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Capital Adjustment in U.S. Agriculture and Food Processing: A Cross-Sectoral Model

Carlos Arnade and Munisamy Gopinath

Significant differences exist in the rates of capital adjustment in the four major sectors of the U.S. economy: agriculture, food, manufacturing, and services. A multi-output adjustment cost model is specified to compute the rates of capital adjustment. This specification allows us to derive dynamic output supply and investment demand functions for the four sectors, which are then fitted to time-series data. Our estimates show that capital in agriculture and manufacturing is almost fixed and adjusts toward respective long-run equilibrium at a rate of about 2% per year. The food processing and services sectors are more flexible in that their capital stocks fully adjust in less than five years. Thus, the rate of adjustment of agricultural capital is lower than that of other sectors in the U.S. economy.

Key words: adjustment costs, capital adjustment, dynamic duality

Introduction

Capital is crucial to the growth of the U.S. economy. During 1947–85, capital accumulation contributed, on average, about 40% of the growth in gross domestic product (GDP) of the United States (Jorgenson, Gollop, and Fraumeni). However, significant differences exist in its contribution to the growth of various sectors of the economy. Capital contributed less than 3% to the growth in agricultural output, while it accounted for about one-third and one-fourth of the growth in the food processing and manufacturing sectors during 1959–91 (Ball et al.; Gopinath, Roe, and Shane; U.S. Department of Labor). The above pattern reflects, in part, the ability of the sectors to adjust their capital, and thus augment output.[1]

The agricultural sector is unique among the sectors of the economy because its production depends on weather and involves long time lags. It is often claimed that agricultural capital, once invested, stays fixed within the sector (Johnson and Quance).[2] In addition, several authors have modeled agricultural capital as quasi-fixed with adjustment costs, and tested its empirical validity (Vasavada and Chambers; Howard

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The authors are economist, Economic Research Service, USDA, and assistant professor, Department of Agricultural and Resource Economics, Oregon State University, respectively. We acknowledge the comments and suggestions of Mark Gehlhar, Terry Roe, Mathew Shane, Spiro Stefanou, Lloyd Teigen, and three anonymous referees. Although their input helped us substantially improve this paper, the authors claim full responsibility for the final product.

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[1] Other factors like capital-saving or labor-using technical change can also explain capital's contribution to growth in various sectors.

[2] As a reviewer noted, hysteresis is a possible explanation for locked-in assets. The definition of a fixed-asset problem has been a subject of debate. Interested readers should refer to Hsu and Chang, and to Richards. Note that our adjustment cost model deals with quasi-fixed factors.

and Shumway; Vasavada and Ball; Luh and Stefanou 1991). This study contributes to the above literature by computing an adjustment rate of agricultural capital in the context of the broader economy.

Following Epstein's demonstration of the applicability of dynamic duality theory, a number of empirical studies have attempted to measure the rate of input adjustment in individual sectors (for agriculture—Vasavada and Chambers; Howard and Shumway; Luh and Stefanou 1991; for manufacturing—Epstein and Denny; Meese). Applications both to agriculture and manufacturing have ignored the linkages among the major sectors of the economy. The focus on individual sectors is important, but provides little insight into the differences in input adjustment behavior between the sectors. For instance, if capital is relatively slow to adjust in agriculture, a decline in agricultural prices relative to the price of nonagricultural goods and services would lower both returns to capital in agriculture and growth in the broader economy because too much capital remains allocated to agriculture.

If the rate of capital adjustment in agriculture is low, then adopting technology embodied in capital inputs would take longer, which can slow agricultural output growth. Conversely, if capital in other sectors adjusts faster, these sectors may use relatively newer capital equipment which could give them a productivity advantage. This could make agriculture a less attractive investment in capital markets.

The objective of this study is to estimate the rates of capital adjustment and the resulting divergence between the short- and long-run responses of supply and capital demand in four major sectors of the U.S. economy. Specifically, we test (*a*) whether agriculture is constrained by sluggish capital adjustment relative to the rest of the economy, and (*b*) whether agricultural output is more responsive to economywide changes than other sectors of the economy.

A multi-output framework with profit-maximizing, forward-looking agents and capital adjustment costs is used to represent economic decisions. Capital is assumed to be specific to each of the four sectors. Labor is treated as an input that is mobile among the four sectors. Output supply and quasi-fixed factor investment demand functions are derived from a dynamic optimization problem and econometrically estimated as a system of simultaneous equations. Annual time-series data for the period 1958–91 are used, derived from the National Bureau of Economic Research (NBER) productivity database (Bartelsman and Gray) and the U.S. Department of Commerce (1929–93a, b).

The Model

The existence of input adjustment costs has provided the basis for many dynamic models in the economic literature (Sargent; Epstein). A multi-output adjustment cost model assumes the existence of a transformation function:

$$(1) \qquad F(\mathbf{y}, \mathbf{x}, \mathbf{K}, \mathbf{I}, \tau) = 0,$$

where $\mathbf{y}$ is a vector of outputs, $\mathbf{x}$ is a vector of variable inputs, $\mathbf{K}$ is a vector of quasi-fixed inputs, $\mathbf{I}$ is a vector of new investment in the quasi-fixed input, and τ is an indicator of the level of technology. F is a continuous, twice differentiable function that is strictly increasing in $\mathbf{y}$, decreasing in $\mathbf{x}$ and $\mathbf{K}$, and strictly increasing in $\mathbf{I}$. F is also closed and convex in $\mathbf{y}$, $\mathbf{x}$, $\mathbf{K}$, and $\mathbf{I}$.

The assumption that $F(\cdot)$ is increasing in **I** represents the existence of adjustment costs. New investment must be transformed to capital stock, but this transformation requires resources in the short run. Therefore, capital investment has the opposite influence on the function $F(\cdot)$ as does the level of capital, **K**.[3] If there were one output and the equation were explicitly solved for that output (y), then short-run production would decrease as investment is increased. Thus, investment can be viewed as temporarily diverting resources rendered toward production and decreasing output in the short run. For example, production lines are often temporarily shut down when new equipment is installed.

Profit-maximizing firms that have adjustment costs make dynamic decisions in a forward-looking manner; that is, a choice on investment influences output across a range of time periods.[4] Thus, a representative price-taking firm chooses the sequence of investments to maximize profits over an infinite horizon as follows:

$$(2) \qquad \max_{(\mathbf{y},\mathbf{I},\mathbf{x})} \left\{ \int_{t_0}^{\infty} e^{-rt}(\mathbf{p}'\mathbf{y} - \mathbf{c}'\mathbf{x} - \mathbf{w}'\mathbf{K})\, dt \right\}$$

$$\text{s.t.:} \quad \dot{\mathbf{K}} = \mathbf{I} - \delta\mathbf{K},$$

$$F(\mathbf{y}, \mathbf{x}, \mathbf{I}, \mathbf{K}, \tau) = 0,$$

$$\mathbf{K}(t_0) = \mathbf{K}^0,$$

where, **p** is a vector of output prices, **c** is a vector of variable input prices, **w** is a vector of rental rates of quasi-fixed factors, $\mathbf{K}^0$ is the vector of initial (given) levels of quasi-fixed factors (capital), r is the interest rate, and δ represents the rate of depreciation. The equation $\{\dot{\mathbf{K}} = \mathbf{I} - \delta\mathbf{K}\}$ represents the accumulation of capital, where $\dot{\mathbf{K}}$ is net investment. The solution to the problem in (2) is the value function $J(\mathbf{p}, \mathbf{c}, \mathbf{w}, \mathbf{K}^0, \tau)$, which is a function of output and input prices, initial levels of the quasi-fixed factors, and an indicator of technology, τ (Epstein). Note that new capital in each sector can arise from profits in the sector or profits reallocated from other sectors.

The firm expects prices at t_0 (the initial period) to persist indefinitely, but as new prices are observed, the firm continuously revises its previous plans. Thus, only the t_0 part of the plan is necessarily carried out (Hsu and Chang). An alternative formulation of the problem in (2) is the Hamilton-Jacobi equation (Intriligator), where the dynamic choice model can be converted into its static equivalent. Letting $J(\mathbf{p}, \mathbf{c}, \mathbf{w}, \mathbf{K}^0, \tau)$ denote the optimal value of the problem in (2), and assuming that the price expectations are static, the Hamilton-Jacobi equation takes the form:

$$(3) \qquad rJ(\mathbf{p}, \mathbf{c}, \mathbf{w}, \mathbf{K}^0, \tau) = \max_{(\mathbf{y},\mathbf{I},\mathbf{x})} \Big\{ \mathbf{p}'\mathbf{y} - \mathbf{c}'\mathbf{x} - \mathbf{w}'\mathbf{K} + J_{K^0}(\mathbf{p}, \mathbf{c}, \mathbf{w}, \mathbf{K}^0, \tau)'(\mathbf{I} - \delta\mathbf{K}^0) \Big\} + J_{\tau}.$$

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[3] Adjustment costs can be asymmetric. For instance, it may cost more to install new capital than to detach and move existing capital (Hsu and Chang).

[4] Another way to derive a dynamic model is to let the stationary properties of data determine its structure, i.e., an error correction model (Vasavada and Cook). However, we prefer to use theory and account for the possibility of nonstationary data in estimation.

Note that the function J denotes the total value of the firm over the infinite horizon (a stock) which, when pre-multiplied by the interest rate r, denotes a single-period flow (rJ). In other words, J is the total value of the firm, whereas rJ represents profits for a single period. The derivatives of the value function with respect to τ and $\mathbf{K}^0$ are denoted as J_τ and $\mathbf{J}_{K^0}$, respectively. Intuitively, the problems in (2) and (3) are equivalent in the sense that the solution to (3), which is a one-period choice, lies in the path derived by (2). The advantage of the above formulation is that it is possible to use the envelope properties of the optimal value function, as derived by Epstein, without explicitly solving the dynamic problem. Epstein explains the properties of the value function in detail. The dynamic output supply, variable input demand, and quasi-fixed factor investment demand functions are derived from the Hamilton-Jacobi formulation (Epstein) as follows:

(4)
$$\begin{aligned}
\mathbf{y} &= r\mathbf{J}_p - \mathbf{J}_{K^0 p}\dot{\mathbf{K}} - \mathbf{J}_{\tau p}, \\
\mathbf{x} &= -r\mathbf{J}_c + \mathbf{J}_{K^0 c}(\mathbf{I} - \delta\mathbf{K}^0) + \mathbf{J}_{\tau c}, \\
\dot{\mathbf{K}} &= [\mathbf{J}_{K^0 w}]^{-1}(r\mathbf{J}_w + \mathbf{K}^0 - \mathbf{J}_{\tau w}),
\end{aligned}$$

where J_i denotes the first derivative, and J_{ij} is the second derivative of the value function with respect to $i, j = \tau$, $\mathbf{c}$, $\mathbf{w}$, $\mathbf{p}$, $\mathbf{K}^0$.

We consider four outputs—agriculture, food processing, manufacturing, and services; one variable input—labor; and four quasi-fixed and sector-specific capital stocks—one each for agriculture, food, manufacturing, and services.[5] We specify a value function that uses the properties in (4) to derive the output supply, variable input demand, and quasi-fixed investment as functions of $\{\mathbf{p}, \mathbf{c}, \mathbf{w}, \mathbf{K}^0, \tau\}$. Thus (4), along with an assumed quadratic functional form, provides the basis for an empirical investigation into dynamic output supply and investment demand. A normalized (on labor price) quadratic value function is given by:

(5)
$$\begin{aligned}
J(\mathbf{p}, \mathbf{c}, \mathbf{w}, \mathbf{K}^0, \tau) = a_0 &+ \sum_{i=1}^{4} a_i p_i + \sum_{j=1}^{4} b_j w_j + \frac{1}{2}\sum_{i=1}^{4}\sum_{s=1}^{4} a_{is} p_i p_s \\
&+ \frac{1}{2}\sum_{j=1}^{4}\sum_{m=1}^{4} b_{jm} w_j w_m + \frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4} c_{ij} p_i w_j \\
&+ \sum_{i=1}^{4}\sum_{n=1}^{4} d_{in} p_i K_n^0 + \sum_{j=1}^{4}\sum_{n=1}^{4} e_{jn} w_j K_n^0 \\
&+ \sum_{i=1}^{4} g_i p_i \tau + \sum_{j=1}^{4} h_j w_j \tau + q\tau,
\end{aligned}$$

where p_1, p_2, p_3, and p_4 are output prices for agriculture, food, manufacturing, and services, respectively; w_1, w_2, w_3, and w_4 are the corresponding capital rental rates; K_1^0, K_2^0, K_3^0, and K_4^0 are levels of capital in the four sectors; and τ is a time trend that is

[5] Assuming labor as a quasi-fixed input would lead to two separate models, one each for agriculture and nonagriculture, which have been analyzed extensively in the past.

a surrogate for technological change.[6] All prices in the value function were divided by the price of labor, ensuring that homogeneity conditions are met. While the requirements of concavity in quasi-fixed factors and convexity in prices are determined by theory, the adherence of the data to these requirements is tested by estimating the parameters of the model. Epstein shows that the convexity properties of a dynamic value function have the additional requirements that $rJ - \mathbf{J}'_{K^0}(\mathbf{I} - \delta\mathbf{K}^0)$ be convex in prices. The above functional form ensures that $\mathbf{J}_{K^0}$ is linear in prices so that convexity of $J(\cdot)$ in prices is sufficient for this general convexity condition to be met (Howard and Shumway).

Classifying capital into four distinct types represents one aspect of a specific-factors model, where each sector is assumed to have an input specific for its production (Kohli). To ensure capital adjustment in each sector is only a function of the type of capital used in that sector, the following restriction on the coefficients of the function in (5) are imposed:

$$e_{jn} = 0, \quad \text{if } j \neq n; \;\; j,n = 1,2,3,4. \tag{6}$$

Thus, independent adjustment becomes an aspect of the maintained (univariate accelerator) model. Otherwise, a multivariate accelerator leads us to a highly nonlinear specification of the system of investment demand equations. Attempts to estimate a nonlinear multivariate specification failed to converge. In order to estimate multivariate accelerator models, previous researchers either have restricted their models to two inputs (Howard and Shumway; Luh and Stefanou 1993), or have estimated a reduced form where nonlinear structural parameters are reduced so as to use linear estimation procedures (an exception being Buhr and Kim). It would be arbitrary for us to assume that two out of the four capital inputs are quasi-fixed and the other two are variable. Faced with these tradeoffs among competing assumptions, we chose the univariate accelerator model to make our system tractable.

Note that (5) satisfies the condition for consistent aggregation over firms $J_{K^0K^0} = 0$. The empirical counterparts to (4), dynamic output supply and investment demand equations for four outputs and four capital stocks, then can be derived from (5). The estimated equation representing the supply of agriculture is written as:

$$Y_1 = r\left(a_1 + g_1 + \sum_{s=1}^{4} a_{1s}p_s + \sum_{j=1}^{4} c_{1j}w_j + \sum_{n=1}^{4} d_{1n}K_n^0 + g_1\tau\right) - \sum_{n=1}^{4} d_{1n}\left(I_n - \delta K_n^0\right), \tag{7}$$

where I_n is investment for $n = 1, 2, 3, 4$. Similar equations are specified for the other three outputs.

Using (4) and the derivatives of the value function, the equation representing changes in agricultural capital ($\dot{K}_1$) is specified as:

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[6] Diewert and Wales suggest several alternate functional forms. However, some parameters of these new functional forms, like the Barnett/McFadden forms, are left to the subjective choice of an investigator, which discouraged us from pursuing them.

(8) $$\dot{K}_1 = \frac{K_1^0 + r\left(b_1 + h_1 + \sum_{m=1}^{4} b_{1m}w_m + \sum_{i=1}^{4} c_{i1}p_i + e_{11}K_1^0 + h_1\tau\right)}{e_{11}}.$$

Similarly, investment equations for food, manufacturing, and services are derived from (5). Though output supply and variable input demand equations are linear in parameters, the investment demand equation is not. However, the investment demand equation can be rearranged and estimated in linear form. For example, (8) can be rewritten as:

(9) $$\dot{K}_1 - rK_1^0 = \theta_1 K_1^0 + \eta_1 r + \sum_{m=1}^{4} \alpha_{1m}(w_m r) + \sum_{i=1}^{4} \beta_{i1}(p_i r) + \gamma_1\tau,$$

where

$$\theta_1 = \frac{1}{e_{11}}, \quad \eta_1 = \frac{b_1 + h_1}{e_{11}}, \quad \alpha_{1m} = \frac{b_{1m}}{e_{11}},$$

$$\beta_{i1} = \frac{c_{1i}}{e_{11}}, \quad \text{and} \quad \gamma_1 = \frac{h_1}{e_{11}}.$$

Equations (7) and (9) form a system of simultaneous equations which can be estimated using linear estimation techniques. Note that our system of equations in (8) can be simplified to be linear in the parameters as in (9) because of the univariate-flexible accelerator form of the model. This simplification is possible because the model was specified as restricting one sector's capital investment to be independent of the level of capital in other sectors.

Data and Estimation

Time-series data on prices and value of output in each of the four sectors, quantities of primary inputs (employment and capital input), and shares of labor and capital in GDP are obtained from the National Income and Product Accounts of the Bureau of Economic Analysis, U.S. Department of Commerce, and from the NBER manufacturing productivity database (Bartelsman and Gray) for the period 1958–91.[7] The data on value of output are based on the 1987 revised Standard Industrial Classification (SIC) codes. The agricultural sector includes primary (raw) farm products. The food processing sector includes meat packing, milk, and other animal products, grain and baking products, processed vegetables, tobacco, and other processed crop products. The major industrial products include mining, manufacturing (durables and nondurables, excluding food processing), and construction. Services include finance, insurance, real estate, health, legal, educational, government, and others. Since GDP is defined as the value of output produced by labor and property located in the U.S., the output measures are value added by each sector (gross output less payments to intermediate inputs).

[7] All the data series for the food processing sector are taken from the NBER manufacturing productivity database, while the data on the other three sectors are from the U.S. Department of Commerce.

The productive capital stock (in constant 1987 billions of dollars) series in each of the four sectors is derived by the U.S. Department of Labor, Bureau of Labor Statistics as gross stock (perpetual inventory) less depreciation (hyperbolic decay). The Bureau of Labor Statistics accounts for quality improvements in the capital stock by adjusting the producer price indexes that value the structures and equipment (U.S. Department of Commerce 1929–93a). Labor is given by the number of full-time equivalent employees in the economy. Wages for each sector were obtained by dividing compensation to employees by the number of employees. A similar price index for capital was constructed using payments to capital.

Recall that all prices must be normalized on one of the prices because (5) represents a normalized quadratic value function. The price of labor (wage) was chosen to be the numeraire for the system. Since there are four specific factors, the estimated system contained four output supply equations (7) and four capital adjustment equations (9). Following conventional practice (Vasavada and Chambers; Howard and Shumway), changes in quasi-fixed factors were represented by first differences of annual data. Right-hand-side values of **K** in (7) and (9) were represented by capital lagged one period. A fixed interest rate of 5.5% was used in the estimation.[8] In addition, the agricultural output price index was lagged by one period to account for the lag in production.[9] The specification includes a trend variable in every equation. We assume that the data series are deterministic about the trend, and thus ensure the validity of model statistics.

As noted in (9), parameter restrictions were used to ensure that the capital investment equations could be estimated using linear methods.[10] The SYSLIN procedure in SAS was used to estimate four output supply and four investment equations, using 3SLS (instrumental variables, Bowden and Turkington) and the data from 1958–91. Symmetry among output equations was imposed, but it was not possible to impose the complete set of symmetry restrictions as investment equations are specified in reduced form. Tests failed to reject the null hypothesis of symmetry among the output equations. However, the Hessian of the value function was not positive semidefinite, thereby violating the convexity conditions (seven out of eight eigenvalues were positive). Following Vasavada and Chambers; Luh and Stefanou (1991); and others, we argue that this failure should not deter an investigator in reporting the results. Hence, the parameter estimates of the eight equations presented in table 1 with high t-ratios and a system R^2 of 97% should be viewed with caution.

Results

In this section, we first discuss the rates of adjustment of capital in the four sectors of the U.S. economy. This will set the stage for comparing short- and long-run elasticities

[8] Following others (Epstein and Denny; Vasavada and Chambers; Howard and Shumway; Luh and Stefanou 1991), we fix the interest rate (r) in equations (7), (8), and (9) to be a constant. The real interest rates computed from International Monetary Fund data varied slightly around 5.5%

[9] Nonstatic output price expectations (Luh and Stefanou 1996) were incorporated as additional laws of motion into the problem in (2). Equations (7) and (9) were then derived under linear and quadratic price expectations. Unfortunately, all supply (demand) elasticities were negative (positive) under these specifications.

[10] Nonlinear estimation can produce unreliable and unstable parameter estimates. Often it is found that final parameter estimates are sensitive to an analyst's estimate of starting values, the algorithm used, the step size used over a grid search, and the convergence criteria.

Table 1. Parameter Estimates and *t*-Ratios of Supply Equations for Four Major Sectors of the U.S. Economy

Variable	Agriculture	Food	Manufacturing	Services
*Price*1	3.60	11.98	-86.92	-10.53
	(1.29)	(1.02)	(-2.03)	(-0.54)
*Price*2	11.98	46.62	-449.83	-70.81
	(1.02)	(0.52)	(-1.75)	(-0.53)
*Price*3	-86.95	-449.83	2,303.20	682.28
	(-2.03)	(-1.75)	(2.40)	(1.60)
*Price*4	-10.53	-70.81	682.28	183.24
	(-0.54)	(-0.53)	(1.60)	(0.74)
*Rental Rate*1	-8.87	-76.96	313.95	16.88
	(-0.75)	(-1.48)	(1.52)	(0.19)
*Rental Rate*2	15.18	61.26	-112.07	171.54
	(1.25)	(1.34)	(-0.61)	(1.86)
*Rental Rate*3	35.84	177.02	-496.14	-107.51
	(1.84)	(1.75)	(-1.25)	(-0.60)
*Rental Rate*4	-162.95	-803.79	2,406.80	2.68
	(-1.86)	(-1.81)	(1.38)	(0.003)
*Capital*1[a]	-2.01	-8.75	51.59	12.10
	(-2.05)	(-1.48)	(2.49)	(1.22)
*Capital*2	2.02	-11.27	33.35	47.36
	(0.85)	(-1.04)	(0.85)	(2.56)
*Capital*3	0.15	1.65	-8.14	-3.48
	(1.23)	(2.57)	(-2.87)	(-2.87)
*Capital*4	-0.20	-1.03	6.32	1.81
	(-2.48)	(-2.74)	(3.39)	(2.39)
Time Trend	-0.001	-0.008	0.11	0.07
	(-1.33)	(-1.84)	(5.46)	(9.70)
Capital lagged 1 period	-0.0752	-0.4622	-0.0767	-0.3561
	(-1.97)	(-3.33)	(-0.73)	(-7.64)
*Price*1	3.98	0.268	9.95	-6.82
	(3.40)	(0.71)	(1.44)	(-1.06)
*Price*2	23.20	3.35	-15.20	-95.71
	(4.51)	(2.04)	(-0.50)	(-3.26)
*Price*3	-35.06	3.84	52.80	1.98
	(-3.79)	(1.17)	(0.96)	(0.05)
*Price*4	-60.95	2.25	-120.70	402.16
	(-4.53)	(0.49)	(-1.63)	(5.47)
*Rental Rate*1	-1.37	2.75	-2.71	-6.05
	(-0.23)	(1.41)	(-0.08)	(-0.18)
*Rental Rate*2	-16.34	-7.46	-49.082	179.41
	(-1.89)	(-2.90)	(-1.18)	(4.10)
*Rental Rate*3	16.01	-0.23	48.92	94.39
	(3.34)	(-0.16)	(1.68)	(3.69)
*Rental Rate*4	-19.71	11.61	-41.58	-978.45
	(-0.67)	(1.25)	(-0.25)	(-5.93)
Time Trend	-0.003	0.001	0.01	0.036
	(-1.34)	(3.01)	(0.46)	(6.56)

Notes: Numbers 1–4 following variables are defined as follows: 1 = agriculture sector, 2 = food processing sector, 3 = manufacturing sector, and 4 = services sector. Numbers in parentheses are *t*-ratios.
[a] Refers to the parameter d_{in} on $[(r + \delta)K_n - I_n]$ in equation (7).

Table 2. Adjustment Rates of Capital in Four Major Sectors of the U.S. Economy

Sectors	θ [a]	S.E. (θ)	Adjustment Rates	95% Confidence Interval Lower	Upper
Agriculture	-0.0752	0.0383	-0.020	-0.036	-0.005
Food Processing	-0.4622	0.1387	-0.407	-0.460	-0.354
Manufacturing	-0.0767	0.1054	-0.022	-0.055	0.011
Services	-0.3561	0.0466	-0.301	-0.363	-0.239

[a] θ is the adjustment rate parameter in the matrix **M** in equation (10).

because a slow rate of adjustment would imply larger differences between these elasticities.

Capital Adjustment

Notice that the equations in (9) can be rewritten to represent a univariate-flexible accelerator model with constant adjustment coefficients as:

$$\dot{\mathbf{K}}^* = \mathbf{M}(\mathbf{K} - \bar{\mathbf{K}}), \tag{10}$$

where $\dot{\mathbf{K}}^*$ denotes optimal net investment, $\bar{\mathbf{K}}$ is the long-run optimal level of capital (steady-state), and **M** is a rate-of-adjustment matrix which is diagonal, since capital is assumed specific to each sector. The diagonal elements of the matrix, which are the constant rates of adjustment of capital in each of the four sectors, are given by $(\theta_i + r)$, for $i = 1, 2, \ldots, 4$, where r is the interest rate and θ_i is the estimated parameter on lagged capital from (9). A system likelihood-ratio test for instantaneous adjustment of capital was performed. The sum of the coefficients on K_{t-1} in (9) equals $\{1 + \theta_i + r\}$. Hence, the constraint $\{\theta_i = -(1 + r)$, for $i = 1, 2, \ldots, 4\}$, which is equivalent to instant adjustment of capital to changes in prices and technology, was imposed (Howard and Shumway) and the system of equations was reestimated. This equation-by-equation test rejected the null hypothesis of instant adjustment at the 1% level. The χ^2 statistic with one degree of freedom was 107.6 for agriculture, 39.4 for food processing, 20.5 for manufacturing, and 23.8 for services. The estimated adjustment rates are reported in table 2. The 95% confidence interval (upper and lower bounds) for the adjustment rates also were derived.

The adjustment coefficients for the agriculture, food processing, and services sectors are significant at the 5% level. They suggest that the rate of adjustment of capital in the food processing sector is relatively fast and falls in the 35.4–46% interval, while that of the services sector falls in the 23.9–36.3% interval. The calculated rates for the manufacturing sector indicate relatively low rates of adjustment of capital in that sector (annual average of 2.2% per year). Epstein and Denny reported a relatively low adjustment rate of capital in manufacturing at 12% per year over the period 1947–76, while Meese found quarterly adjustment rates of 3%, which translates into 12.6% per year. Since our sample includes the 1980s, which witnessed a relative decline of the manufacturing sector, the slow adjustment is not surprising. As noted earlier, these rates of capital adjustment are consistent with the observed pattern of capital's contribution to GDP growth. We find that in the more dynamic sectors like food processing and services, capital's contribution to growth is high, unlike primary agriculture and manufacturing (Jorgenson, Gollop, and Fraumeni; Gopinath, Roe, and Shane).

Capital adjustment in the agriculture sector indicates that agriculture's capital behaves almost like a fixed factor. Our estimate of the rate of adjustment of agricultural capital is 2% per year, which is smaller than most studies (Vasavada and Chambers; Howard and Shumway; Luh and Stefanou 1993). However, our sample is different from the other studies and includes the 1980s.

The agricultural and manufacturing sectors' rate of capital adjustment is low compared with other sectors of the U.S. economy. For any given change, it takes under five years for the services and food processing sectors to adjust to their respective levels of steady-state capital, while manufacturing and agricultural sectors take more than 25 years to adjust. However, note that our model cannot determine if adjustment costs are the only source of slow adjustment. Habit formation, credit constraints, or uncertainty also could affect the rate of adjustment of capital.

The slow rate of adjustment in agriculture and manufacturing suggests that capital investment-oriented policies, such as investment tax credits, are likely to have only small effects on growth in these two sectors. This quasi-fixity makes the returns to capital highly variable. It also makes the returns to capital relatively low, because the marginal products of capital remain fixed and data show that the real price indexes of agriculture and manufacturing are falling (Gopinath and Roe). With low returns to capital, rational investors will reduce investment in agriculture and diminish its ability to grow by increasing capital. This view is consistent with several studies showing that total factor productivity (TFP), which includes technological change, has been the major contributor to agricultural growth over the postwar period rather than capital growth (Ball et al.; Jorgenson, Gollop, and Fraumeni).[11]

Supply and Capital Demand Elasticities

Capital is fixed in the short run, but is allowed to adjust in the long run. Short-run elasticities are those obtained when quasi-fixed factors are held fixed. Long-run elasticities are the responses given that quasi-fixed factors have fully adjusted to their long-run optimal or desired levels (steady-state). The lower the rates of capital adjustment in these sectors, the larger will be the difference between the short-run and long-run elasticities. In the short run, the supply and capital demand responses need not be consistent with what static economic theory would predict, because there are adjustment costs to quasi-fixed factors. However, in our case, we obtain positive own-price supply elasticities both in the short and long run. In the case of capital demand equations, only one of the four own-price demand elasticities (manufacturing sector) has the wrong sign in the short and long run. The standard errors for the short-run elasticities (table 3) were computed using Fieler's theorem (following Bhuyan and Lopez),which provides the formula for computing the variance of a ratio of two

[11] TFP is defined as the ratio of aggregate output to an aggregate of inputs. (See Ball et al., and Jorgenson, Gollop, and Fraumeni for a discussion.)

Table 3. Short-Run Elasticities of Supply and Capital Demand in Four Major Sectors of the U.S. Economy

Sectors	*Price*1	*Price*2	*Price*3	*Price*4	*Rental Rate*1	*Rental Rate*2	*Rental Rate*3	*Rental Rate*4
Supply Elasticities:								
Agriculture	0.22	0.56	-3.81	-0.40	-0.10	0.53	1.43	-0.54
	(6.91)	(5.74)	(-11.50)	(-3.05)	(-4.31)	(7.21)	(10.56)	(-10.61)
Food Proc.	0.40	1.16	-10.55	-1.45	-0.47	1.14	3.79	-1.43
	(5.56)	(2.92)	(-9.93)	(-2.99)	(-8.57)	(7.78)	(10.02)	(-10.35)
Manuf.	-0.18	-0.70	3.39	0.88	0.12	-0.13	-0.67	0.27
	(-11.00)	(-9.82)	(13.60)	(9.21)	(8.82)	(-3.48)	(-7.22)	(7.96)
Services	-0.02	-0.11	0.98	0.23	0.01	0.20	-0.14	0.001
	(-2.73)	(-2.99)	(9.05)	(4.22)	(1.78)	(10.91)	(-3.39)	(0.07)
Capital Demand Elasticities:								
Agriculture	0.06	0.25	-0.35	-0.53	-0.01	-0.13	0.15	-0.02
	(3.74)	(3.55)	(-3.29)	(-3.91)	(-3.57)	(-4.28)	(3.62)	(-3.73)
Food Proc.	0.01	0.10	0.10	0.05	0.02	-0.16	-0.01	0.02
	(3.70)	(13.80)	(11.80)	(2.99)	(9.88)	(-30.85)	(-1.63)	(5.96)
Manuf.	0.03	-0.04	0.11	-0.23	-0.002	-0.08	0.10	-0.01
	(1.22)	(-1.67)	(1.61)	(-1.31)	(-0.06)	(-1.34)	(1.35)	(-1.70)
Services	-0.01	-0.10	0.01	0.33	-0.002	0.14	0.08	-0.07
	(-6.19)	(-15.50)	(1.65)	(31.80)	(-1.38)	(25.29)	(18.09)	(-2.36)

Notes: Numbers following variables in column heads are defined as follows: 1 = agriculture sector, 2 = food processing sector, 3 = manufacturing sector, and 4 = services sector. Numbers in parentheses are *t*-ratios.

parameters.[12] However, this theorem is not applicable for complex combinations of parameters (additive, multiplicative, and ratio); hence, we do not derive the standard errors of the long-run elasticities.

Short-run supply and input (capital) demand elasticities are presented in table 3. Elements in rows 1–4, columns 1–4 represent own- and cross-price supply elasticities. Agriculture's own-price response is 0.22, the smallest among the four sectors, while the other three sectors are relatively more responsive to respective prices. The food processing sector appears to be complementary to agriculture. In general, the large cross-price elasticities suggest strong linkages among these four sectors of the economy. Note that the labor share of value added is about 70% in the U.S. economy. Hence, a mobile labor force can bring about large cross-price responses.

An increase in the rental rate of agricultural capital decreases its output, as expected, and similar responses are obtained for the manufacturing and services sectors (elements in rows 1–4, columns 4–8 of table 3). However, the effect on food processing output from an increase in its capital's rental rate is positive, but note that short-run responses need not be of the right sign.

Capital adjustment in agriculture and manufacturing is lower than the rates of adjustment in the services and food processing sectors (table 2). In the lower half of table 3, the diagonal elements of the matrix formed by rows 1–4, columns 4–8 suggest

[12] To compute the variance of $\{(a/b) = \zeta\}$, we use Fieler's theorem (Bhuyan and Lopez):

$$\text{S.E.}(\zeta) = [\text{var}(a) - 2\zeta\,\text{cov}(a,b) + \zeta^2\text{var}(b)]^{1/2}.$$

Table 4. Long-Run Elasticities of Supply and Capital Demand in Four Major Sectors of the U.S. Economy

Sectors	*Price1*	*Price2*	*Price3*	*Price4*	*Rental Rate1*	*Rental Rate2*	*Rental Rate3*	*Rental Rate4*
Supply Elasticities:								
Agriculture	1.36	6.38	-12.15	-10.72	-0.18	-0.51	4.27	-0.97
Food Proc.	1.38	13.65	-31.83	-12.42	-0.53	-0.05	-1.57	-0.63
Manuf.	-0.60	-6.07	12.36	6.68	-0.07	1.09	-2.40	0.61
Services	-0.06	-0.52	-2.93	0.62	0.01	0.26	-0.26	0.06
Capital Demand Elasticities:								
Agriculture	2.77	11.81	-16.69	-25.22	-0.17	-6.14	6.99	-0.71
Food Proc.	0.03	0.24	0.25	0.13	0.05	-0.39	-0.01	0.06
Manuf.	1.49	-1.68	5.45	-10.83	-0.07	-4.00	4.61	-0.32
Services	-0.03	-0.32	0.01	1.11	-0.01	0.45	0.27	-0.23

Note: Numbers following variables in column heads are defined as follows: 1 = agriculture sector, 2 = food processing sector, 3 = manufacturing sector, and 4 = services sector.

sluggish adjustment of capital in all four sectors. Short-run response of capital in food processing to an increase in its rental rate is the largest (-0.16), followed by that of services and agricultural capital (-0.07 and -0.01, respectively). The positive sign on the own-price demand elasticity of manufacturing capital is not contradictory, but consistent with most empirical adjustment cost models where short-run responses can be of different signs (Treadway). The effect of output prices on investment demand is also of interest. The demand for capital in agriculture increases as the price of agricultural output increases (0.06). Similar responses are found for the food processing, manufacturing, and services sectors (0.10, 0.11, and 0.33, respectively).

Long-run elasticities of supply and capital demand are presented in table 4. The formula used for deriving the long-run elasticities is:

(11)
$$\epsilon_{ij}^{L} = \left(\frac{\partial Y_i}{\partial p_j}\right)\left(\frac{p_j}{Y_i}\right) = \left[\left(\frac{\partial Y_i}{\partial p_j}\right)_{K=\bar{K}} + \sum_{i=1}^{4}\left(\frac{\partial Y_i}{\partial \bar{K}_j}\right)\left(\frac{\partial \bar{K}_j}{\partial p_j}\right)\right]\frac{p_j}{Y_i},$$

where $\bar{K}_j$ (for j = 1, 2, 3, 4) is the steady-state capital which was derived by setting investment equal to zero in the investment demand equations in (8).

All own-price supply elasticities are positive in the long run, and are larger than their short-run counterparts. However, the elasticities of manufacturing and food processing are relatively larger than others. The long-run cross-price elasticities are qualitatively similar to those of the short run. The own-price capital demand elasticities are larger for all the sectors in the long run, except manufacturing. As before, the manufacturing sector's response has the wrong sign. The long-run elasticities are large because they require all four capital stocks to adjust to the respective steady-state levels. Since it takes substantially longer for the capital stocks of agriculture and manufacturing to adjust to the steady-state levels, we obtain large long-run elasticities. Compared to static models with constant returns-to-scale technologies, where such elasticities are infinite, our adjustment-cost model provides plausible results.

Summary and Conclusions

Private capital adjustment behavior in four sectors—agriculture, food, manufacturing, and services—of the U.S. economy are tested using a multi-output adjustment cost model. The agricultural sector's rate of capital adjustment is relatively low as compared with other sectors of the economy, suggesting fixity of its capital. The services and food processing sectors are more flexible in the sense that their respective capital stocks adjust to their long-run levels in less than five years, while manufacturing capital takes more than 25 years to adjust. The observed rates of adjustment are consistent with capital's contribution to growth in various sectors of the U.S. economy. In the more dynamic sectors like food processing and services, capital's contribution to growth has been observed to be large, unlike primary agriculture and manufacturing. Our elasticities suggest that agriculture's supply response is small, contrary to other studies. The processed food and agricultural sectors are complementary, and cross-price elasticities show strong linkages among the four major sectors of the U.S. economy.

The estimated capital fixity for agriculture implies highly variable returns to agricultural capital because the residual returns from production are attributed to capital. Moreover, fixed marginal products and observed falling real prices for agricultural outputs will cause lower returns to capital in agriculture. These slow rates of capital adjustment also imply that the adoption of technology embodied in new capital inputs will take longer in agriculture.

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