their respective levels. Evidence of complementarity between intermediate inputs and capital is found, a result consistent with Jorgenson et al. (1987).

All sectors except grain appear to use material and family labor inputs relatively intensively. The response of factor rental rates to increases in output prices (Stolper-Samuelson like effects) follows the pattern of relative factor intensity. Consequently, the returns to family labor are more responsive to an increase in the prices of meat, followed by dairy and crops (other than

grains). In contrast to other studies, all own price supply elasticities and some cross price effects are positive, while others, such as the cross price effect between grain and crops, are relatively large and negative suggesting competition for sector specific resources like land. Direct price elasticities of supply vary from 0.192 for grains to 0.082 for meat. These results tend to reinforce Binswanger's (1989) argument that 'large' supply responses from partial equilibrium analyses can be misleading because, they do not to capture the constraint of sector specific resources on total output.

Hired labor is treated as an economy wide and non-internationally traded factor for which agriculture must compete with the rest of the economy. Consequently, hired labor becomes an endogenous variable which links changes in industrial and services sector prices, economy wide endowments and other non-agricultural sector shocks to agricultural supply and factor returns. A rise in the real price of services, a sector which uses labor relatively intensively (Jorgenson et al., 1987), causes an increase in hired labor's rental rate, and a decrease in the supply of meats, dairy and crops. A rise in the hired labor rental rate tends to pull labor from agriculture, forcing a substitution of other factors and a decline in the rental values of agriculture's sector specific resources. With the exception of grains, changes in the price of industrial goods tends to have the opposite, though much smaller, effects on agriculture. Using a more aggregate data set, Gopinath and Roe (1994) find a similar result. They conjecture that the reason lies in the derived demand effects for agriculture's output as the industrial sector includes those sub-sectors that add value to agriculture's primary products. Growth in economy wide capital and labor endowments have relatively small but positive effects on agricultural supply and rental rates.

To the extent that time correlates with technological change, the results suggest that techno-logical progress, on average over the period, has tended to be family labor and material using, real property and capital saving, and indeterminate with respect to hired labor. Holding static effects constant, technological change has caused the returns to family labor to grow by an annual average of over 7 percent per year. The importance of technology to agricultural supply is common knowledge, but its importance to growth in returns to family labor has not been

emphasized. Efficiency gains appear to favor crops and grains with estimated average annual rates of growth in their supply due to technological change alone is nearly 3%.

Based on the estimated general equilibrium elasticities and the data, the effects of the observed evolution of the exogenous variables (both the static and rate effects) on the predicted values of the endogenous variables were computed. The static effects ranged from - 64 percent to 28 percent of the average annual growth in predicted supply. These results reaffirm that actual changes in prices and inputs have not really increased supply instead, technology has been the driving force. Most of the decline in the demand for hired labor is attributed to the increases in the price of services. Changes in agricultural output prices had large positive effects on the growth in real property and capital rental rates. However, a major cause for the decline in the rental rate of real property appears to be the negative rate effects. Static effects on the returns to family labor are relatively small, leaving technological change as the major contributor to its positive growth.

Appendix I

The economy wide GDP function is defined as

$$G(p_A, p_N, \bar{v}_A, \bar{v}_N, \bar{v}_E) \equiv \max_{\chi}\{p_A Y_A(v_A, v_E^A) + p_N Y_N(v_N, v_E^N)\} \tag{18}$$

where,

$$\chi = \{(v_A, v_N, v_E^A, v_E^N) : v_A \leq \bar{v}_A, v_N \leq \bar{v}_N, v_E^A + v_E^A \leq \bar{v}_E\}$$

The following are the envelope properties of the GDP function (Woodland 1982):

(i) Supply functions for outputs

$$\frac{\partial G}{\partial p_j} = y_j, j = A, N$$

(ii) Factor return function for sector specific inputs

$$\frac{\partial G}{\partial v_i} = \lambda_i, i = A, N$$

(iii) Factor return function for economy wide input

$$\frac{\partial G}{\partial v_E} = \lambda_E$$

Let the solution to the maximization problem in (18) be $(v_A^*, v_N^*, v_E^{A*}, v_E^{N*}, \lambda_A^*, \lambda_N^*, \lambda_E^*)$. Set $v_A^* = \tilde{v}_A$ and $v_N^* = \tilde{v}_N$ and define $\tilde{G}$ as follows:

$$\tilde{G}(p_A, p_N, \tilde{v}_A, \tilde{v}_N, \bar{v}_E) \equiv \max\{p_A Y_A(v_E^A, \bar{v}_A) + p_N Y_N(v_E^N, \bar{v}_N) - \sum \lambda_E v_E^j\} \tag{19}$$

$$\chi = \{(v_A, v_N, v_E^A, v_E^N) : v_A \leq \bar{v}_A, v_N \leq \bar{v}_N, v_E^A + v_E^A \leq \bar{v}_E\}$$

Proposition 1

$$\tilde{G}(p_A, p_N, \tilde{v}_A, \tilde{v}_N, \bar{v}_E) \equiv \tilde{G}_A(p_A, \tilde{v}_A, \lambda_E) + \tilde{G}_N(p_N, \tilde{v}_N, \lambda_E) + \lambda_E \bar{v}_E$$

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Proof. The Kuhn-Tucker conditions for the problem in (19) include (interior solution)

$$p_A \frac{\partial Y_A}{\partial v_E^A} - \lambda_E = 0$$

$$p_N \frac{\partial Y_N}{\partial v_E^N} - \lambda_E = 0$$

so that, for j = A,N

Note the "separability" of the problem in the choice variables leads to solutions for economy wide inputs used in j = A,N

$$\tilde{v}_E^j = v(p_j, \tilde{v}_i, \overline{v}_E)$$

and therefore,

$$\tilde{G}(p_A, p_N, \tilde{v}_A, \tilde{v}_N, \overline{v}_E) \equiv p_A Y(\tilde{v}_E^A, \tilde{v}_A) + p_N Y(\tilde{v}_E^N, \tilde{v}_N)$$

$$\equiv \tilde{G}_A(p_A, \tilde{v}_A, \lambda_E) + \tilde{G}_N(p_N, \tilde{v}_N, \lambda_E) + \lambda_E \overline{v}_E$$

Once again, Envelope Theorem applied to this $\tilde{G}_j$ gives the following:

(i) Supply functions for outputs

$$\frac{\partial \tilde{G}_j}{\partial p_j} | \lambda_E - \text{ constant } | = y_j, j = A, N$$

(ii) Factor return function for sector specific inputs

$$\frac{\partial \tilde{G}_j}{\partial v_i} | \lambda_E - \text{ constant } | = \lambda_i, i = A, N$$

(iii) Factor return function for economy wide input

$$\frac{\partial \tilde{G}_j}{\partial \lambda_E} | \lambda_E - \text{ constant } | = -v_E^j, j = A, N$$

Appendix II

Following Diewert (1974) a translog form for the sectoral GDP function,

$$\ln g(p_A, \lambda_E, v_A) \equiv \alpha_0^t + \sum_{j=1}^{N} \alpha_j^t \ln p_{A,j} + (\frac{1}{2}) \sum_{j=1}^{N} \sum_{k=1}^{N} \alpha_{j,k} \ln p_{A,j} \ln p_{A,k} + \alpha_E^t \ln \lambda_E + \sum_{i=1}^{M} \beta_i^t \ln v_{A,i}$$

$$(\frac{1}{2}) \alpha_{E,E} (\ln \lambda_E)^2 + +(\frac{1}{2}) \sum_{i=1}^{M} \sum_{l=1}^{M} \beta_{i,l} \ln v_{A,i} \ln v_{A,l} + \sum_{j=1}^{M} \gamma_{E,j} \ln p_{A,j} \ln \lambda_E$$

$$\sum_{i=1}^{N} \gamma_{E,i} \ln v_{A,i} \ln \lambda_E + \sum_{j=1}^{M} \sum_{i=1}^{N} \delta_{j,i} \ln p_{A,j} \ln v_{A,i}$$

Note that the first order parameters are time dependent. Setting $\sum_{j=1}^{N} \alpha_j^t + \alpha_E^t = 1, \sum_{i=1}^{M} \beta_i^t = 1$ and restricting second order parameter summations to zero (e.g. $\sum_{j=1}^{N} \alpha_{j,k} = 0, \sum_{i=1}^{M} \beta_{i,l} = 0$) imposes the homogeneity properties of this function. The translog functional form is originally due to Christensen, Jorgenson and Lau (1971).

Table 1

Table 1: Parameter Estimates of Share Equations

Shares	Price of					Endowment of				Time
	Meat	Dairy	Grain	Crops	H.Lab	F.Lab	Matrl	R Prop	Capl.	
Meat	0.229	-0.110	-0.047	-0.091	0.018	0.013	0.016	-0.013	-0.016	-0.0027
	(17.5)	(-8.9)	(-3.1)	(-10.5)	(3.1)	(1.1)	(0.9)	(-1.1)	(-3.0)	(-6.0)
Dairy	-0.110	0.230	-0.063	-0.053	-0.005	0.035	-0.046	-0.004	0.015	-0.0010
	(-8.9)	(15.3)	(-4.1)	(-5.1)	(-0.7)	(2.5)	(-2.3)	(-0.3)	(2.2)	(-2.1)
Grain	-0.047	-0.063	0.198	-0.111	0.023	-0.046	0.030	0.005	0.011	0.0011
	(-3.1)	(-4.1)	(9.6)	(-10.4)	(3.2)	(-2.9)	(1.5)	(0.4)	(1.7)	(1.9)
Crops	-0.091	-0.053	-0.111	0.262	-0.008	-0.005	0.023	0.006	-0.024	0.0022
	(-10.5)	(-5.1)	(-10.4)	(14.2)	(-1.2)	(-0.4)	(1.2)	(0.6)	(-2.1)	(2.4)
-H.Lab	0.018	-0.005	0.023	-0.008	-0.028	0.002	-0.023	0.006	0.015	0.0004
	(3.1)	(-0.7)	(3.2)	(-1.2)	(-5.2)	(0.2)	(-1.7)	(0.8)	(3.5)	(1.4)
F.Lab	0.013	0.035	-0.046	-0.005	0.002	0.043	0.004	-0.036	-0.011	0.0112
	(1.1)	(2.5)	(-2.9)	(-0.4)	(0.3)	(1.5)	(0.1)	(-1.5)	(-1.3)	(12.6)
Matrl	0.016	-0.046	0.030	0.023	-0.023	0.004	0.077	-0.086	0.005	0.0019
	(0.9)	(-2.3)	(1.5)	(1.2)	(-1.7)	(0.1)	(1.1)	(-2.9)	(0.4)	(2.5)
R Prop	-0.013	-0.004	0.005	0.006	0.006	-0.036	-0.086	0.111	0.011	-0.0094
	(-1.1)	(-0.3)	(0.4)	(0.6)	(0.8)	(-1.5)	(-2.9)	(4.0)	(1.7)	(-10.2)
Capl.	-0.016	0.015	0.011	-0.024	0.015	-0.011	0.005	0.011	-0.006	-0.0037
	(-3.0)	(2.2)	(1.7)	(-2.1)	(3.5)	(-1.3)	(0.4)	(1.7)	(0.36)	-(2.47)

t ratios in parentheses.

Table 2

Table 2: Supply and Factor Return Elasticities

		Elasticity with respect to								
		Price of						Endowment of			Time
		Meat	Dairy	Grain	Crops	H.Lab	F.Lab	Matrl	R Prop	Capl	
Supply											
	Meat	0.082	-0.119	0.038	0.026	-0.028	0.276	0.484	0.144	0.096	0.0136
	Dairy	-0.132	0.145	-0.043	0.138	-0.108	0.365	0.253	0.176	0.206	0.0191
	Grain	0.056	-0.055	0.192	-0.215	0.024	0.003	0.580	0.215	0.203	0.0284
	Crops	0.022	0.106	-0.127	0.111	-0.113	0.216	0.498	0.208	0.079	0.0294
H.Lab (demand)		0.091	0.312	-0.052	0.426	-0.778	0.208	0.682	0.127	-0.016	0.0185
Factor Returns											
	F.Lab	0.348	0.412	0.002	0.319	-0.081	-0.585	0.447	0.033	0.104	0.0716
	Material	0.327	0.153	0.270	0.394	-0.143	0.239	-0.392	-0.009	0.162	0.0273
	R Prop	0.221	0.241	0.226	0.372	-0.060	0.039	-0.02	-0.228	0.208	-0.0266
	Capital	0.185	0.357	0.270	0.179	0.009	0.160	0.463	0.264	-0.887	-0.0018

Table 3

Table 3: General Equilibrium Supply and Factor Return Elasticities

	Price of						Endowment of						Time
	Meat	Dairy	Grain	Crops	Indus	Serv	F.Lab	Matrl	R.Prop	Capl	E.Lab	N.Cap	
Supply													
Meat	0.08	-0.12	0.04	0.02	0.00	-0.02	0.28	0.48	0.14	0.10	0.01	0.00	0.013
Dairy	-0.14	0.14	-0.05	0.13	0.01	-0.09	0.40	0.23	0.15	0.22	0.03	0.01	0.018
Grain	0.06	-0.05	0.19	-0.21	-0.00	0.02	-0.01	0.59	0.22	0.20	-0.01	-0.00	0.029
Crops	0.02	0.10	-0.13	0.10	0.01	-0.10	0.25	0.47	0.18	0.09	0.03	0.01	0.028
H.Lab (demand)	0.04	0.27	-0.09	0.36	0.08	-0.66	0.44	0.48	-0.07	-0.07	0.23	0.08	0.008
Factor Returns													
F.Lab	0.29	0.37	-0.03	0.26	0.01	-0.07	-0.56	0.43	0.01	0.11	0.02	0.01	0.071
Matrl	0.27	0.11	0.23	0.33	0.01	-0.12	0.28	-0.43	-0.05	0.18	0.04	0.02	0.025
R Prop	0.17	0.19	0.19	0.31	0.01	-0.05	0.06	-0.04	-0.24	0.22	0.02	0.01	-0.027
Capl.	0.13	0.31	0.23	0.12	-0.00	0.01	0.16	0.46	0.27	-0.89	-0.00	-0.00	-0.002

Elasticity with respect to

Table 4

Table 4: Contributions to Predicted Outputs and Factor Returns

(Average Annual Percent Change, 1949-91)

	Supply of				Demand	Factor Returns of			
	Meat	Dairy	Grain	Crops	H.Lab	F.Lab	Matrl	R Prop	Capl
Growth Rate %	1.61	1.05	4.05	2.96	-0.36	11.26	3.31	-0.80	1.36
Price									
Meat	17.41	-45.18	4.93	1.71	36.32	9.08	28.63	72.87	33.58
Dairy	-14.68	25.30	-2.63	6.51	143.94	6.34	6.23	47.67	44.72
Grain	4.37	-8.41	9.10	-8.43	-46.26	-0.56	13.41	45.42	32.75
Crops	3.77	30.45	-13.40	8.72	255.31	5.77	25.34	98.37	21.83
Indus	0.71	4.05	-0.24	1.53	87.02	0.29	1.74	3.04	-0.28
Serv	-7.72	-44.09	2.56	-16.63	-946.37	-3.17	-18.89	-33.02	3.01
Endowment									
F.Lab	-42.45	-88.49	0.26	-20.09	-290.74	11.95	-20.37	-17.21	-27.78
Material	48.14	33.89	23.60	25.58	216.07	6.14	-21.00	-7.24	55.63
R Prop	1.47	2.38	0.94	1.04	-3.27	0.02	-0.23	-5.25	3.37
Capital	5.11	16.90	4.12	2.57	16.89	0.84	4.46	22.46	-54.40
E.lab	1.00	5.72	-0.33	2.16	122.82	0.41	2.45	4.29	-0.39
N.cap	0.63	3.63	-0.21	1.37	77.84	0.26	1.55	2.72	-0.25
Static Effects	17.77	-63.84	28.70	6.04	-330.43	37.37	23.31	234.05	111.79
Rate Effects	82.23	163.84	71.30	93.96	230.43	62.63	76.69	-334.05	-11.79
Sum	100	100	100	100	-100	100	100	-100	100

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