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LONG-RUN STRUCTURAL AND PRODUCTIVITY CHANGE
IN U.S. AGRICULTURE:
EFFECTS OF PRICES AND POLICIES

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Abstract

Long-Run Structural and Productivity Change in U.S. Agriculture: Effects of Prices and Policies

by Wallace E. Huffman and Robert E. Evenson

This paper presents (1) a conceptual framework for structural change when farms may be multiproduct or specialized and (2) an econometrics examination of causes of structural and total factor productivity (TFP) change for U.S. agriculture. Farm size, farm specialization, and part-time farming are the structural dimension emphasized, and they become potential channels to TFP change. Using state aggregate data starting in 1950, we conclude that input prices, public and private research, public extension, and government commodity programs have directly and indirectly caused change in U.S. farm structure and TFP. Our results suggest that changes in farm size, however, have been dominated by input price changes rather than by technology or government programs.

Key Words: farm structure, productivity, farm size, farm specialization, part-time farming, research, technical change, agriculture

Long-Run Structural and Productivity Change in U.S.
Agriculture: Effects of Prices and Policies

by Wallace E. Huffman and Robert E. Evenson*

A century ago, U.S. farms numbered 4.9 million, and the number of farms grew slowly, peaking about 1920 at 6.4 million. Since then, a long term decline in farm numbers has occurred with the rate being especially rapid during 1950-70 (-3.3% per year compound). The rate of decline slowed considerably during the 1970s but increased during the 1980s. In 1990, there were 1.9 million U.S. farms. Given steady growth in U.S. aggregate agricultural output (at 1.8% over past 100 years and 2.1% for past 50 years), average farm size on (real) output base has increased. The average rate of increase in farm size (using the output measure) was only 0.9 percent per annum (compounded) from 1890 to 1940, but it was a much faster 4.4 percent per annum during the past 50 years. Average farm size was 1.6 times larger in 1940 than in 1890, but 8.8 times larger in 1990 than in 1940.

A century ago, 87 percent of the farm inputs were supplied by farmers (primarily labor, land services, animal power, livestock feed, and seed); only 12 percent were commercial, i.e., purchases of intermediate inputs from nonfarmers (Kendrick 1961, 347). In contrast, in 1990 more than 45 percent of the farm inputs (e.g., agricultural chemicals, energy, seed, livestock feed, machinery and equipment) were commercial (USDA 1991, Table 3.1). The most dramatic changes have been associated with labor, a decline in labor's production cost share--from over 50 percent to about 24 percent (Ball, Matson, and Somwaru 1994) and decline in labor intensity relative to chemicals, machinery, and land (Gardner 1992). Furthermore, the technologies embodied in inputs have changed dramatically over the past century or half century (see Huffman and Evenson 1993). The technologies embodied in new seed varieties, breeding stock, farm chemicals, farm machinery, and information

systems are much different than in the distant past (Office of Technology Assessment 1992; National Research Council).

The objective of this paper is to present a conceptual framework for structural change where farms may be multiproduct or specialized and an econometric examination of causes of structural and total factor productivity (TFP) change for U.S. agriculture using state aggregate data. Farm size, farm specialization, and part-time farming are the structural dimensions emphasized. Hypotheses tested are that input prices, public and private research, public extension, and government commodity programs cause structural and TFP change in U.S. agriculture and that part of productivity change is channeled through structural change.

Many of the early trends in farm and enterprise size and scale are summarized by Ball and Heady (1972). Quance and Tweeten (1972) summarize some of the effects of price support, supply controls and other farm policies on farm size starting in 1930. During the past 40 years, livestock production, especially poultry, dairy, and cattle finishing, and to a lesser extent crop production have become increasingly specialized on fewer and larger farms (see Huffman and Evenson 1993b, Ch.7). Other studies of structure of American agriculture include Hallam (1993b), Gardner and Pope (1978), Huffman (1980), Barkley (1990), Gale (1993), Gardner (1992), Goddard et al. (1993), Kislev and Peterson (1982, 1996), Sumner and Leiby (1987), Moschini (1990), and Zepeda (1995). Kislev and Peterson relate change in farm size to change in the off-farm wage, an opportunity cost of farm labor, and change in available agricultural technology. Griliches (1963) suggested that economies of scale and increased specialization in agriculture were part of the TFP story for U.S. agriculture. Most later studies for U.S. agriculture, however, have ignored the interrelationship between TFP and structure of agriculture, e.g., Huffman and Evenson (1993b), Chavas and Cox (1992), Evenson (1980), Knutson and Tweeten (1979). Our current paper builds upon preliminary analyses undertaken earlier of public policies on agricultural productivity and structure of agriculture (Evenson and Kramer 1988; Huffman and Evenson 1993a).

Industrial Structure: A Conceptual Perspective

Farms are typically multiproduct, but the variety of products produced has changed over time. Most of the discussion of structure in the agricultural economics literature, however, has used single product technology (Hallam 1993b), and this limits significantly the options for structural adjustment when economic forces facing agriculture change. We present a precise definition of economics of size and scope of multiproduct firms. Hence, the model must permit firms/farms to be multiproduct or specialized.

Consider the following farm/firm level multiproduct (total) cost function:

$$(1) \quad C = C(q; w, \tau, \phi)$$

where q is $p \times 1$ vector of products/outputs, w is a vector of input prices, τ is a vector of technologies, and ϕ is a vector of governmental policies. The cost function is concave in w and homogeneous of degree 1 in w (see Varian 1992; Chambers 1988). In addition, the (total) cost function may include fixed cost of generally useful inputs, e.g., firm-specific public inputs and product-specific fixed costs.

When the cost function is multiproduct, no natural scalar quantity exists to define average cost. One alternative is to measure cost along a product ray, as in Baumol, Panzar, and Willig (1982). Product-ray average cost of producing the output vector $q (\neq 0)$ can be defined as

$$(2) \quad \text{RAC}(q, w, \tau, \phi) = C(q; w, \tau, \phi) / \sum_{i=1}^p q_i.$$

Implicitly the attribute of RAC that makes it exact is the product mix is being held constant as changes are occurring. $\text{RAC}(q, w, \tau, \phi)$ declines (increases) when a small proportional change in all outputs causes a less than (larger than 1 equal) proportional change in total cost. For each product-ray, there will be a point where RAC is a minimum (Baumol, Panzar, and Willig 1982).

For the single output case ($p=1$), scale (S) can be defined as the ratio of average (total) cost to marginal cost or the inverse of the quantity elasticity of (total) cost, i.e., $S = AC/MC = 1/e_{cq}$. For $p > 2$, define the degree of scale economies over the entire product set, holding the output mix constant, as:

$$(3) \quad S_p(q, w, \tau, \phi) = C(q; w, \tau, \phi) / \sum_{i=1}^p q_i C_i(q, w, \tau, p)$$

where $C_i = \partial C(\cdot) / \partial q_i = MC_i(q; w, \tau, \phi)$ or marginal cost of product i . Scale economies at q are increasing, decreasing, or constant if $S_p > 1$, < 1 , or $= 1$. S_p can be interpreted as the inverse of the elasticity of total cost with respect to a 1 percent increase in all outputs. Because S_p is measured for a given product mix, changing the product mix can reasonably be expected to change S_p .

As economic conditions change, a farm might increase or decrease the number of outputs produced, i.e., expand or contract their “product line.” Hence, product/output-specific cost concepts become important and useful. Define “incremental cost” for product q_i at q as

$$(4) \quad IC_i(q, w, \tau, \phi) = C(q, w, \tau, \phi) - C(q_{p-i}, w, \tau, \phi)$$

where q_{p-i} is a $p \times 1$ vector of outputs with a zero quantity inserted for the i -th output, q_i , and all other outputs are the same as in q .¹ Then average incremental cost is $AIC_i(q, w, \tau, \phi) =$

$IC_i(q, w, \tau, \phi) / q_i$. If a farm is considering adding a product q_i to its mix, an increment to fixed (and sunk) may be required.² Product-specific fixed (or sunk) costs imply that the cost function $C(\cdot)$ is discontinuous, having one or more jumps in it. Product-specific scale economies can be defined as, $S_i(q, w, \tau, \phi) = AIC_i(q, w, \tau, \phi) / C_i(q, w, \tau, \phi)$, i.e., the ratio of average incremental cost to marginal cost for output i .³

For multioutput farms to be economically successful, they must have some cost advantages over more specialized farms, including those farms that produce only one of many possible products of the industry. Consider an industry with two outputs, then it is possible that

$C(q_1, q_2) < C(q_1, 0) + C(0, q_2)$, i.e., total cost of producing a given quantity of q_1 and q_2 is less if it is undertaken in one farm producing both of them, e.g., grain and animals, than in two separate farms that specialize in the production of a single output, grain or animals. Because we observe that no farm produces anything like the more than 200 total products of the U.S. agriculture industry, some diseconomies of scope (and limiting specialized resources) must exist.

Intra-farm spillover effects of product mix may occur which create a type of scope economies or diseconomies. Partition the p products into two groups, t and $p-t$, then the degree of economies of scope can be defined as:

$$(5) \quad SC_t(q, w, \tau, \phi) = [C(q_t, w, \tau, \phi) + C(q_{p-t}, w, \tau, \phi) - C(q, w, \tau, \phi)] / C(q, w, \tau, \phi)$$

Panzer and Willig (1980) and Baumol, Panzar, and Willig (1982). It measures the difference in cost when p outputs are produced on two separate farms, one produces t of them and the other producing the $p-t$ remaining ones versus producing all p of the outputs on one farm. If $SC_t(q, w, \tau, \phi) < 0$, then splitting up industry production into separate “specialized” farms reduces industry cost.⁴

Economies of scope and economies of scale are related:

$$(6) \quad S_p(q, w, \tau, \phi) = \frac{[\alpha_t S_t(q, w, \tau, \phi) + (1 - \alpha_t) S_{p-t}(q, w, \tau, \phi)]}{1 - SC_t(q, w, \tau, \phi)}$$

where S_t and S_{p-t} are “product- or sector-specific” scale economy measures and $\alpha_t = \sum_{j=1}^t q_j C_j / \sum_{j=1}^p q_j C_j$,

Baumol, Panzar; and Willig (1982). If no scope economies exist,

$SC_t = 0$, then scale economies for a p -product farm is just, $S_p = \alpha_t S_t + (1 - \alpha_t) S_{p-t}$, or a weighted average of the product- or sector-specific scale economies for farms specializing in product groups t and $p-t$. If scope economic exist, $SC_t > 0$, multiproduct farms will tend to have a cost advantage over specialized farms. Furthermore, scale diseconomies could exist for the specialized farms, i.e., S_t and $S_{p-t} < 0$; but with sufficient economies of scope, the farms producing p -products could have scale economies. This situation would give a major economic advantage to the diversified farms relative to specialized farms. If scope diseconomies exist, then specialized farms will tend to have a cost advantage over diversified farms.

In the midwest from 1900 to the 1950s, a larger share of farms produced feed grains, leguminous meadow, beef, swine, dairy, poultry, fruit, and vegetable outputs. They were what the Census of Agriculture counted as general farms. A very small share of the midwestern farms of this era specialized in sub-groups of these outputs, which suggests that significant economies of scope existed at

that time. In the 1990s, however, we observe farms of the midwest to be relatively more specialized, producing crops or livestock but not both. Also, among farms producing crops the number of crops has been reduced, and among farms producing livestock, the number of different types has been reduced. A hypothesis is that technical change in U.S. agriculture since the 1960s has reduced economies of scope.

What is the real foundation for scope economies? With multiproduct production, weak cost complementarities are a sufficient condition to insure economies of scope. Weak cost complementarity over the product set p up to q exists if $\partial^2 C(\hat{q}, w, \tau, \phi) / \partial q_i \partial q_j \equiv \partial MC_i(\hat{q}, w, \tau, \phi) / \partial q_j \leq 0$, $i \neq j$, for all \hat{q} , $0 \leq \hat{q} \leq q$, with the inequality holding over $\hat{q} > 0$ (see Baumol, Panzar, Willig 1982). With weak cost complementarity, the marginal cost of producing any output i jointly with other outputs decreases when the quantity produced of any other output j increases. Furthermore, the concept can be extended to situations where product-specific fixed costs exist. Consider the cost function $C(q) = F(t) + c(q)$ where $F(t)$ is the product-specific fixed cost associated with $q_t > 0$ and $c(q)$ is twice differentiable and exhibiting weak complementarity over output set t up to q . Then, if $F(t) + F(p-t) \geq F(p)$, the cost function exhibits economies of scope. If the inequality is reversed diseconomies of scope occur.

What are the practical implications of cost complementarities and scope economies for agriculture? In some cases, production is truly joint, e.g., wheat and wheat straw, beef and beef hides, wool and mutton, cow's milk and veal. In other cases, the jointness is very much affected by relative input prices and the state of technology, e.g., crops and livestock. Farm/firm-specific pure public inputs also give scope economies. In this case, an input when acquired for the production of q_i by a farm is available costlessly for the production of other outputs; for example, local weather and climatic information, biological information about production processes, and accounting and information processing skills of farm operators.

Also, quasi-public inputs can be shared by two or more production processes without complete congestion, e.g. services of general durable goods that are available in large discrete units, being somewhat indivisible or lumpy. These include farm tractors, farm shops, general purpose barns, trucks and cars, and farm operators/managers. When technology is embodied in new durable goods, they may become somewhat product-specific in their usefulness, e.g., automatic temperature, feed, and water controlled swine farrowing houses; environmentally controlled pig nurseries; confined broiler growing houses, confined swine finishing buildings; electronically controlled, dairy milking and feeding parlors/farms; no-till planters, self-propelled combines; grain drying equipment and storage facilities. Also, new technologies of livestock and poultry disease control use isolation of one animal species from another, e.g., swine from poultry, or one age-group of a given species from another, e.g., baby pigs from older pigs. This reduces scope economies in livestock production and increases scale economies under farm specialization. Increases in product-specific fixed costs which are associated with specialized buildings/facilities and equipment for livestock and crop production seem to have been a major source of recent U.S. product-specific scale economies and reduced economies of scope. The developments of large scale planting and harvesting technologies for grain crops are not too dramatic for scale economics because of limits on use due to seasonal plant cycles and uncertain weather.

Changes in w and ϕ can change economies of scale and scope and the equilibrium product mix of farms and total number of farms for the industry. To see the impact of a change in input price w_i on scale economies measured along a product-ray, return to equation (3) and let w_i change:

$$(7) \quad \frac{w_i}{S_p} \frac{\partial S_p}{\partial w_i} = s_i \left[1 - S_p \sum_{\ell=1}^I e_{\ell ip} \right], \quad s_i = \frac{w_i x_i}{C}, \quad e_{\ell ip} = \frac{q_\ell}{x_i} \frac{\partial x_i}{\partial q_\ell}$$

(Baumol, Panzar, and Willig 1982, p. 157). Scale economies with a broad product mix will increase (decrease or stay unchanged), if $1 - S_p \sum_{\ell=1}^I e_{\ell ip} > 0 (< 0 \text{ or } = 0)$. A positive relationship is more likely when scale diseconomies exist, i.e., $S_p < 1$, and the impact is proportional to the size of the cost

share of the input whose price changes. For example, labor was a large share of the cost of agricultural production in 1950, and with wage rates rising over time (relative to the price of other inputs), the potential exists for a large impact on scale economies.

Scope economies may be affected by a change in w_i , too. Let's consider specialization into two sectors producing t and $p-t$ outputs, then the effect of w_i on the relative degree of scope economies is:

$$(8) \quad \frac{w_i}{SC_t} \frac{\partial SC_t}{\partial w_i} = \frac{w_i x_i(q)}{C(q)} \left[\frac{SC_{ti}}{SC_t} - 1 \right]$$

where SC_t is defined in eq(5) and $SC_{ti} = [x_i(q_t, w, \tau, \phi) + x_i(q_{p-t}, w, \tau, \phi) - x_i(q, w, \tau, \phi)] / x_i(q, w, \tau, \phi)$. Hence, if the percentage cost saving in use of input x_i achieved by producing all p products together is greater than the saving in total cost by producing split into two product groups, a increase in w_i will increase scope economies. Otherwise scope economies will decrease (or remain unchanged).

The implications for scope economies are most easily seen by considering special cases. First, if input x_i is used in fixed proportion with output, e.g. like seed, then $SC_{ti} = 0$ and $\partial SC_t / \partial w_i < 0$, and an increase (decrease) in w_i reduces (increases) economies of scope. Second, if input x_i is a firm's pure-public input, then $x_i(q) = x_i(q_t) = x_i(q_{p-t})$, $SC_{ti} = 1$ and $SC_t < 1$, so $\partial SC_t / \partial w_i > 0$. Thus, if the price of a pure public input increases(decreases), scope economies increase(decrease). A conjecture is that the relative price of farm-specific public inputs has declined on average over the past 45 years, and this has reduced economies of scope in agriculture. Third, when transray convexity of the multiproduct cost function exists and input price w_i decreases, the increase in outputs (which are proportional along a product-ray) is greater in proportion than the increase in the input whose price has fallen. This reduces economies of scope or increases specialization and reduces opportunities for sharing of a firm's quasi-public inputs. Another conjecture is that the relative price of farm's quasi public inputs have

decreased over the past 45 years and this has decreased economies of scope and contributed to specialization.

Government commodity (and conservation) policies affect output prices and have in the past placed restrictions on crop rotations, land use, and eligibility to produce particular commodities. These restrictions affect cost surfaces, some have multiple output effects and others are commodity specific. The programs in effect 1950-1995 seem likely to have reduced product-specific scale economies. The effect on scope economies seems ambiguous because the crop programs have contained strong incentives to protect base acres which reduces the diversity of crops produced. The conservation compliance requirements starting in the late-1980s most likely made a small contribution to crop output diversity of farms because they placed severe restrictions on soybean and other row crop production on land with high erosion-rate potential.

The Empirical Model

In the previous section, farm cost was linked to input prices, technologies, and governmental policies. If inputs and outputs are separable, then total factor productivity can be represented as a ratio of the farm output index to the farm input index. Farmers' engage in part-time rather than full-time farming as a result of the relative attractiveness of on-farm and off-farm uses of farmers' labor which differ regionally and change over time (Ahearn and Lee 1991; Huffman 1980; Barkley 1990). With a significant decline in the demand for farm labor since about 1950, an increase in part-time farming might be associated with productivity gains in agriculture. Alternatively, a farmer's off-farm work may take time away from farm related activities of gathering technical information and early technology adoption (Wozniak 1993), which would reduce productivity of agriculture.

In this study, empirical measures of farm specialization, farm size, and part-time farming are linked to agricultural productivity in the empirical model.⁵ Furthermore, we test that input prices, public and private research, public extension, and government commodity programs cause structural

and TFP changes and that part of TFP change is channeled through structural change. Although much of the discussion of structural change in U.S. agriculture has focused at the national aggregate level or individual farm level, we propose to examine state aggregate data to build on past data construction efforts, to obtain substantial variation in variables, and to obtain substantial degrees of freedom for testing our model.

Both “short-run” and “long-run” perspectives on relationships among variables are considered. In the short-run, we suggest that interesting agricultural structural interactions occur which are best viewed in a simultaneous equation framework. In this format, the "endogenous" variables of the econometric model are:

- Total Factor Productivity (measured for both the crop and livestock sectors),
- Specialization Indexes (measured for both the crop and livestock sectors),
- Farm Size (measured for the aggregate agricultural sector),
- Part-Time Farming (measured for the aggregate agricultural sector).

The "exogenous" variables of the model are:

- Prices (treated as exogenous at the state level),⁶
- Technology (as measured by research and extension variables),
- Farmers Skills (as measured by schooling indexes),
- Institutions (farm program and geoclimatic variables).

We suggest that farmers find it costly to change farm size, farm specialization, and part-time farming participation in the short-run. As a first approximation, farmers behave as if size, specialization, and part-time farming are fixed. When farm output and input prices, new technologies, infrastructure, and institutions change, farmers respond by changing the quantity demanded of inputs and quantity supplied of outputs as suggested by a restricted profit function. Suppose, for example, that improvements in animal health technologies enable more effective control of animal diseases

under high density-confined-isolated conditions and production using new technologies is not land intensive or climate sensitive. This would create product-specific scale economies enabling larger concentrated production units. As farmers respond to these scale opportunities by building larger technically enhanced units, incentives for changing the scope/specialization of the farm and part-time farming seem likely to occur. Human capital needed for specialized activities is costly to create and economic incentives exist because of finite life and an annual time constraint for individuals and managers to specialize their work (Becker 1975, Huffman 1985).

We have suggested that new technology becoming available is one cause of structural change. For example, the initiating factor might be the invention of and the commercializations of new animal health technology. This, in turn, leads to trial and adoption by farmers who discover that they can now build larger product specific units without experiencing the severity of disease problems associated with larger units in the past. Because the new technology requires a significant fixed cost and specie isolation, the incentive is to specialize or narrow the scope of the farming operation and to most likely reduce the economic attractiveness of off-farm work and to change the size of the farm which creates structural interactions between the endogenous variables. The productivity response to the new technology will unfold over time.

Relative input prices, e.g., the price of machinery and fertilizer relative to the wage rate for hired farm labor can be expected to twist cost surfaces and to affect size (and specialization). Hayami and Ruttan (1985) expressed the belief that “the scale economies usually stem from the lumpiness or indivisibility of fixed capital” (p. 146). For example, when a machine is large and its price is high, the opportunity cost of under utilizing machine services is great. A large farming operation is one way of more fully utilizing lumpy farm machinery. Kislev and Peterson (1982, 1996) counter that in the long run the size of machinery, herds, etc., are continuous and not lumpy. In the few cases where large machines have a major efficiency advantage over smaller ones, rental markets develop. Hence, they argue that relative input ratios are the driving force behind farm size and not large machines (or

buildings) driving farm size. Hence, they see a rise in the wage-rental ratio as being the major force behind the long-term increase in U.S. average farm size. Also, when the price of fertilizer is high, incentives exist for farmers to substitute away from commercial fertilizers toward livestock manures and organic forms of fertilizer. This requires relatively more land and livestock resources which increases farm size and reduces specialization.

Major differences in the role of land and climate, potential for successful applications of science, and shapes of cost curves are reasons for considering crop and livestock specialization and productivity separately. Empirical evidence shows that average cost of production for specialized farming enterprises at a point in time first declines as output increases and then flattens out, e.g., flat bottomed cost curves, and eventually turn up (Hallam 1991; Hallam 1993a; Moschini 1990). Furthermore, the length of the flat section is in a sense much longer for specialized livestock than for crop production (Hallam 1993a). Some of the differences in cost curve shapes for crop and livestock enterprises are due to differences in the use of land and impact of weather/climate (e.g., geoclimatic region). Almost all agricultural crops are photo-period or length of growing season sensitive, and the potential maximum length of this season is set by nature. Because planting and other field work use up valuable potential growing season time and crop yields are very sensitive to timeliness, this severely limits the size of crop producing farms. No one state can be operated as a single farm. Modern poultry, dairy, and swine producing enterprises use relatively little land and much confined housing which greatly reduces weather/climatic effects.

The Empirical Analysis

In this section, we describe the data and the six equation econometric model of agricultural structure and productivity and present and evaluate the econometric results.

The Data and Econometric Model

This study builds upon the earlier Huffman and Evenson model and data for state multifactor productivity (Huffman and Evenson 1992; 1993b) primarily by including new variables and equations for specialization, size, and part-time farming. In the earlier Huffman and Evenson model, state multifactor productivity was expressed as a three equation model, one each for a crop sector, livestock sector, and aggregate agricultural multifactor productivity.

The Huffman-Evenson data set (see Huffman and Evenson 1993b, pp.192-94) was developed at Yale University, and it builds upon the recommendations of the AAEA Task Force on Productivity Statistics (USDA 1980) and earlier work by Landau and Evenson. In this data set, the New England states, Alaska, and Hawaii were excluded primarily because they accounted for a small share of total U.S. farm output (about 2% in 1974), and this share has been declining over time. In addition, Alaska and Hawaii are geographically isolated from the other forty-eight contiguous states, and this isolation makes spillovers of public agricultural research different than for contiguous states. Thus, forty-two of the fifty states are included in this study. This data set spans the years of 1950-82. Although it would be nice if the data extended to the mid-1990s, it would require a large investment to do this.

Definitions of all of the variables used in this article for the econometric model are summarized in Table 1. The six endogenous variables are TFPC, TFPL, SPLZEC, SPLZEL, SIZE, and OF/(1-OF), or odds of off-farm work. Both crop and livestock specialization indexes are derived. Each specialization index measures the extent to which farms in a particular state specialize in the production of major crop or livestock commodities. Hence, they are indexes of farm-level specialization and not state average specialization. For crop specialization, we have five types that are weighted: cash grain farms, vegetables and melon farms, fruits and tree nut farms, cotton and tobacco farms, and other field crop farms. For livestock specialization, we have only three types that are weighted: poultry farms, dairy farms, and other livestock farms.⁷

The farm-size index (SIZE) is an index of the average (real) services obtained from relatively fixed capital used in farming. It is the annual service flow from cropland-equivalent farmland and from

farm machinery and breeding stock. This measure of farm size differs from a size measure based strictly on tillable farmland (Kislev and Peterson 1982, 1996; Batte and Sonka 1985). Our measure, also, is not strictly natural resource-based because it includes services from reproducible capital to better approximate a critical dimension of farms that is more closely associated with capital needed for annual production than with land area (or value).

Part-time farming is represented by the odds of off-farm work by farmers on an annual basis. Total factor productivity in this study is expressed differently than in the earlier Huffman and Evenson papers (1992, 1993b) in the sense that we use a five-year moving average of annual multifactor productivity rather than the actual annual values. The reason for this change is our emphasis in this paper on structure and organization of agriculture which we believe to be a medium- to long-run phenomena. The five-year averaging removes a lot of "noise" from the productivity series.

In this article, the econometric model of agricultural structure and productivity is a six-equation structural model. There are a total of 38 exogenous variables in the model, including 15 geoclimatic variables. The latter variables represent region-specific fixed effects over the period of analysis that seem likely to affect structure of agriculture and TFP. The two productivity equations have specifications similar to Huffman and Evenson (1992, 1993b). The two farm specialization equations contain 27 exogenous variables, and the farm size and off-farm participation equations contain 30 exogenous variables. Interaction effects/variables are excluded from these last four equations to simplify the relationships in seemingly reasonable ways.

The structural model is highly integrated in the sense that all equations contain a total of three or four (but not all the same) endogenous variables; the left-hand side variable and two or three endogenous variables. It is also consistent with some farm structure variables not being directly related. This structure permits us to examine the joint explanation/ determination of agricultural structure and productivity and to examine the effects of (1) specialization and size on part-time farming, (2) specialization and part-time farming on size, (3) size and part-time farming on

specialization, and (4) specialization, size, and part-time farming on agricultural productivity.⁸ These are relationships about which little empirical evidence exists in the literature (e.g., see Hallam 1993b).

The Econometric Results

The econometric model of agricultural structure and productivity was estimated using three-stage least squares to take account of endogeneity of regressors and contemporaneous correlation of disturbances. Coefficients are reported in Table 2. The model fits well in the sense of having a system R-square of 0.70, and a large share of the estimated structural coefficients are significantly different from zero at the five percent level, including 15 of the 16 estimated coefficients of the included endogenous variables. These results are interpreted as strong support for the hypothesis that input prices, public and private research, public extension, and government commodity programs directly and indirectly caused structural and TFP change in U.S. agriculture during 1950-82.

Because of the complexities of the structural model and the interaction terms in the productivity equations, we have computed the implied reduced-form coefficients for the model and they are presented in Table 3.⁹ In order to get to bottom line issues which are closer to the published literature, much of our discussion focuses on the implied reduced-form coefficients. The structural equations do, however, provide information about the relationship among farm structural variables and between TFP and farm structure, holding the exogenous variables constant, and they are emphasized. Part-Time Farming (off-farm work). Part-time and full-time occupations as a farmer are conditioned on the individual having a farm business. When economic conditions change adversely toward agriculture, some farmers leave agriculture for other occupations or retire (see Huang and Orazem 1997). Given that individuals continue farming, the reduced-form coefficients suggest that the odds of farm operators' working off the farm are reduced by technology associated with public sector crop and livestock research. Additional private sector crop research, which has on average a more directly applied focus than public research, increases the odds of off-farm work. The two extension variables pull in opposite directions. An increase of crop extension decreases the odds of off-farm work, but

additional public livestock extension increases it. Additional farmers' schooling increases the odds of off-farm work among those who continue in farming.

The farm and off-farm wage rates have very different effects on the odds of part-time farming. An increase in the opportunity (off-farm) wage (WAGEMG) increases the odds of off-farm work by farmers, but an increase in the farm wage (WAGEF) has the opposite effect. These effects are expected when skills of farm operators and hired farm labor are quite different (see Huffman 1996). An increase in crop price supports, which both increases the expected crop prices and reduces price variability, reduces the odds of off-farm work, but an increase of the dairy price support increases it.

The structural equation for off-farm work shows, other things equal, that an increase of crop specialization reduces the odds of off-farm work of farmers, but an increase in livestock specialization and farm size increases the odds of off-farm work. Hence, livestock specialization might be interpreted as being more compatible than crop specialization with off-farm work during the study period. The positive structural effect of farm size on the odds of off-farm work is possible when the total number of farms decreases. Being part-time rather than full-time in farming is then part of the transition of labor out of agriculture (Huffman 1991).

Farm Size. The reduced-form coefficient estimates for explaining farm-size suggest strongly that public sector research programs have little effect on long-term changes in farm size. But added private crop research leads to reduced farm size while added private livestock research leads to increased farm size (as does livestock extension). The key variables explaining farm size, however, are prices. An increase in the opportunity (nonfarm) wage rate increases average farm size with a relatively large elasticity (partly through the off-farm work effect.) A decrease in the real machine price also increases farm size. These results support the earlier findings of Kislev and Peterson (1982; 1996).

An increase in both crop and dairy price supports have negative effects on farm size, but an increase in diversion payments increase farm size. Hence, government farm programs have been a

factor in explaining past changes in farm size, and the recent major restructuring of farm programs seems likely to cause average farm size to increase.

The structural equation for farm size shows, other things equal, that an increase in crop specialization or odds of off-farm work increases farm size. An increase of livestock specialization, however, reduces farm size. We suggest that the different effects of crop and livestock specialization on farm size are related to differences in the role played by land in specialization of the two sectors. The positive effect of off-farm work on size might occur if income from off-farm work is used to guarantee payments on farm assets. The effect could also be associated with a change in farm size distribution.

Specialization (crops). The reduced-form coefficient estimates explaining crop specialization have relatively small research effects. Both larger public and private crop research reduce crop specialization. Additional crop extension, however, does increase crop specialization.

Input prices, on the other hand, have quite substantial effects. An increase of the nonfarm and farm wage rates increase specialization as does a decrease in machinery prices. Higher government price supports (both crop and dairy) increase crop specialization. This occurs in spite of program payment limits. Large diversion payments retard crop specialization.

The structural equation for crop specialization shows that an increase in farm size increases crop specialization. This result suggests a narrowing of scope as farm size increases. An increase in the odds of off-farm work reduces crop specialization. When a farmer participates in off-farm work, it generally places limitations on the amount of time that he can allocate to timely planting and harvesting activities of any given crop. For a given size of farm, diversified cropping permits spreading out timing of planting and harvesting activities.

Specialization (livestock). The reduced-form (and structural) coefficient estimates for livestock specialization are in general the opposite of those for crop specialization. Additional public livestock research increases livestock specialization. In contrast, additional private livestock research, which is

more applied and heavily focused on commercial products for farmers than public livestock research, reduces livestock specialization during the study period. This negative effect of private livestock research may seem puzzling to some because of the recent advances in animal health practices that seem to be heavily based on specie or age-group isolation. We acknowledge that the direction of private livestock research over the past decade seems most likely associated with greater livestock specialization. An increase in livestock extension has a large positive impact on livestock specialization.

Input prices have modest effects on livestock specialization. An increase of wage rates (farm and nonfarm) retard specialization, an increase of the fertilizer price retards it, and an increase of the machine price stimulates it. Higher government price supports (both crop and dairy) retard livestock specialization, but a larger diversion payments increase livestock specialization.

The structural equation for livestock specialization shows that an increase in farm size reduces livestock specialization or causes a broadening of scope. An increase in the odds of off-farm work increases livestock specialization. The performance of most livestock enterprises is less closely tied to day length and good weather than for crop enterprises, and this seems to be one of the sources of differences in the effect of off-farm work on livestock and crop specialization.

Total Factor Productivity. One impetus for this paper was a question by Griliches about the possibility that changes in farm size and specialization are part of a broad story of TFP changes in U.S. agriculture over 1950-82, as he had found in earlier data (Griliches 1963). The structural equation for crop and livestock sector TFPs show, other things equal, that an increase in specialization increases productivity (significantly different from zero at the 1 percent level). In the crop sector, the impact of additional crop specialization is very large, having an elasticity of 1.1. In the livestock sector, the impact is small, an elasticity of 0.2. An increase in farm size has effects on crop and livestock productivity that are significantly different from zero at the 1 percent level. The direction of the impacts are, however, different in the two sectors. An increase in farm size increases livestock sector

productivity, and the impact is very large--an elasticity of 1.2. In the crop sector, an increase in size reduces productivity (elasticity of -0.4). One possibility is a decrease in timeliness as size increases in the crop sector. Griliches (1963) found positive effects of both size and specialization in national aggregate agricultural data. Hence, our results are a little different, and differences could be due to degree of data aggregation and (or) different time periods.

When Griliches conducted his study, part-time farming was relatively less common but became more important later. Our results show that an increase in the odds of farmers off-farm work reduces crop sector productivity but increases livestock sector productivity. Our arguments for reduced operator time for acquiring technical information and early technology adoption and limitations on timing of planting and harvesting activities caused by off-farm work are some reasons for this negative effect. The reason for the positive (and significantly different from zero at the 1 percent level) effect of off-farm work on livestock sector productivity is not as clear.

The implied reduced-form coefficients (Table 3) show some of the same results as reported in Huffman and Evenson (1992, 1993b). Some other results are new and receive the bulk of the emphasis. The specification of the structural model in Table 2 is such that some variables have direct and indirect effects on agricultural productivity and others have only indirect impacts on productivity through farm specialization, farm size, or odds of off-farm work and do not enter the structural TFP equations.

The impact of public crop research on crop sector TFP is positive (elasticity of 0.28) and of public livestock research on livestock sector TFP is negative (elasticity of -0.21) as in Huffman and Evenson (1992, 1993b). This study, however, shows additional impacts of public research variables on TFP through indirect (cross-sector spillover) effects. Additional public livestock research also increases crop sector TFP (elasticity of 0.14), and additional public crop research also reduces livestock sector TFP (elasticity of -0.03). The cross-sector impacts of public livestock research provide a significant

boost toward obtaining overall positive impacts of public livestock research on agricultural productivity.

Our implied reduced-form coefficients show interesting price effects on TFP. An increase of the real wage for farm labor and manufacturing labor increase productivity in both sectors with the impact of the wage for farm labor being much larger than for manufacturing labor. A decrease in the price of machinery and of commercial fertilizer increases crop sector productivity. These last two effects seem to be consistent with technical advances and competition in the nonfarm input sectors leading to new agricultural technologies that use machinery services and commercial fertilizer. The fertilizer price effects in the livestock sector is opposite that of the crop sector. This is most likely associated with the substitution possibilities between organic and commercial fertilizer.

Government programs are affecting productivity. Higher crop price supports increase TFP in both sectors. A higher milk price support has a large positive impact on livestock sector productivity and a large negative impact on crop sector productivity. Diversion payments are favorable to TFP in the crop sector but unfavorable to livestock sector productivity. Thus, results suggest that reducing or removing crop and milk price supports will reduce TFP in agriculture.

Summary and Conclusions

Our earlier research primarily focused on econometric evidence of a positive contribution of public and private agricultural research to state agricultural productivity in a crop sector, livestock sector, and an aggregate agricultural sector (Huffman and Evenson 1993). We also showed that public extension, farmer's schooling, and agricultural commodity programs have been contributors to agricultural productivity. Our earlier work, however, did not examine the contributions of specialization, size, or part-time farming to agricultural productivity or the contribution of public and private agricultural research and other policies to structural change in agriculture.

In U.S. agriculture, there is a long history of structural change and total factor productivity change. This paper has presented a framework for conceptualizing structural change when farms may be multi-product or specialized and an econometric examination of structural and TFP change using state aggregate data. We found that input prices, public and private research, public extension and government commodity programs directly and indirectly cause change over the study period in crop and livestock specialization, average farm size, and the frequency of part-time farming (among operators engaged in farming) and in total factor productivity of the crop and livestock sectors. We also found that increased specialization has increased crop and livestock sector productivity, and increased farm size (or part-time farming) has increased livestock sector productivity but seems to have reduced crop sector productivity.

A few additional results for the study period are highlighted. First, changes in farm size are dominated by input price changes rather than by technology (i.e., public and private research) or government programs. Second, input price changes have been a dominant factor in increasing crop specialization. In contrast, specialization in the livestock sector seems to be driven primarily by new technology resulting from research. Third, changes in the structure of agriculture--farm size, specialization, and part-time farming--were shown to be important channels to productivity increases in agriculture.

Although the data to which the model of agricultural structure and productivity was fitted do not extend to the 1990s, the model can be used to predict likely changes caused by the 1996 FAIR Act which eliminated many of the commodity programs. To make this prediction, we computed the percentage change in the endogenous variables of the model caused by setting all three of the government program variables [crop price supports (NPSUPPORT), milk price support (NPSUPMLK), and cropland diversions (NDVERSION)] to zero relative the respective sample mean value of the program variables. The prediction is for an increase in average farm size, a decrease in crop

specialization, an increase in livestock specialization, and a decrease in part-time farming. The prediction is also for a reduction in crop and livestock sector total factor productivity. The direction of these changes is unaffected by use of either the structural or reduced form model, but the magnitude of each change is larger for the structural than the reduced form model.

Endnotes

- * Authors are professor of economics, Iowa State University and Yale University, respectively. Peter Orazem provided valuable comments on an earlier draft. They acknowledge assistance of M. Ann Judd at Yale University with data analysis and Alan McCunn at Iowa State University with constructing state specialization indexes. They also acknowledge financial assistance from the Economic Growth Center, Yale University, and the Iowa Agriculture and Home Economics Experiment Station.
1. The size of the relevant input price vector might also be reduced by dropping the production of q_i .
 2. Sunk costs are ones that have little opportunity value once committed to product q_i .
 3. The concept of incremental cost can be extended to product sets that are larger than a single product (but less than the full product set p).
 4. The concept can easily be extended to a comparison of production of q in n_1 versus n_0 farms when $n_1 > n_0 > 2$. The farms specializing in producing t outputs of the industry can be denoted the t -products sector, and the farms specializing in the remaining outputs denoted the $p-t$ products sector of the industry.
 5. This study does not focus on the number of farms because it does not seem to be closely related to agricultural productivity when farm size is included. Average farm size and the number of farms in a state are negatively correlated over time.
 6. Considerable evidence exists that local input markets for mobile inputs, including labor, are well integrated in the United States.
 4. The specialization indexes used in this paper are totally different from the earlier Huffman and Evenson (1993a) definition. Additional details about the construction of the specialization and size indicators are available from the authors upon request.
 8. Of course there is some subjectiveness to our structure. We admit that others are possible.
 9. They are the actual reduced-form coefficients except for interaction variables.

References

- Ahearn, Mary and John E. Lee, Jr. "Multiple Job-Holding Among Farm Operator Households in the United States." in M.C. Hallberg, et al., eds., *Multiple Jobholding Among Farm Families*. Ames, IA: Iowa State University Press, 1991, pp. 79-111.
- Ball, A.G. and E.O. Heady. "Trends in Farm and Enterprise Size and Scale." in A.G. Ball and E.O. Heady, eds., *Size, Structure, and Future of Farms*, Ames, IA: Iowa State University Press, 1972.
- Ball, A.G. and E.O. Heady, eds. "Size, Structure, and Future of Farms." Ames, IA: Iowa State University Press, 1972.
- Baumol, W.J., J.C. Panzar, and R.D. Willig. *Contestable Markets and The Theory of Industrial Structure*, New York, NY: Harcourt Brace Jovanovich, Inc., 1982.
- Ball, V. Eldon, J. Matson, and A. Somwaru. "Agricultural Productivity Revisited." USDA-ERS Paper, July 1994.
- Barkley, Andrew P. "The Determinants of the Migration of Labor out of Agriculture in the United States: 1940-85." *American Journal of Agricultural Economics* 72(1990):567-73.
- Batte, Marvin T. and S.T. Sonka. "Before and After Tax Size Economies: An Example for Cash Grain Production in Illinois." *Am. J. Ag. Econ.* 67(1985):600-608.
- Batte, Marvin T. and R. Johnson. "Technology and Its Impact on American Agriculture," in A. Hallam, Ed., *Size, Structure, and the Changing Face of American Agriculture*, Boulder, CO: Westview Press, 1993, pp 308-335.
- Becker, Gary S. *Human Capital*. New York, NY: Columbia University Press for the NBER, 1975.
- Carlton, D.W. and J.M. Perloff. "Modern Industrial Organization," New York, NY: Harper Collins College Publishers, 1994.
- Chambers, Robert G. *Applied Production Analysis: A Dual Approach*, New York, NY: Cambridge University Press, 1988.
- Chavas, J.P. and T.L. Cox. "A Nonparametric Analysis of the Influences of Research on Agricultural Productivity." *American Journal of Agricultural Economics* 74(1992): 583-591.
- Evenson, Robert E. "A Century of Agricultural Research and Productivity Change Research, Invention, Extension and Productivity Change in U.S. Agriculture: An Historical Decomposition Analysis," in A.A. Araji, eds., *Research and Extension in Agriculture*. Dept. of Economics, University of Idaho, Moscow, IA, 1980, pp. 146-228.
- Evenson, R.E. and R.A. Kramer. "Public Policy, Technology, and the Structure of U.S. Agriculture: Some Econometric Evidence." Paper, Yale University, New Haven, Conn., 1988.

- Gale, H.F. "Why Did the Number of Young Farm Entrants Decline?" *Am. J. Agr. Econ.* 75(Feb 1993):138-146.
- Gardner, B.L. "Changing Economic Perspectives on the Farm Problem," *J. Econ. Lit.* 30(March 1992):62-101.
- Gardner, B.D. and R.D. Pope. "How is Scale and Structure Determined in Agriculture," *Am. J. Agr. Econ.* 60(May 1978):295-302.
- Goddard, E., A. Weersink, K. Chen, and C.G. Turvey. "Economics of Structural Change in Agriculture," *Can. J. Agr. Econ.* 41(Dec 1993):475-89.
- Griliches, Zvi. "The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960." *Journal of Political Economics* 71(1963):331-46.
- Hallam, A. "Economies of Size and Scale in Agriculture: An Interpretative Review of Empirical Evidence." *Rev. Agr. Econ.* 13(Jan 1991):155-172.
- Hallam, Arne. "Empirical Studies of Size, Structure, and Efficiency in Agriculture," in A. Hallam, ed., *Size, Structure, and the Changing Face of American Agriculture*. Boulder, CO: Westview Press, 1993a, pp 204-231.
- Hallam, Arne (Ed.) *Size, Structure, and the Changing Face of American Agriculture*. Boulder, CO: Westview Press, 1993b.
- Hayami, Yujiro and Vernon W. Ruttan. *Agricultural Development: An International Perspective*. 2nd ed, Baltimore, MD: Johns Hopkins University Press, 1985.
- Huang, Tzu-Ling and P.F. Orazem. "Rural Population Growth, 1950-1990: The Role of Human Capital, Industry Structure and Government," Dept. Economics, Iowa State University, January 1997.
- Huffman, Wallace E. "Farm and Off-Farm Work Decisions: The Role of Human Capital." *Rev. Econ. Statist.* 62(Feb 1980):14-23.
- Huffman, Wallace E. "Human Capital, Adoptive Ability, and the Distributional Implications of Agricultural Policy." *American Journal of Agricultural Economics* 67(1985):429-34.
- Huffman, Wallace E. "Agricultural Household Models: Survey and Critique," in *Multiple Job-Holding Among Farm Families*, M.C. Hallberg, J.L. Findeis, and D.A. Lass, eds., Ames, IA: Iowa State University Press, 1991, pp. 79-111.
- Huffman, Wallace E. "Labor Markets, Human Capital, and the Human Agent's Share of Production," in *The Economics of Agriculture: Papers in Honor of D. Gale Johnson*, Vol. 2, J.M. Antle and D.A. Sumner, eds., The University of Chicago Press, 1996, pp. 55-79.
- Huffman, Wallace E. "Farm Labor: Key Conceptual and Measurement Issues on the Route to Better Farm Cost and Return Estimates," ISU Dept. Economics, Staff Paper Series, Staff Paper #280, April 1996.

- Huffman, Wallace E. and Robert E. Evenson. "The Effects of R&D on Farm Size, Specialization and Productivity," in S.R. Johnson and S.A. Martin, eds., *Industrial Policy for Agriculture in the Global Economy*, Ames, IA: Iowa State University Press, 1993a, pp. 41-72.
- Huffman, Wallace E. and Robert E. Evenson. *Science for Agriculture*. Ames: Iowa State University Press, 1993b.
- Kendrick, J.W. *Productivity Trends in the United States*. National Bureau of Economic Research. Princeton, NJ: Princeton University Press, 1961.
- Kislev, Y. and W. Peterson. "Prices, Technology, and Farm Size." *Journal of Political Economics* 90(1982):578-95.
- Kislev, Y. and W. Peterson. "Economies of Scale in Agriculture: A Reexamination of the Evidence." in *The Economics of Agriculture: Papers in Honor of D. Gale Johnson*, Vol. 2, J.M. Antle and D.A. Sumner, eds., The University of Chicago Press, 1996, pp. 156-170.
- Knutson, M. and L. G. Tweeten. "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension." *Am. J. Agr. Econ.* 61(1979):70-76.
- Moschini, G. "Nonparametric and Semiparametric Estimation: An Analysis of Multiproduct Returns to Scale." *Am. J. Agr. Econ.* 72(1990):589-96.
- National Research Council, Committee on New Information Systems for Agriculture, Report, forthcoming.
- Office of Technology Assessment. *A New Technological Era for American Agriculture*. Washington, D.C.: U.S. Government Printing Office, 1992.
- Olfert, M.R. "Nonfarm Employment as a Response to Underemployment in Agriculture." *Can. J. Agr. Econ.* 40(1992):443-458.
- Panzar, J.C. and R.D. Willig. "Economies of Scope," *Amer. Econ. Rev.* 71(May 1980):268-272.
- Quance, Leroy and L.G. Tweeten. "Policies, 1930-1970." In A.G. Ball and E.O. Heady, eds., *Size, Structure, and Future of Farms*. Ames: Iowa State University Press, 1972.
- Sumner, O. and J.D. Leiby. "An Econometric Analysis of the Effects of Human Capital on Size and Growth Among Dairy Farms," *Am. J. Agr. Econ.* (May 1987):465-470.
- U.S. Department of Agriculture. *Economic Indicators of the Farm Sector: State Financial Summary, 1990*. Rockville, Md.: ERS-NASS, 1991.
- U.S. Department of Commerce, Census Bureau. *Census of Population: 1950*. Washington, D.C.: U.S. Government Printing Office, 1953.
- U.S. Department of Commerce. *Census of Population, 1950*. Vol. 4. Special Report, Part 5, Chapter B, Education. Washington, D.C.: U.S. Government Printing Office, 1953a.

- U.S. Department of Commerce. Census of Agriculture, 1982. Vol. 2. Washington, D.C.: U.S. Government Printing Office, 1983.
- U.S. Department of Commerce, Census of Agriculture 1987. Washington, D.C.: U.S. Government Printing Office, 1989.
- Varian, H.R. *Microeconomic Analysis*. 3rd Ed., New York, NY: W.W. Norton & Co., 1992.
- Weersink, A. "Off-Farm Labor Decisions by Ontario Swine Producers," *Can. J. Agr. Econ.* 40 (July 1992):235-251.
- Wozniak, Gregory D. "Joint Information Acquisition and New Technology Adoption: Late versus Early," *Rev. Econ. Statist.* 75(Aug 1993):438-445.
- Zepeda, L. "Asymmetry and Nonstationarity in the Farm Size Distribution of Wisconsin Milk Producers: An Aggregate Analysis." *Am. J. Agr. Econ.* 77(Nov 1995):837-852.

Table 1. Definition of Variables

Symbol	Definition
Endogenous	
TFPC and TFPL	Five-year moving average crop sector (C) and livestock sector (L) multi-factor productivity indexes. Annual TFP series derived as Tornqvist-Theil output index divided by Tornqvist-Theil input index, 1.00 for national mean 1949-52 averaged using values for the current and four preceding years (Huffman and Evenson 1993b).
SPLZEC and SPLZEL	Crop (C) and livestock (L) specialization index: Index represents the extent to which farms in a particular state specialize in the production of major crop (or livestock) commodities (devised from the farm-type data, Census of Agriculture, and interpolated between census years; see Appendix). For each state, the crop and livestock specialization indexes are normalized by their respective values in 1950.
SIZE	Index of average farm size: Index representing the real service flow from cropland - equivalent farmland and from other farm capital stocks (e.g., machinery, breeding stocks). This index is normalized by its average value over 1949-52.
OF	The share of farm operators reporting any days of off-farm work (taken from Census of Agriculture and interpolated between Census years).
OF/(1-OF)	The average odds of off-farm by farm operators.
Exogenous	
APPC and APPL	Stock of public applied crop (C) and livestock (L) research in 1984 dollars, total lag of 33 years, trapezoidal shape weights 7 rising + 6 constant + 20 declining. Research spillins from similar subregions and regions are included (Huffman and Evenson 1993b).
SCC and SCL	Stock of public pre-technology science crop (C) and livestock (L) research in 1984 dollars. Lag pattern and spillin as in APP and APPL (Huffman and Evenson 1993b).
RESC	SCC + APPC: The stock of public crop research.
RESL	SCL + APPL: The stock of public livestock research.
PRIVCG and PRIVLG	Private crop (C) and livestock (L) research stock in 1984 dollars, total lag of 33 years, trapezoidal shape 7 + 6 + 20, adjusted for the number of geoclimatic subregions (Huffman and Evenson 1993b).

Table 1. (continued)

Symbol	Definition
EXTCG and EXTLG	Public extension stock having a commodity focus in days per year, total time lag of 3 years (.5, 0.25, 0.25), adjusted for number of geoclimatic subregions (Huffman and Evenson 1993b).
SCH	Schooling of farmers: average years of schooling completed by rural males 15-65 years of age, interpolated between census years (Huffman and Evenson 1993b).
WAGEF	Real wage rate for hired farm labor (Huffman and Evenson 1993b).
WAGEMG	Real wage rate for production workers in manufacturing (Huffman and Evenson 1993b).
PMACH	Price index for farm tractors (Ball 1985).
PFERT	Price index for fertilizer (Huffman and Evenson 1993b).
NPSUPPORT	Government crop price support: weighted ratio of support price to market price for crops (Huffman and Evenson 1993b).
NPSUPMLK	Government milk price support: weighted ratio of milk support price to milk market price (Huffman and Evenson 1993b).
NDVERSION	Government crop diversion payments: equivalent price ratio of direct government crop acreage payments (Huffman and Evenson 1993b).
YEAR	Trend
D_r	Share of a state's agricultural land classified in r th geoclimatic regions, $r = 1, \dots, 16$ (Huffman and Evenson 1993b).

Table 2. Three-Stage Least-Squares Estimate of Six-Equation Model of Agricultural Structure and Productivity: U.S. Aggregates, 1950-82

Variables	Crop		Livestock		Overall Average	
	ln MFPC	ln SPLZEC	ln MFPL	ln SPLZEL	ln SIZE	ln [OF/(1-OF)]
A. Endogenous Variables						
ln SPLZEC	1.129 ^{a/}	-	-	-	0.065	-2.636 ^{a/}
ln SPLZEL	-	-	0.194 ^{a/}	-	-0.219 ^{a/}	0.408 ^{a/}
ln SIZE	-0.427 ^{a/}	0.199 ^{b/}	1.330 ^{a/}	-0.388 ^{a/}	-	1.898 ^{a/}
ln [OF/(1-OF)]	-0.058 ^{b/}	-0.146 ^{a/}	0.116 ^{a/}	0.180 ^{a/}	0.077 ^{b/}	-
B. Exogenous Variables						
ln RESC	0.805 ^{a/}	-0.057 ^{a/}	-	-	0.021	-0.318 ^{a/}
ln RESL	-	-	-0.627 ^{a/}	0.266 ^{a/}	0.070 ^{a/}	-0.429 ^{a/}
ln PRIVCG	0.731 ^{a/}	-0.006	-	-	-0.413 ^{a/}	0.648 ^{a/}
ln PRIVLG	-	-	-0.341 ^{c/}	-0.156 ^{a/}	0.241 ^{a/}	-0.297 ^{a/}
ln EXTCCG	-1.133 ^{a/}	0.105 ^{a/}	-	-	-0.012	0.167 ^{a/}
ln EXTLG	-	-	0.558 ^{b/}	-0.123 ^{a/}	0.063 ^{a/}	0.056
SCH	-0.013	-0.043 ^{a/}	0.057 ^{b/}	-0.012	0.003	-0.037
ln RESC x ln PRIVCG	-0.046 ^{a/}	-	-	-	-	-
ln RESC x ln PRIVLG	-	-	0.047 ^{a/}	-	-	-
ln RESC x ln EXTCCG	0.099 ^{a/}	-	-	-	-	-
ln RESL x ln EXTLG	-	-	-0.074 ^{a/}	-	-	-
ln PRIVCG x ln EXTCCG	-0.054 ^{a/}	-	-	-	-	-
ln PRIVLG x ln EXTLG	-	-	0.058 ^{a/}	-	-	-
SCH x ln EXTCCG	-0.015	-	-	-	-	-
SCH x EXTLG	-	-	0.018 ^{c/}	-	-	-
ln WAGENG	0.211 ^{c/}	0.372 ^{a/}	-0.348 ^{a/}	-0.417 ^{a/}	-0.021	2.286 ^{a/}
ln(WAGEF/WAGEMG)	0.194 ^{a/}	0.224 ^{b/}	0.098 ^{b/}	-0.406 ^{a/}	-0.281 ^{a/}	2.051 ^{a/}
ln(PMACH/WAGEF)	-	-0.016	-	-0.323 ^{a/}	-0.392 ^{a/}	0.246 ^{a/}
ln(PFERT/WAGEF)	-	0.022	-	-0.162 ^{a/}	-0.036	1.691 ^{a/}
NPSUPPORT	0.528 ^{a/}	0.513 ^{a/}	0.299 ^{a/}	-0.129	-0.142 ^{b/}	1.459 ^{a/}

Variables	Crop		Livestock		Overall Average	
	ln MFPC	ln SPLZEC	ln MFPL	ln SPLZEL	ln SIZE	ln [OF/(1-OF)]
NPSUPMLK	-1.942 ^{a/}	0.749 ^{a/}	1.290 ^{a/}	-1.230 ^{a/}	-0.368 ^{a/}	2.700 ^{a/}
NDVERSION	1.551 ^{a/}	-0.909 ^{a/}	-0.744 ^{a/}	0.254	0.483 ^{a/}	-2.999 ^{a/}
YEAR	-0.017 ^{a/}	0.002	-0.031 ^{a/}	0.038 ^{a/}	0.032 ^{a/}	-0.083 ^{a/}
D ₁	0.033	0.066	0.241 ^{a/}	-0.158 ^{a/}	-0.075 ^{c/}	0.265 ^{c/}
D ₂	-0.057	0.226 ^{a/}	1.023 ^{a/}	-0.469	-0.170 ^{a/}	0.974 ^{a/}
D ₃	-0.233 ^{a/}	0.432 ^{a/}	1.298 ^{a/}	-0.462 ^{a/}	-0.347 ^{a/}	1.708 ^{a/}
D ₄	-0.484 ^{a/}	0.111 ^{c/}	0.581 ^{a/}	-0.282 ^{a/}	0.180 ^{a/}	0.340
D ₅	-0.526 ^{a/}	0.149 ^{a/}	0.494 ^{a/}	-0.272 ^{a/}	0.022	0.405 ^{b/}
D ₆	-0.327 ^{a/}	0.276 ^{a/}	0.627 ^{a/}	-0.711 ^{a/}	-0.179 ^{b/}	1.359 ^{a/}
D ₇	-0.339 ^{a/}	0.185 ^{b/}	0.189	-0.528 ^{a/}	0.300 ^{a/}	0.924 ^{a/}
D ₈	1.484 ^{a/}	-0.485	0.182	1.497	-1.498 ^{a/}	0.630
D ₉	-0.644 ^{a/}	-0.119 ^{b/}	0.946 ^{a/}	-0.421 ^{a/}	-0.110 ^{b/}	-0.304 ^{c/}
D ₁₀	-0.447 ^{a/}	0.036	0.967 ^{a/}	-0.516 ^{a/}	-0.157 ^{a/}	0.398 ^{b/}
D ₁₁	-2.549 ^{a/}	1.530 ^{a/}	6.111 ^{a/}	0.051	-0.829 ^{b/}	0.948
D ₁₂	-0.536 ^{a/}	-0.000	-0.102	-0.509 ^{a/}	0.150	0.372
D ₁₃	-0.457 ^{a/}	0.295 ^{a/}	0.291 ^{a/}	-0.123 ^{b/}	0.040	0.662 ^{a/}
D ₁₄	0.770 ^{a/}	-0.275 ^{b/}	0.300 ^{b/}	-0.564 ^{a/}	-0.160	-0.094
D ₁₅	-1.182 ^{a/}	1.317 ^{a/}	2.197 ^{a/}	-1.218 ^{a/}	-0.754 ^{a/}	5.070 ^{a/}
Intercept ^{d/}	20.157 ^{a/}	-2.310	64.445 ^{a/}	-76.962 ^{a/}	-62.008 ^{a/}	172.445 ^{a/}

^{a/} Coefficient is significantly different from zero at 1% level.

^{b/} Coefficient is significantly different from zero at 5% level.

^{c/} Coefficient is significantly different from zero at 10% level.

^{d/} System weighted $R^2 = 0.702$.

Table 3. Implied Reduced-Form Coefficients: Model of U.S. Agricultural Structure and Productivity^{a/}

Variables	Crop		Livestock		Overall Average		Sample Mean
	ln MFPC	ln SPLZEC	ln MFPL	ln SPLZEL	ln SIZE	ln[OF/(1-OF)]	
ln RESC	0.278	-0.013	-0.031	-0.056	0.010	-0.289	16.138
ln RESL	0.136	0.087	-0.210	0.159	-0.005	-0.604	17.063
ln PRIVCG	0.117	-0.127	-0.535	0.213	-0.452	0.211	8.076
ln PRIVLG	-0.066	0.058	0.720	-0.271	0.306	0.020	6.970
ln EXTCG	0.059	0.136	-0.050	-0.036	-0.012	-0.230	-1.582
ln EXTLG	-0.078	-0.015	0.017	0.170	0.107	0.250	-1.787
SCH	-0.072	-0.062	0.054	0.011	0.008	0.147	9.350
ln WAGEMG	0.028	0.151	0.009	-0.060	0.315	0.411	-2.994
ln WAGEF	0.516	0.315	0.225	0.061	0.144	-0.417	0.424
ln PMACH	-0.478	-0.412	-0.072	0.204	-0.286	2.317	-0.920
ln PFERT	-0.032	-0.012	0.016	-0.121	0.009	0.245	-1.952
NPSUPPORT	1.150	0.511	0.142	-0.113	-0.092	-0.109	0.226
NPSUPMLK	-1.158	0.694	1.042	-1.157	-0.045	0.312	0.092
NDVERSION	0.444	-0.827	-0.184	0.095	0.408	-0.007	0.045

^{a/} Derived from coefficients of structural model in Table 2. Effects of interaction variables in the reduced form are evaluated at sample mean values in order to express implied reduced-form effects in terms of the primary regressors.