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Structural and productivity change in US agriculture, 1950–1982

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Abstract

This paper tests whether structural change in US agriculture is an important channel to TFP growth and evaluates the relative impact of (i) public research and education policies, (ii) private R&D and market forces, and (iii) government farm programs on structural change. We specify a structural econometric model, fit it to US state aggregate data, 1953–1982, and use the associated reduced-form model to perform counter-factual policy simulations. The findings include: structural change is a channel to TFP growth in both crop and livestock subsector, i.e. specialization, size, and part-time farming do impact TFP, holding other variables constant. Public R&D and education have been at least as important as private R&D and market forces for changing livestock specialization, farm size, and farmers' off-farm work participation over the study period, but private R&D and market forces have been relatively more important for crop specialization. Changes in farm commodity programs had little impact on farm structure over these study period. Overall, we conclude that if public R&D and education policies had been unchanged at their 1950 values over 1950–1982, major structural changes in US agriculture would have occurred anyway. The forces of private R&D and market forces were at work, including a decline in the price of machinery services and agricultural chemicals, relative to the farm wage.

Keywords: Farm structure; Total factor productivity; Farm size; Specialization; Part-time farming; Research and development; United States

1. Introduction

During recent decades, productivity growth has been the major source of growth in farm output in OECD countries. All OECD countries experienced positive output growth, but 13 of 18 OECD countries had small negative growth rates for total input use (OECD, 1995, p. 16) — with a large decline of farm labor employment and a large increase in intermediate inputs used. In all of these countries, the number of farms has declined, average farm size and specialization have increased, and net exit, off-farm participation, and out migration rates have increased in the post World War II period.

The changing structure of agriculture in OECD countries has been linked to technology, economy and world-wide market forces, and to governmental policies. Little empirical evidence, however, exists on the effects of farm structure on productivity or on the effects of market forces and governmental policies on structure.[1] If policy makers had a better understanding of these relationships, they could design better agricultural and rural community adjustment programs. Furthermore, significant advances in our

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[1] Weersink and Tauer (1991) have tested for causal relationships between productivity (measured as milk per cow) an farm size (measured as milk cows per farm) using state level data, 1964–1987, and found that size primarily caused productivity.

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understanding of productivity would occur if we can show how changes in market forces and government policies are channelled through structural change to impact productivity growth in agriculture.

Related research on US agriculture includes studies of farm size and structure by Ball and Heady (1972), Reimund and Gale (1992), Hallam (1991, 1993), and Kislev and Peterson (1982, 1996) out-migration from and entry to farming by Barkley (1990) and Gale (1993) and integration of farm and non-farm labor markets by Huffman (1980, 1996). Before Kislev and Peterson (1982), most explanations of changes in farm size (i.e. output per farm or enterprise) relied on the existence of scale economies. Farm sizes were seen as increasing because optimal scale of production was increasing, and this was attributed to changes in technology. Kislev and Peterson showed that most of the changes in US farm size, 1930–1970, could be explained by changes in the price of labor relative to the price of machine services. As the farm and non-farm sectors became more integrated over time, these prices were determined in the broad economy. Furthermore, farm profit maximizing behavior implied that changes in prices of farm outputs and of biological inputs would not affect farm size. Similarly, advances in biological technology would not affect farm size but mechanical technology would.

Barkley showed that migration of labor out of US agriculture, 1940–1985, responded primarily to changes in the returns to agricultural labor relative to nonagricultural labor returns. Gale showed that entry of young farmers over 1979–1987 was affected by demographic and economic factors associated with expected profitability of farming and nonfarm employment opportunities. Huffman showed that individual, household, farm, and off-farm factors affect farmers' off-farm work participation rates.

In earlier work, we (Huffman and Evenson, 1993) focused on the impacts of public and private R&D on agricultural productivity, ignoring farm structure variables. However, structural change may restrict or amplify the impacts of R&D and thereby be an important channel to productivity change. The objectives of this paper are to test whether structural change in US agriculture is an important channel to TFP growth and to evaluate the relative impact of public research and education policies, private R&D and market forces, and government farm programs on structural change.[2] The analysis is conducted with the aid of a six-equation econometric model and state aggregate data for 1950–1982. This time period is chosen because it represents a period of unusually rapid technological and structural change in US agriculture. Confining the analysis to this period also allows us to build upon an unusually rich data set that we have constructed.

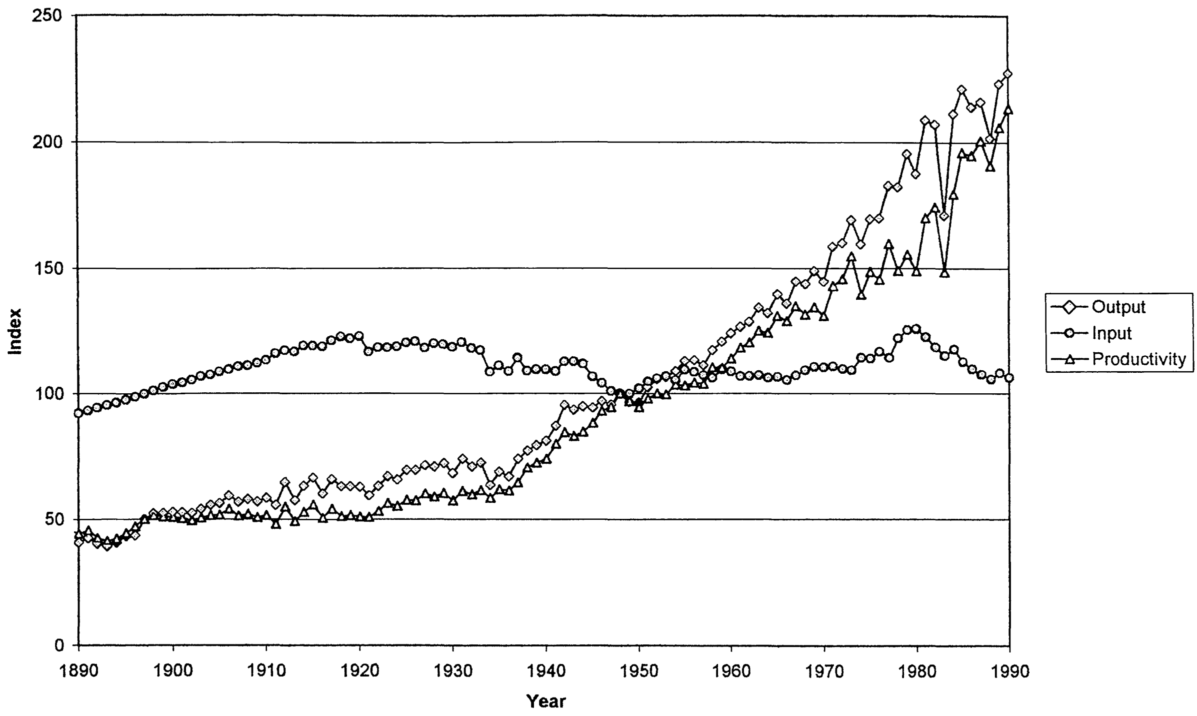
In this paper, we focus on three dimensions of farm structure — farm size, specialization, and part-time farming, and productivity. We do not separately analyze the number of farms because the rate of change in farm numbers and average acres per farm for a given region are very highly negatively correlated, e.g. see Frisvold and Lomax (1991), p. 5. Also, a measure of farm size better reflects farmers' decisions as they respond to market forces and governmental policies. With a large share of farmers participating in off-farm work (OECD, 1994) and off-farm work participation being used as an aid to entry and exit from farming while staying partially employed in agriculture, we have chosen the off-farm work participation rate as the key indicator of operator–labor adjustment associated with structural change.

Part of the evidence presented is from 'counterfactual' scenarios, e.g. if public R&D and education, private R&D and market forces, or government farm programs had remained unchanged over the study period, how would structural change of US agriculture differed? Were the impacts of public R&D and education larger or smaller than those of private R&D and market forces? These are issues that arise frequently in policy and popular discussions of the changing structure of US agriculture.

2. Background on structural change in US agriculture

Agriculture in US has undergone major structural change over the past 100 years. In 1890, US farms numbered 4.5 million; and the number grew steadily to

[2] In an earlier paper (Huffman and Evenson, 1993b), we reported some preliminary evidence of the impacts of public policies on farm productivity and structure. In the current paper, we have changed the set of endogenous variables, changed the empirical definitions of endogenous variables that are similar, and taken a somewhat different focus.



Source: Adapted from Huffman and Evenson 1993, pp. 183.

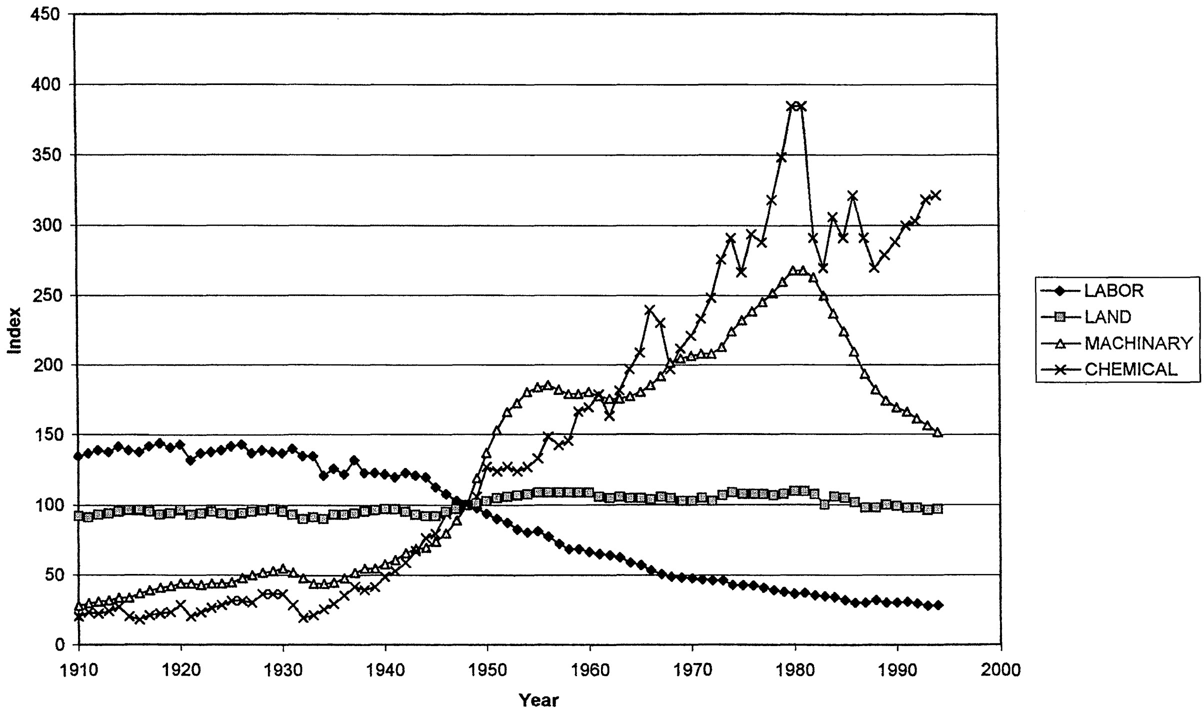
Fig. 1. US (real) farm output, farm input, and total factor productivity, 1890–1990.

6.4 million in 1910. Little change then occurred until the Great Depression pushed the number to 6.8 million in 1935. Farm numbers decreased most rapidly from 1950 to 1969, going from 5.4 to 2.7 million or decreasing at an annual average rate of 3.6% (Gale, 1994). Since 1970, there has been a slow decline in farm numbers. In 1990, the 1.9 million US farms equaled only 30% of the number at the peak in 1935 and 35% of the 1950 number.

Aggregate US farm output was about 5.5 times larger in 1990 than in 1890, and the average annual rate of increase was significantly faster after 1935 (see Fig. 1). With the number of farms declining, and aggregate output growing, average output per farm, one measure of farm size, grew rapidly. Using this measure, average farm size was 1.6 times larger in 1940 than in 1890, but was 8.8 time larger in 1990 than in 1940. Since 1960, farms have also become more specialized in the products or outputs that they produce.

Somewhat surprising, the index of aggregate real input under the control of US farmers has not changed much over the past 100 years, but the composition of inputs has changed dramatically. Aggregate real input in 1990 is only slightly larger than in 1890 (Fig. 1), and larger growth in aggregate output is possible only with productivity growth or technical change.

Fig. 2 shows the trends in labor, land and buildings, farm machinery, and chemical used in agriculture from 1910 to 1994. These data show a sizeable decrease in labor use, especially after 1950, and the changes are generally parallel to the reduction in the number of farms. At the same time, machinery and chemical input use increased, and the land and buildings input remained largely unchanged over time. Thus, land and buildings input per farm has risen at approximately the same annual rate that farm numbers have declined. The positive trend in machinery input showed a major reversal in 1980 and declined through 1994.

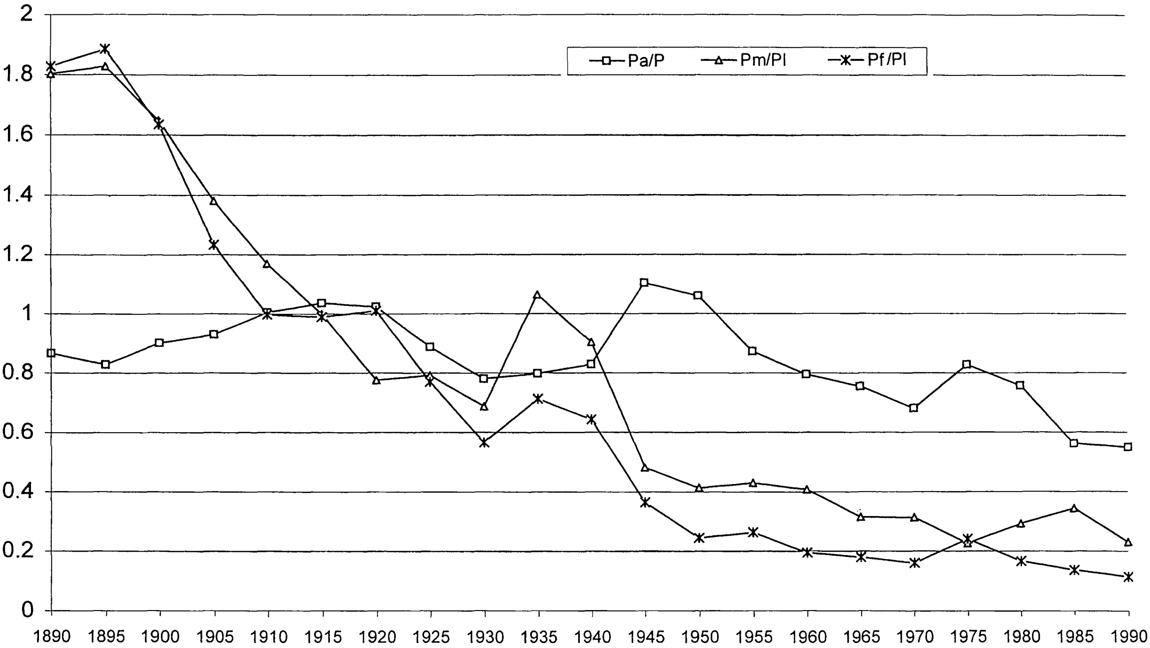


Source: Data for 1910-1948 from Loomis and Barton (1961), and for 1948-1994 from U.S. Presdient (1997, pp. 411).

Fig. 2. US aggregate farm input use, 1910–1994 (1948=100).

Over the long term, changes in the real price of farm output, relative input prices, and innovations have been major forces for structural change in US agriculture. Fig. 3 presents evidence on trends for real output and relative input prices, 1890–1990. It shows that real farm prices, the index of prices received by US farmers for their outputs relative to the implicit GNP deflator, rose over 1890–1920. The abundant and free land period ended about 1890, new agricultural technologies from the applications of science were just starting to emerge during this period (Huffman and Evenson, 1993, pp. 18–19), and very rapid US immigration and population growth were occurring during this period, and ended in 1921 with imposition of the first comprehensive immigration quota system. Real farm prices declined over 1920–1930, rose sharply during World War II (1940–1945), then went into a long term decline starting in 1945, except for the grain stock and oil shock years of 1972–1976. Over 1890–1990, the price of farm machinery relative to the wage of hired farm labor and price of agricultural chemicals relative to wage for hired labor show long term large and persistent downward trends, except for the 1930s. They end the period at approximately one-tenth the beginning of period level but a large share of the decline was over by 1890–1950.

Although agricultural production in the distant past was relatively labor intensive, this has changed dramatically over time. Much of the work has been mechanized or automated, intensive seed-bed preparation for field crops has been replaced by no-till planting, and modern pest control is accomplished by a combination of chemical and pharmaceutical methods. Furthermore, new information technologies using computers, sensors, and satellites have greatly advanced measurement possibilities for collecting data with spatial and temporal dimensions on physical and environmental conditions, input use, and crop yields.



1/ Pa/P is the index of prices received by farmers for all commodities divided by the implicit GNP deflator; P_m/P_l is the price of farm machinery relative to the wage rate for hired farm labor; P_f/P_l is the price of agricultural chemicals divided by the wage rate for hired farm labor. The data are at 5-year intervals. Before 1950, the ratios are constructed from 5-year average values, and for 1950-1990, the ratios are constructed from annual values.

Source: 1890-1950, from Hayami and Ruttan (1985, pp. 482-3), except for the implicit GNP deflator which is from Friedman and Schwartz (1982; table 4.8). 1950-1990, from Ball et al. (1997, pp. 1058-61), except for the implicit GNP deflator which is from Friedman and Schwartz (1982) for 1950-1975 and from the U.S. President (1991) for 1975-1990.

Fig. 3. Relative prices for farm output and inputs, 1890–1990 (1910–1914=1.00).

Compared to 50 or 100 years ago, today's farmers spend relatively more time in planning, analyzing, and managing their farm business and less in field work and livestock care. Hence, information acquisition and analytical and decision making skills that are made possible with higher levels of formal schooling are increasingly important in US agriculture.

Starting about 1900, US secondary schools were transformed into new institutions emphasizing training for the work of life and not just college preparation (Goldin, 1998). The Midwest, where family farming was important, was a leader in the transformation. School enrollment rates of US farm children, 5–19 years of age, grew steadily during 1900–1950 from 50 to 75% (US Department of Education, 1993), then very rapidly during 1950–1960 as much larger share of farm youth continued on to high school. In 1950, the proportion of farm male youth (18–24 years of age) that had completed high school was about 20% points lower than for nonfarm youth but by 1980, high school completion rates for farm and nonfarm male youth were essentially equal (US Bureau of the Census, 1981, p 71; 1964, p 408–415).[3] Schooling completion levels of US farmers have increased since 1950. Using evidence on rural farm males 25 years of age and older, average years of schooling completed in 1950 was 7.4 years, and in 1980, it was 11.0 years.[4]

The frequency of reported off-farm work by farmers is affected by the definition of a farm. If we use a broad

[3] The frequency with which farm youth complete college continues to be lower than for nonfarm youth.

[4] The average years of schooling completed by nonfarm adult males was 9.5 years in 1950 and 12.0 years in 1980.

definition, as the USDA does generally, the frequency of off-farm work by US farmers was about 30% from 1900 to 1939, dropping during the two World Wars, and rebounded to 39% in 1949 (Ahearn and Lee, 1991). This percentage increased during the next two decades to 54% in 1969 while at the same time the number of farmers was declining dramatically. During the subsequent two decades, the frequency of off-farm work by farmers stayed approximately unchanged.

3. Conceptual issues

Production on farms is one of biological processes, but major differences exist between crop and livestock production. The seasonal and spatial nature of crop production place severe constraints on large scale units and mechanized production. With plant biological (clocks) processes sequenced by day-length and temperature, little opportunity exits to use mechanization to speed up the production processes. Because planting and harvesting for any given crop must occur within a narrow time window at any location, a major limit to size of specialized enterprises occurs. Crop rotation, or nonspecialized production, has historically been one important method for controlling pest and disease problems in crops and balancing soil nutrient availability with plant nutrient needs. Chemical and biological control of pests and chemical fertilizer applications are relatively new technological alternatives to crop rotation, and they have facilitated crop specialization.

Because plants occupy fixed land area as they grow, machines suitable for mechanization of crop production must be mobile and move across the fields or through plant materials that are fixed in location. Thus, a special type of mechanization is required for crops. This contrasts with industrial (and livestock) production where the production plant is fixed and materials move through it. The latter type of production permits workers to become specialized in one phase of the total production process and this has aided labor productivity in the industrial sector. It is difficult for workers in crop production to be fully employed and to specialize in any phase of production. Also, Kislev and Peterson (1982) argued that a farm requires a manager giving full time attention to the farm. To move to hired management entails a significant cost increase, and this provides an opportunity for machines developed to increase the area cultivated.

Livestock production is relatively free of constraints due to seasonal and spatial attributes. It is economically feasible to speed up or slow the rate of production by changing the diet and activity level of animals and poultry during the growing and finishing phases. Production can be organized in sequential phases with different farms specializing in each phase or all phases occurring on one farm. Advances in animal health products, animal feeding, housing and equipment, and management have made it possible to speed up the growing and finishing phases by using large confined animal production systems which greatly increase animal densities and populations (Fuglie et al., 1998). To further reduce disease problems in confined systems, animals of different ages can be segregated and raised apart in 'all-in, all-out' systems. With the growing and finishing of animals and birds in a facility in phased groups, livestock production becomes similar to production of industrial goods where workers have the opportunity to specialize in a particular phase of production.

Farm size has many different measures; some volume of output based and some 'capacity' based (e.g. land, capital, cows per farm; see Hallam, 1993). If we adopt the capacity concept of size, then many biological and chemical technologies seem to be size neutral. However, significant fixed information and adoption costs turn them into size economies for larger production units (e.g. see Rahm and Huffman, 1984; Wozniak, 1993; Putler and Zilberman, 1998). Also, Smith et al. (1984) found that Texas cotton farms had increased revenue per unit output and reduced cost as farm size became larger. The added revenue came from larger farms having slightly better marketing decisions and reduced costs were associated with opportunities for vertical integration of farming with an input supply business. Hence, larger farms may have an advantage in accessing or using institutional arrangements that can increase profits.

Continuing with the capacity concept of farm size, size is seen to have a complex set of determinants. Drawing upon static and dynamic agricultural household models by Huffman (2000) and models of farm size by Kislev and Peterson (1982, 1996), farm size is determined by a household's human capital and land holdings, available agricultural technologies, relative input prices, the off-farm wage and commuting costs to off-farm work, output prices, and possibly the price of consumption goods and tastes. For a farm family to be full-time in farming and to earn an opportunity wage on their labor, the farm size must increase as the real off-farm wage increases. Farm households that are at a locational disadvantage relative to off-farm jobs can be expected to have different enterprise activities and a higher frequency of full-time farming than those that are located within commuting distance to a large urban labor market. Farm households that live within commuting distance of a large urban labor market may choose to reduce their farm size as the off-farm wage increases and to engage in part-time farming or full-time off-farm work. Hence, farm size is intimately related to off-farm work opportunities and other factors, including available technologies.

Public and private R&D have been the primary sources of new agricultural technologies. Public agricultural research has as its major focus enhancing or maintaining the biological efficiency of farm plants and animals (Huffman and Evenson, 1993; Fuglie et al., 1995). Some public research is in the basic and pre-technology sciences, e.g. biochemistry, plant and animal physiology, molecular biology, microbiology, genetics, entomology. Applied agricultural research in agronomy, animal and poultry science, horticulture is also undertaken in public research systems. The R&D activities of the private sector have been conditioned very much by expected profitability which is closely linked to the intellectual property right system. The private sector has found it profitable to focus its R&D efforts on agricultural chemicals; animal health/pharmaceuticals; and agricultural machinery, equipment, and housing (Huffman and Evenson, 1993; Fuglie et al., 1995; Fuglie et al., 1998). The private sector's role in developing new crop varieties and animal breeds has been very selective. Private development and marketing of hybrid corn varieties has a 70-year history (Huffman and Evenson, 1993), but commercial successes in other areas awaited recent strengthening of intellectual property rights, e.g. the Plant Variety Protection Act of 1970 and the favorable court decisions in the 1980s extending patent protection to biological discoveries (also see Office of Technology Assessment, 1992).

To frame the questions that we attempt to address, we develop four testable hypotheses. Each of these hypotheses is stated in negative form consistent with classical statistical practices. Although it is well accepted that R&D, extension, education, and commodity programs affect agricultural productivity, several related issues remain. Firstly, to what extent is productivity change channeled through structural change in agriculture (Griliches, 1963, 1992). To obtain large TFP growth, it may require that farms become larger and more specialized. If this is the case, policies followed in some countries to retard structural change, e.g. the European Economic Community, would slow TFP growth.

Hypothesis 1. Structural change in US agriculture is not a channel to TFP growth

Secondly, a debate continues about the effects of farm size on specialization and of specialization on farm size. Furthermore, differences in seasonal and spatial constraints on crop and livestock production and other factors may lead to substantial differences across subsectors.

Hypothesis 2. Increasing farm size has no effect on specialization

Thirdly, larger and more diversify farms have the potential to provide year-round full-time employment for farm operators, but larger size seems to be associated with greater specialization. With specialization, especially in crop production, labor use is seasonal and farmers tend to have an excess supply of hours during the 'off-season' which can be supplied to the nonfarm labor market. Hence, the effects of larger farm size and greater specialization seem to pull in opposite directions on farmers' off-farm work participation.

Hypothesis 3. Changes in farm size and specialization have no effect on off-farm work participation rates of farmers

Fourthly, a debate continues about the relative importance of public agricultural R&D and education policies, private R&D and market forces, and government farm commodity programs on the structure of US agriculture. Farmers have had to adjust to many changes and these changes are seen as having unusually costs by some groups, e.g. the anti-technology activists. These groups see US public agricultural R&D

policy as primarily causing the changing structure of agriculture. Others see technical and farm structure changes as being necessary for US agriculture to be integrated into the US economy and competitive in domestic and foreign markets. Thus, the relative magnitudes of economic forces for change are at issue.

Hypothesis 4. Public agricultural R&D and education policies have been unimportant relative to private R&D and market forces for changing the structure of agriculture.

Hypothesis 5. Farm commodity programs have had no effect on farm structure.

By testing these hypotheses within an econometric model, we hope to shed new light on the structural change debate. We, however, expect many other unanswered questions to remain.

4. Empirical evidence

To test these hypotheses, we specify a model, fit it to state aggregate data 1953–1982, and perform counter factual simulations of different historic scenarios.

4.1. The data, variables, and model

Although the methods used and data are not perfect and the evidence is not easy to interpret, we submit it in an attempt to elevate the quality of the farm structure and productivity debate. We build upon the Huffman and Evenson model and data for state total factor productivity (Huffman and Evenson, 1992) by including new variables for farm specialization, farm size, part-time farming, the farm wage relative to the nonfarm wage, price of machinery services relative to the farm wage, and price of fertilizer relative to the farm wage.

In the Huffman and Evenson model, state total factor productivity is expressed as a three equation model. The three equations are for a crop subsector, livestock subsector, and aggregate agricultural sector. In the current study, we focus on six endogenous variables: crop subsector total factor productivity (TFPC) and specialization (SPLZEC), livestock subsector total factor productivity (TFPL) and specialization (SPLZEL), overall farm size (SIZE), and odds of farmers' off-farm work participation [OF/(1−OF)]. See Table 1 for the exact definition of these variables.

The Huffman and Evenson data set (see Huffman and Evenson, 1993, pp. 122–124) 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 collectively for only a small share of total US farm production (about 2% in 1974), and this share has been declining over time. Farming in Alaska and Hawaii also face unusual geoclimatic conditions relative to farming in the other 48 states.

The Huffman and Evenson data set spans the years 1950–1982. Although agricultural productivity and structural change have continued after 1982 (e.g. see Office of Technology Assessment, 1992), the period 1950–1982 spans an unusual period from a historical perspective. During 1950–1970, US agriculture experienced very rapid technical and structural change, and the real agricultural output price decreased rapidly. The number of farms declined by 50% over this period (Gale, 1994), output per farm grew rapidly, farms became more specialized, and farms adopted significantly more powerful and versatile farm equipment (Binswanger, 1986; Gardner, 1992, p. 70) and larger quantities of agricultural chemicals (Fig. 2). Furthermore, the rapid increase in agricultural chemical usage continued through 1981. The remainder of the 1980s, however, was one of US agriculture adjusting to a financial crisis, associated with freeing interest rates in the late 1980s, and slower growth in world demand for US agricultural products which caused a new set of changes leading to a decline in aggregate inputs used in agriculture (Ahearn et al., 1998). We, however, believe that the period under analysis is an important one, and we will argue that we do not anticipate dramatic changes in the relationships over later years of the 20th century.[5]

[5] Furthermore, it would be quite costly to extend all of the series used in this study. The USDA (Ball et al., 1999) has been engaged in constructing a new set of state accounts for the agricultural sector 1960–1996, but these data do not contain crop and livestock subsectors, which have been impacted differently by technical change during the post-World War II period.

Table 1
Definition of variables

Symbol	Definition
Endogenous	
TFPC and TFPL	A 5-year moving average crop subsector (C) and livestock subsector (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 1949–1952 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, US Bureau of the Census (1952, 1956, 1961, 1964, 1967, 1972, 1977, 1980, 1984), and interpolated between census years; see Table 4). 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 1949–1952.
OF	The share of farm operators reporting any days of off-farm work (taken from US Bureau of the Census (1952, 1956, 1961, 1964, 1967, 1972, 1977, 1980, 1984) 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).
EXTCG and EXTLG	Public extension stock having a commodity focus in days per year, total time lag of 3 years (0.5, 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	Wage rate for hired farm labor (Huffman and Evenson, 1993b).
WAGEMG/P	Nominal wage rate for production workers in manufacturing divided by the cost of living index (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 rth geoclimatic regions, r=1,..., 16 (Huffman and Evenson, 1993b).

In this study, total factor productivity is expressed differently than in the earlier Huffman and Evenson paper in the sense that here we use a 5-year moving average of annual total factor 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 5-year averaging removes 'noise' from the productivity series.

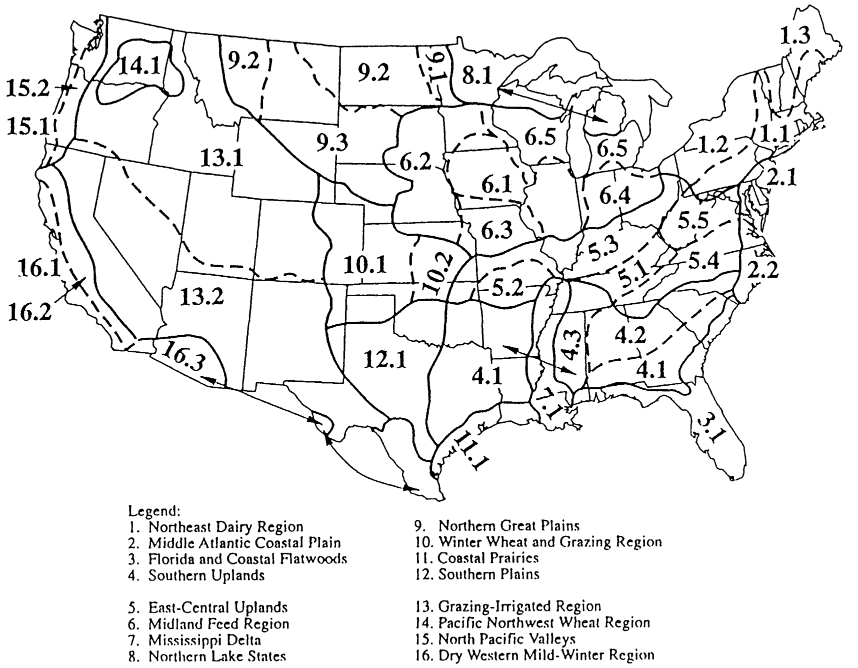
Special attention is given to the new variables and variables where ambiguity about definitions might arise. In defining specialization, we have chosen to maintain the crop-livestock subsector distinction. Each specialization index measures the extent to which specialized farms of a particular type produce particular crop (or livestock) products rather than farms that have a diverse or general farm output mix. Hence, they are indexes of farm level specialization, i.e. production of a particular commodity by its specialized farm type relative to total output of the commodity produced by all farms. For crop specialization, five agricultural census farm-types are distinguished and weighted in the index. They are cash grain farms, vegetable and melon farms, fruits and tree nut farms, cotton and tobacco farms, and other field crop farms. For livestock specialization, only three agricultural census farm-types are available for weighting. They are poultry farms, dairy farms, and other livestock farms. Specialization indexes created at agricultural census years are linearly interpolated between census years.

In other studies, farm size has taken a variety of definitions. They include output-based measures (e.g. Hanson et al., 1989) and 'capacity' measures, e.g. value of farm assets, acres operated, milk cows per farm, and full-time equivalent number of employees (Kislev and Peterson, 1982, 1996; Batte and Sonka, 1985; Reimund et al., 1987; Weersink and Tauer, 1991; Hallam, 1993). Each of these measures has its advantages and disadvantages. We employ a 'capacity' type measure of farm size, defined as an index of the average (real) value of annual capital services from cropland-equivalent farmland, farm machinery, and breeding stock. With this measure, an emphasis is placed on the fact that agricultural production requires input of capital services but does not require ownership of the associated capital assets. This measure of farm size differs from those based strictly on tillable acres of farmland, e.g. see Kislev and Peterson (1982, 1996) and Batte and Sonka (1985). Furthermore, our measure is not strictly natural resource-based because it includes services from reproducible capital in machinery and breeding stock.

Part-time farming is defined as the odds (in favor) of farm operators' off-farm work participation. Data from off-farm work participation are taken from US Bureau of the Census (1952), and values between census years are linearly interpolated. We express off-farm work participation as the odds, which gives it better statistical properties than the proportion participating.

Private agricultural research expenditures by state and year were constructed by Huffman and Evenson as follows. First, Huffman and Evenson worked from US private sector expenditures on agricultural research on (i) engineering and management, (ii) diseases of plants and animals, and (iii) insects, weed control and plant nutrition (see Huffman and Evenson, 1993, p. 119). Private agricultural research expenditures in categories (i) and (ii) were split into crop and livestock components using data on the share of private inventions by sector intended for use on livestock versus crop farms (Huffman and Evenson, 1993, p. 143). Crop sector private research expenditures then consist of R&D expenditures on crop related engineering and management, plant diseases, insects, weed control and nutrition. Livestock sector private research expenditures consist of R&D expenditures on livestock related engineering and management and diseases of animals. Second, these annual expenditures were then converted to constant prices (1984 dollars) using the Huffman and Evenson research price index (Huffman and Evenson, 1993, pp. 96) and then into a national stock of private R&D using trapezoidal timing weights, which were the same as for public agricultural research. Third, state private R&D stock variables were obtained by weighting the national private R&D stock variables by state input cost shares. A state's private crop R&D stock is obtained by weighting the national crop related engineering and management research stock by the state's farm crop production capital service cost share and the national plant disease, insects, weed control and plant nutrition research stock by the state's farm crop production fertilizer and other chemicals cost share. A state's private livestock R&D stock is obtained by weighting national livestock relatedly engineering and management research stock by the state's farm livestock production capital service cost share and the national livestock disease and insect related stock by the state's farm livestock production feed cost share (see Huffman and Evenson, 1993, p. 193).

The model of structure of agriculture and productivity is a six-equation structural econometric model having six endogenous variables and 38 exogenous variables including a time trend and 15 geoclimatic variables. The geoclimatic region variables are the share of a state's agricultural land that is classified in the *r*th geoclimatic region (see Fig. 4). The geoclimatic variables represent region-specific fixed effects



Source: Huffman and Evenson (1993, pp. 195).

Fig. 4. US agricultural geo-climate regions and subregions.

over the period of analysis relative to the 16th region which is excluded. Econometrically, these regional variables behave very much like qualitative dummy variables. They have been shown to affect TFP (e.g. see Huffman and Just, 1994) and are expected to affect structure of agriculture.

The two productivity equations have specifications similar to those in Huffman and Evenson (1992), except four variables for farm structure are added as possible channels to productivity change. These variables are crop and livestock sector specialization, farm size, and (odds of) farmers' off-farm work participation. We also include in the TFP equation the farm-nonfarm wage ratio as an indicator of equilibrium in farm and nonfarm labor market adjustments. The ratio has historically been significantly below one (Huffman, 1996), and an increase of the ratio is expected to signal tightening in labor market conditions, to encourage mechanization of agriculture, and to increase TFP.

In specifying the equations for SPLZEC, SPLZEL, SIZE, and OF/(1−OF), we present a model which permits SIZE and off-farm participation, [OF/(1−OF)], to affect the extent of crop and livestock specialization but cross-sector specialization effects are restricted to be zero. In the SIZE equation, both specialization variables and odds of farmers' off -farm work are permitted to have nonzero effects, and in the odds of off-farm work participation equation, both specialization variables and farm size are permitted to have nonzero effects. Weersink and Tauer (1991) found little evidence of productivity causing size of dairy herds, and our primary interest is in testing for structural effects on productivity. Hence, in our model, TFP is not permitted to have feedback effects on specialization, farm size or farmers' participation in off-farm work. We argue that farmers respond to the observed research, extension, and prices but not directly to productivity. The exogenous variables entering each of the farm structure equations include public research, extension, and farmers' schooling, private research, market forces (represented by the farm-to-nonfarm wage rate, price of machinery services relative to farm labor, price of fertilizer relative to farm labor), and government commodity program variables. Because our model is one of relationships among real variables, we represent the effects of the off-farm wage in real terms and the price of machinery services and price of fertilizer relative to the wage for hired farm labor. The two farm input price ratios represent signals to farmers that affect input substitution. Overall, these variables capture many of the effects suggested in related earlier studies of farm structure and farm labor adjustment. Interaction effects are excluded from the farm structure equations as a way of simplifying the model, given that no obvious justification exists for including them.

4.2. 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. Although our farm structure variables start in 1950, we lose some observations at the beginning of our series because of averaging TFP. The structural model is fitted to annual data 1953–1982 for 42 states. Estimated coefficients of the structural model are reported in Table 2. The model fits well in the sense of having a system R^2 of 0.70, and a large share of the estimated coefficients are significantly different from zero at the 5% level, including 15 of the 16 estimated coefficients of the included endogenous variables. We use this model for directly testing Hypotheses 1–3.

Hypothesis 1 is strongly rejected: Structural change, as represented in our model, is a channel to TFP change in both the crop and livestock subsectors. An increase in crop specialization increases significantly crop subsector TFP and an increase in livestock subsector specialization increases livestock subsector TFP. The effects on TFP of larger farm size or more extensive off-farm work participation by farmers differ between the crop and livestock subsectors, and the difference may be associated with the more severe constrains imposed by the seasonal and spatial nature of crop than livestock production. An increase in farm size, measured as capacity, reduces crop subsector productivity but increases livestock subsector productivity. In contrast, an increase in farmers' off-farm work participation reduces crop subsector productivity but increases livestock subsector productivity. Also, reducing the disequilibrium between farm and nonfarm labor markets, as reflected in a rise of the farm wage (relative to the nonfarm wage) has a positive impact on crop and livestock subsector productivity.

Hypothesis 2 is rejected. A larger farm size (capacity) increases crop subsector specialization but reduces livestock subsector specialization. Hence, during the period 1950–1982, larger farm size as measured in this study was not uniformly increasing specialization in agriculture. Also, an increase in farmers' off-farm work participation reduced crop subsector specialization but increased livestock subsector specialization. Hence, an increase in farm size (capacity) and off-farm work participation by farmers have mixed effects on tendencies for specialization. [6]

Hypothesis 3 is also rejected; farm size and specialization have significant effects on farmers' off-farm work participation rate. An increase in crop and livestock specialization, however, does not unilaterally change off-farm work participation rates of farmers. Added crop specialization reduces the odds of off-farm work participation but added livestock specialization increases it. The results are consistent with informal evidence reported by Huffman (1991, p. 86) An increase in average farm size (capacity), however, is associated with an increase in the odds of farmers' off-farm work participation.

Additional results include evidence that an increase in livestock specialization reduces farm size (capacity). This may reflect the fact that livestock production becomes less land intensive as it specializes and that livestock housing and equipment services are relatively small or scale economies in using housing and equipment. An increases in crop specialization, however, has a positive (but insignificant) effect on farm size. An increase in (the odds) off-farm work

[6] Also, we find that a decrease in the price of farm machinery relative to the wage for farm labor increases specialization in both subsectors. Willis Peterson has suggested to us that farm capital is less flexible than labor among farm enterprises. Therefore, as the capital-to-labor ratio increases due to the decline in the relative price of farm capital, farms will become more specialized. Alternatively, if farms were highly labor intensive, e.g. as in the distant past, it would not matter much what mix of crops or livestock was produced.

Table 2
Three stage least-squares estimate of six-equation model of agricultural structure and productivity: US state aggregates, 1953–1982 (n=1218)

Variables	Crop		Livestock		Overall average	
	ln TFPC	ln SPLZEC	ln TFPL	ln SPLZEL	ln SIZE	ln [OF/(1−OF)]
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]	
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 EXTCG	−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 × ln PRIVCG	−0.046[a]					
ln RESC × ln PRIVLG			0.047[a]			
ln RESC × ln EXTCG	0.099[a]					
ln RESL × ln EXTLG			−0.074[a]			
ln PRIVCG × ln EXTCG	−0.054[a]					
ln PRIVLG × ln EXTLG			0.058[a]			
SCH × ln EXTCG	−0.015					
SCH × ln EXTLG			0.018[c]			
ln (WAGEMG/P)	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]
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[a]	−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[c]	−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]The fitted effect of a state having land in geoclimate region 16 is included in the intercept; system weighted R^2=0.702.

Table 3
Implied reduced-form coefficients: model of US agricultural structure and productivity[a]

Variables	Crop		Livestock		Overall average		Sample mean
	ln TFPC	ln SPLZEC	ln TFPL	ln SPLZEL	ln SIZE	ln [OF/(1−OF)]	
Public R&D and education							
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 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
Private R&D and market forces							
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 (WAGEMG/P)	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	−0.467	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
Government commodity programs							
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 reported 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.

participation increases average farm size (capacity). This result suggests that off-farm income is used to finance the direct or indirect purchase of capital services or possibly to increase the capital service intensity of agricultural production. The conclusion from this part of the analysis is that changes in farm structure are a channel to TFP change, increases in farm size measured as capacity have different effects on crop and livestock subsector specialization, and increases in farm size and specialization affect the off-farm participation rate of farmers.

To test Hypotheses 4 and 5, we use the implied reduced-form coefficients derived from the model in Table 2 to conduct counter-factual simulations. The implied reduced-form coefficients are reported in Table 3. The exogenous variables are collected together in three groups: (a) public R&D and education, (b) private R&D and market forces, and (c) government commodity programs (see Table 3). For each year, we compute the sample mean value across the 42 states for each of the four farm structure variables (which are displayed in Fig. 5) and the exogenous variables. Armed with this information, we are prepared to conduct counter-factual experiments which will provide the evidence for Hypotheses 4 and 5.

Table 4
Mean values across 42 states of key variables, 1950 and 1982

Variables	1950	1982
Endogenous variables		
ln SPLZEC	−0.003	0.367
ln TFPL	−0.039	0.474
ln SPLZEL	−0.006	0.262
ln SIZE	0.000	0.561
ln [OF/(1−OF)]	−0.472	0.122
Exogenous variables		
Public R&D and education		
ln RESC	15.424	16.937
ln RESL	16.454	17.772
ln EXTCG	−2.340	−0.091
ln EXTLG	−2.215	−0.798
SCH	7.641	11.456
Private R&D and market fixes		
ln PRIVCG	6.956	9.119
ln PRIVLG	5.790	7.912
ln (WAGEMG/P)	−3.415	−2.941
ln WAGEF	−0.342	1.327
ln PMACH	−0.770	−0.826
ln PFERT	−1.004	−2.145
Government commodity program		
NPSUPPORT	0.213	0.276
NRSPMLK	0.087	0.112
NDVERSION	0.044	0.039

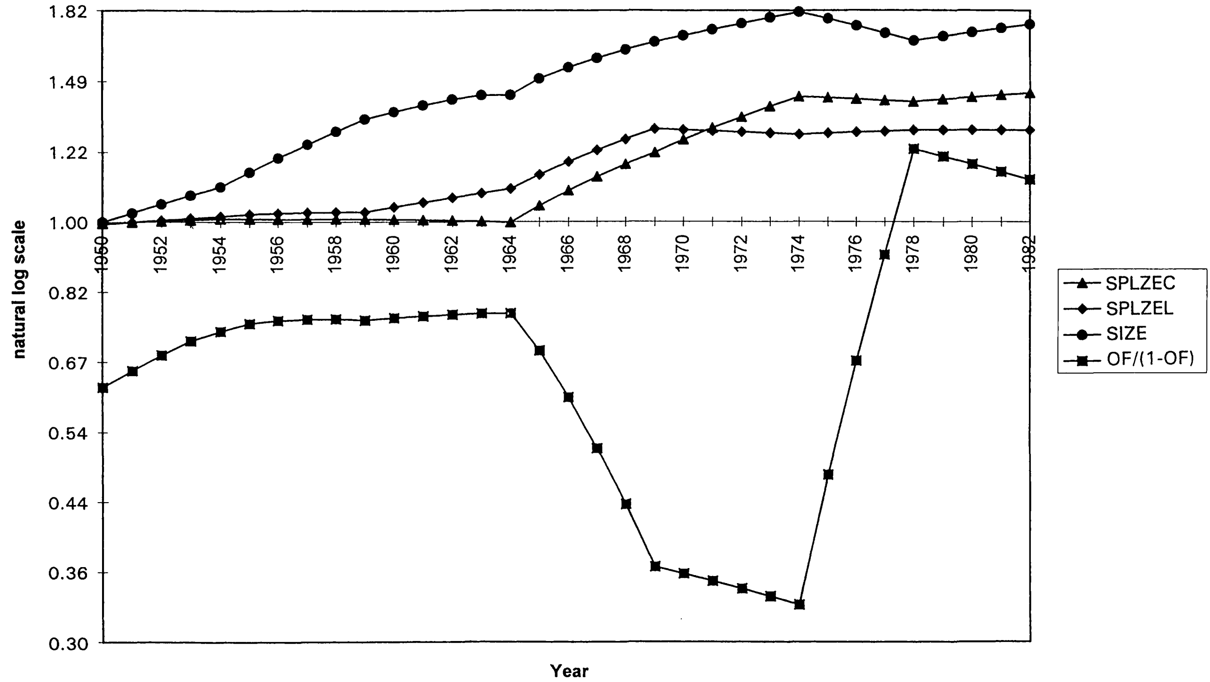


Fig. 5. Farm structure: indexes of crop specialization, livestock specialization, farm size, and operators' off-farm participation — mean of US states, 1950–1982.

These experiments are designed to show the change in path of the farm structure variables that would have occurred if (i) the public R&D and education variables had been unchanged at their 1950 values over the 1950–1982 period, (ii) private R&D and market forces had been unchanged at their 1950 values over the 1950–1982 period, or (iii) government commodity program variables had been unchanged at their 1950 values over the 1950–1982 period.[7]

To show the impact of these counter factual scenarios, we first compute the predicted value of each farm structure variable using the actual time series of mean values, 1950–1982, and from these predictions we subtract the predicted value of the structure variable obtained by setting a subset of the exogenous variables, groups (a), (b), or (c), at their 1950 values for the whole period while all other exogenous variables take on their actual value over the period. Figs. 6–9 display the impacts of the three counter factual scenarios (i), (ii), and (iii) on crop specialization, livestock specialization, farm size, and farmers' off-farm work participation, respectively.

The impact of private R&D and market forces (variable group (b)) on crop subsector specialization is much larger and more dramatic than for public R&D and education (variable group (a) and for government farm programs (variable group (c)). See Fig. 6. The impact of the actual path of private R&D and market forces relative to the 1950 values is to steadily increase crop subsector specialization, except for 1958, and the cumulative effect on crop specialization is large by 1982 (about 50%). In contrast, the impact on crop subsector specialization of the actual path of public R&D and education and of government farm program variables relative to their 1950 values is insignificant before 1973. After 1973, the relative impact of public R&D and education is to steadily increase crop sector specialization. However, the cumulative effects of public R&D and education by 1982 are small (about 10%) compared to the cumulative effects of private R&D and market forces. After 1978, changes in the farm

[7] See Table 4 for beginning and ending year values of key variables.

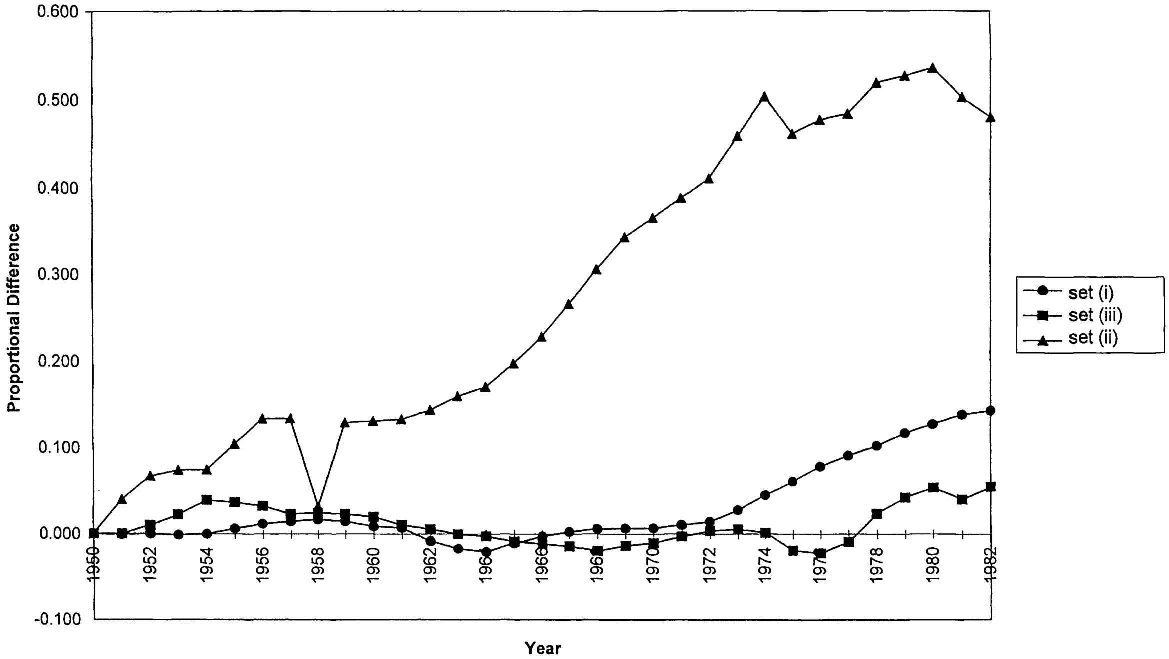


Fig. 6. Crop sector specialization: proportional difference due to actual vs. 1950 values of (i) public R&D and education, (ii) private R&D and market forces, and (iii) farm commodity programs, 1950–1982.

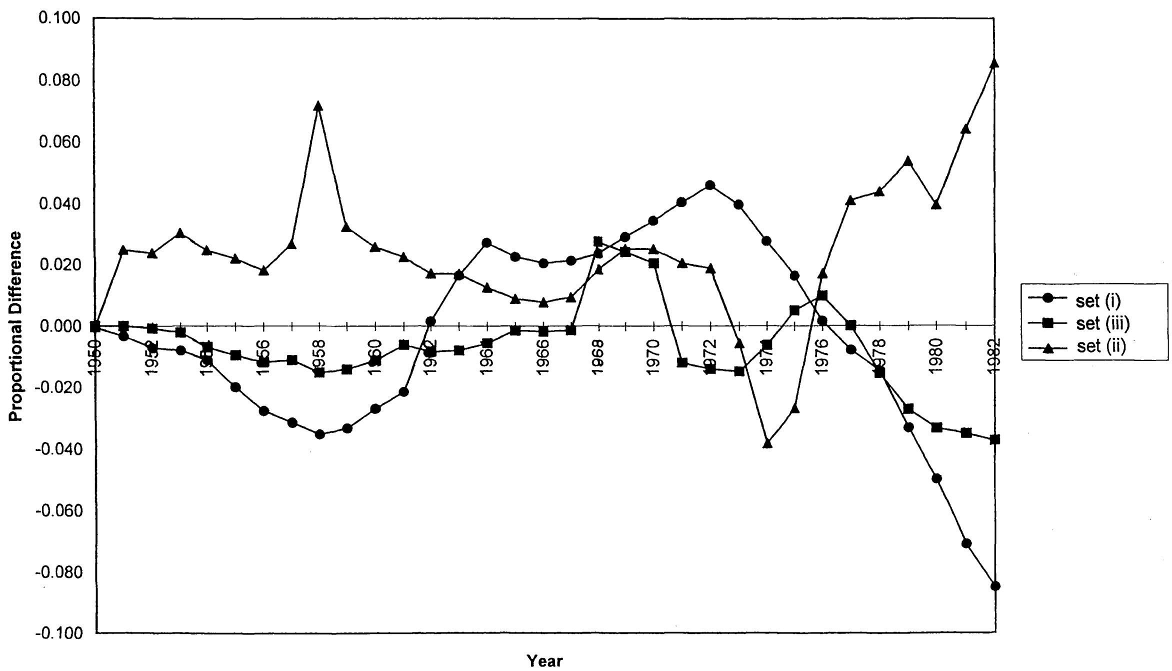


Fig. 7. Livestock sector specialization: proportional difference due to actual vs. 1950 values of (i) public R&D and education, (ii) private R&D and market forces, and (iii) farm commodity programs, 1950–1982.

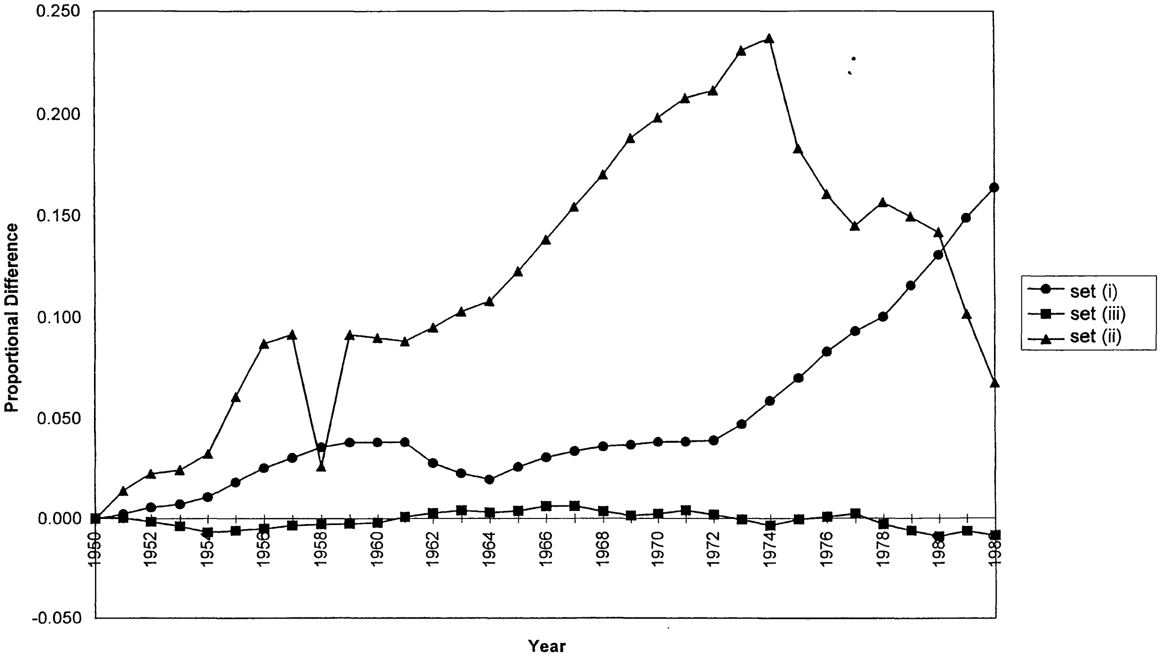


Fig. 8. Farm size: proportional difference due to actual vs. 1950 values of (i) public R&D and education, (ii) private R&D and market forces, and (iii) farm commodity programs, 1950–1982.

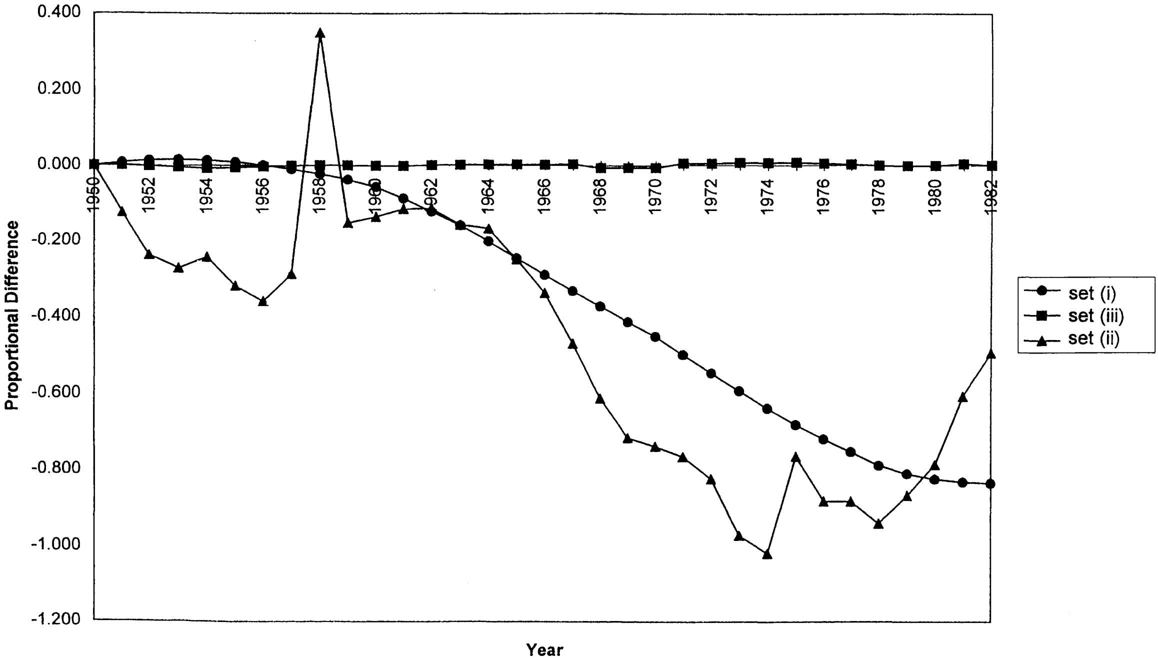


Fig. 9. Odds of farmers' off-farm work: proportional difference due to actual vs. 1950 values of (i) public R&D and education, (ii) private R&D and market forces, and (iii) farm commodity programs, 1950–1982.

program variables also reinforce tendencies for crop specialization, but their cumulative effects by 1982 are relatively small (about 4%).

The three counter-factual scenarios present a cloudy picture of impacts of variables groups (a), (b), and (c) on livestock subsector specialization (see Fig. 7). There is no sustained or dominant trend, and the relative impacts are generally small compared to crop subsector specialization. The impact of the actual path of public R&D and education relative to 1950 values is to decrease livestock subsector specialization over 1950–1958, to increase it over 1958–1972, and then to decrease it over 1972–1982. The cumulative effect of these differences by 1982 is a significant reduction in livestock subsector specialization (by about 8%). The impact of private R&D and market forces run almost counter to those of public R&D and education. The impact of the actual path of private R&D and market forces is to increase livestock subsector specialization over 1950–1958, to decrease it over 1958–1974, and then to increase it over 1974–1982. The cumulative effect of these differences in 1982 is a significant increase in livestock subsector specialization (by about 8%). The impact of the actual path of the government farm program variables relative to their 1950 values is to decrease slightly livestock subsector specialization over 1950–1958 and to slightly increase it over 1958–1967. Over 1967–1976, more dramatic changes occur but they are not sustained. After 1976, the relative impact of the government farm program variables is to decrease livestock sector specialization. The cumulative effect of these changes by 1982 is a reduction in livestock subsector specialization (by about 4%).

Two groups of variables, (a) and (b), have contributed to increased farm size (measured as capacity), and their effects arise from sustained trends over major lengths of time, but not necessarily the whole period (see Fig. 8). The impact of the actual path of public R&D and education relative to their 1950 values is to increase farm size slowly over 1950–1972, except for a slight reversal of tend over 1961–1964. After 1972, the impact of the actual path of public R&D and education is to steadily and more rapidly increase farm size. The cumulative effect on farm size by 1982 is a 17% increase. The impact of the actual path of private R&D and market forces relative to their 1950 values is to steadily and rapidly increase farm size over 1950–1974, except for 1958. The cumulative effect to 1958 is about 24%. However, in 1974 the trend is reversed, and the impact of the actual path of private R&D and market forces is to steadily decrease farm size to 1982 (by about 17%). Hence, the cumulative effect of private R&D and market forces over the whole period is to increase farm size measured by capacity by only 7%. The impact of the path of actual farm program variables relative to their 1950 values on farm size is without trend and insignificant over the study period.

Two sets of variables, groups (a) and (b), have a significant effect on farmers' off-farm work participation. The impact of the actual path of public R&D and education relative to the 1950 values is to increase slightly the odds of farmers participating in off-farm work from 1950 to 1954, but thereafter to steadily decrease it (see Fig. 9). The cumulative effect by 1982 is about an 80% reduction in the odds of off-farm work participation. The impact of the actual path of private R&D and market forces on the odds of off-farm work relative to their 1950 values is to decrease the odds of off-farm work participation from 1950 to 1956, to increase them over 1956–1958, to decrease them over 1958–1973, and then to increase the odds over the remainder of the period, except for a temporary reversal for 1974–1976. However, the cumulative effect of private R&D and market forces by 1982 is a 40% reduction in the odds of off-farm work participation relative to 1950. The impact of the path of actual farm program variables relative to their 1950 values on the odds of off-farm work participation is without trend and insignificant over the study period.

From the evidence presented in Figs. 6–9, we reject Hypothesis 4 for livestock specialization, farm size, and odds of farmers' off-farm work participation. Over the study period, the set of public R&D and education variables has been at least as important as the set of private R&D and market forces for changing these three dimensions of farm structure. However, neither set of forces was persistent or very large for livestock specialization. We accept Hypothesis 4 for crop specialization. Private R&D and market forces have been relatively more important than public R&D and education for increasing crop subsector specialization. We accept Hypothesis 5. Farm commodity programs have had relatively little impact on our four dimensions of farm structure over the study period.

5. Conclusions

In this paper, we have presented new evidence on structural change as a possible channel to TFP growth in US agriculture, on relationships among four dimensions of farm structure, and on the relative impact of public R&D and education, private R&D and market forces, and farm commodity programs on structural change. We formulated and tested five hypotheses about these relationships using state aggregate data 1950–1982. Although the study period was unusual for US agriculture by historical standards, the major forces for change continue very much the same through the 1990s.

Our conclusions are as follows. Structural change in US agriculture as represented in our model is a channel to TFP change in both the crop and livestock subsectors, i.e. specialization, size, and part-time farming do impact TFP, holding other variables constant. A larger farm size, measured as capacity, contributes to greater crop subsector specialization but less livestock subsector specialization. Specialization impacts farmers' off-farm work participation differently depending on where it occurs. An increase in crop subsector specialization reduces the odds of farmers' off-arm work but an increase in livestock subsector specialization increases it. Over the study period, public R&D and education have been at least as important as private R&D and market forces for changing livestock subsector specialization, farm size (measured as capacity), and farmers' off-farm work participation. However, we found that public R&D and education had been significantly less important than private R&D and market forces for increasing crop subsector specialization. Farm commodity programs had relatively little impact on farm structure over the study period.

Overall we conclude that if public R&D and education polices had been unchanged at their 1950 values for the period 1950–1982, major structural change in US agriculture would have occurred anyway. Other major forces were at work, e.g. private R&D and market forces. In particular, our finding that relative input price changes have contributed to farm structure change over 1950–1982 is supportive of the earlier result by Kislev and Peterson (1982). Furthermore, it seems unlikely that society would choose to change significantly the course of relative input prices, given that the wage is central to family incomes. Finally, the story of farm structural change is a relatively complex one with dominate forces varying, depending on the particular dimension(s) of farm structure than one focuses upon.

Although we acknowledge that our data and empirical model are imperfect, we believe that our empirical results will elevate the quality of the farm structure debate. Other important issues, however, remain to be examined. The period starting in the 1980s is one where new types of biological technologies developed by genetic engineering, new information technologies, and institutions for vertical co-ordination of production and marketing were being tested and adopted in US agriculture. We, however, expect the story to be roughly the same over this later period.

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