R&D, Productivity, and Structural Change in U.S. Agriculture, 1960-1996

by

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*Seniority of authorship is not assigned. The first two authors are economists, Economic Research Service, USDA, and the third author is C.F. Curtiss Distinguished Professor of Agriculture and Professor of Economics, Iowa State University. Huffman benefited from a long-term association with Zvi Griliches, which started in 1966 when he entered graduate school at The University of Chicago where Griliches was already Professor of Economics. Much of his research on the effects of education and public R&D on agriculture were stimulated by the early and later works by Griliches. The views expressed are of the authors and do not necessarily represent the policies or views of USDA.

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Abstract: *Our paper begins with a consideration of the causal relationships among productivity, farm structure, government farm payments and public investments in research and extension. We then empirically test key relationships for a relatively recent period (1960-96) in the history of agricultural structural adjustment using a simultaneous equations econometric model.*

Introduction

The industrialization and consolidation of the food system is proceeding at a rapid rate. This is especially evident, and of greatest social interest, in the agricultural production component of the food system. For example, agricultural production has become concentrated on a smaller share of farms. Between 1987 and 1997, the number of farms in the U.S. declined by 8 percent (from 2.1 to 1.9 million), and even more telling, the number of farms accounting for 50 percent of U.S. production declined by 39 percent (from 75,682 to 46,068) (USDC, 1989; USDA, 1999). At the same time, society benefits greatly from having a highly productive farm system because of the resulting low food prices. U.S. consumers currently spend only 11 percent of their disposable personal income on food, compared to 25 percent in 1930 (Putnam and Allshouse, table 99, 1999). This is the smallest share of income spent on food for any country (Putnam and Allshouse, table 101, 1999). Of course, U.S. taxpayers also pay for a myriad of single-purpose programs that are intended to impact the agricultural system.

The links between productivity and structure are both direct and indirect. In fact, the definition of the "farm problem" is closely tied to both productivity issues and structural change issues. The "farm problem" has traditionally been viewed as the social problems associated with agricultural productivity growth and the ability of farm households to earn an "adequate" return on their resources. Penn (1979, p. 3) describes the farm problem as:

> "…fundamentally derived from an excess of resources in the agricultural sector—more resources (land, labor, and capital) were engaged in agricultural production than could earn an adequate return for their services. The low prices from abundant production meant these resources received a lower return than they might have commanded elsewhere in the economy."

Gardner (1992) states:

> "For half a century U.S. agriculture has been seen as a paradigm of technical efficiency and productivity growth, and at the same time an economically depressed sector. The economic difficulties have been identified as 'the farm problem'."

While the definition of the "farm problem" may evolve over time and vary in the eyes of economists--and under some old definitions, the problem may even be solved[1]--new definitions will likely continue to draw on the links between productivity and structure.

The main prior econometric examination of the relationship among structure and productivity of U.S. agriculture is by Huffman and Evenson (2001). They used state level data, 1950-1982, and concluded that structural change is a channel to total factor productivity (TFP) growth in both the crop and livestock subsectors, and public agricultural research and education have been at least as important as private R&D and market forces for changing livestock specialization, farm size, and formers' off-farm work participation. Changes in farm commodity programs were shown to have little impact on farm structure. They also provide some counter-factual simulation results showing that major structural change in U.S. agriculture would have

[1] The farm problem defined strictly as low household income of farm compared to nonfarm households, is known to be obsolete, i.e. solved (Ahearn, 1986).

occurred without changes in public R&D and education policies because of private R&D and market forces.

Our current research is very much in the spirit of searching for multiple sources of productivity change as emphasized by Griliches (2000). The objective of this paper is to use new data for a more recent time period to examine (1) the relationship between productivity and the structure of U.S. agriculture and (2) the role of public policies in affecting productivity and structure. First, we review some trends in U.S. agriculture. The second section presents a selective review of the models of productivity and structure in agriculture. The model of productivity and structural change and the data are presented in section three. The next section contains a discussion of the econometric results and the final section contains conclusions and implications.

Trends in the Farm Sector

A brief summary of major trends in the productivity and organization of U.S. agriculture are presented for the post-War period.

Total Factor Productivity. Over the past century, productivity has been the major force behind the changes in U.S. agricultural output. Between 1948 and 1994, the rate of growth in total factor productivity in agriculture was 1.94 on an annual average basis (Ahearn, Yee, Ball, and Nehring, 1998). Using 1948 as the base year (i.e., 1948 =100), the 1994 index of agricultural output was 237, compared to the index of all farm inputs of 97 (Figure 1). That is, measured aggregate inputs actually declined during that period while output more than doubled.

Factor Proportions. The labor input for U.S. agriculture declined dramatically and steadily over 1948 to 1985, and then declined very slowly to 1996. Capital-service input rose to the early 1980s and then declined at a steady rate. Hence, over 1948 to 1980, the capital-to-labor ratio was rising very rapidly, about 3 percent per year (Huffman 1998, 2002). But over 1980 to 1996, the capital-to-labor ratio actually declined at a rate of about 1 percent per year. Likewise the intermediate input-to-labor ratio rose by more than 3.5 percent per year over 1948 to 1980, but thereafter it rose very slowly. Also, over 1960 to 1996, hired and contract labor, which has the least human capital, became a larger share of total farm labor input (Huffman 2002). This change was, however, not uniform across the country. The largest changes in the composition of the workforce were in the fruit, vegetable, and horticultural crop growing states, e.g., California, Florida, Arizona, Washington.

Consolidation. Because the aggregate amount of agricultural land has been relatively fixed during the 20th century, the change in the number of farms is closely correlated with the change in the size of farms. Figure 2 shows the change in the number of farms and average acres operated per farm over time. However, the rising average acres operated per farm over time masks the growth in the share due to small farms. Most of today's farms are small farms by some definition (USDA, 1998), and many are classified as retirement and lifestyle farms (Hoppe, 2001). After 1978, the total number of farms has remained approximately 2 million, declining only slightly in the 4 agricultural censuses 1978 to 1998. The number of large farms (>1,000 acres) and smallest farms (<50 acres) has increased, but the number of mid-sized farms has declined. However, the size distribution and the trends in size class vary considerably by state.

Part-Time Farming. Most farm families (70% in 1999) have at least one family member working in a non-farm occupation and in about half of those families both the operator and spouse work off the farm. Operators, who are primarily male, are more likely than spouses to work off the farm. Over all only 10 percent of total farm household income is from farm sources. Off-farm income has played a major role in closing the income gap between farm and non-farm households and in reducing income inequality among farm operator households (Ahearn, Strickland, and Johnson, 1985). The most recent Census of Agriculture reports that off-farm income of farm households increased 300 percent between 1988 and 1998 (USDA, 2001a).

Review of the Literature

A selective review of the literature on models of productivity and structure of agriculture are presented.

Productivity Measurement. A large literature exists on measurement of productivity, both in general economics and agricultural economics. The agricultural economics literature started with Barton et al. (1947) and continued with Griliches (1960), Diewert (1976), AAEA Taskforce (1980), Jorgenson et al. (1987), Capalbo and Antle (1988), Craig and Pardey (1990), Jorgenson and Stiroh (2000), and Ball and Norton (2002). In particular, Jorgenson, Ho, and Stiroh (2002) show that U.S. agriculture accounts for 21% of all U.S. growth in productivity over 1958-1999 (but only 1.3 percent of gross domestic product), and it ranks in the top 4 of 37 sectors in average productivity growth over this period.

A general focus of the productivity measurement research, at least after Griliches (1960), has been to incorporate quality change in inputs. The USDA estimates of productivity, as well as others (e.g., Craig and Pardey (1990)), have adjusted the labor input for changing demographics, such as educational attainment of the farm labor force, fertilizer and agricultural chemicals for effective ingredients, land for irrigation, and tractors for horsepower.

Determinants of Productivity Growth. A smaller but significant literature exists on explaining the trends in farm total factor productivity. Most of the literature focuses on the importance of investments in public and private research and development and public extension (Griliches (1963), Huffman and Evenson (1993), Alston, Craig, and Pardey (1998), and Yee, et al. (2002), Griliches (2000)).

The Huffman and Evenson data set covered the period 1950-1982 for 42 U.S. states. They used public and private research stocks and agricultural extension stocks to explain TFP. Although the impacts of public agricultural research were generally positive on agricultural productivity, applied livestock research had a negative impact on livestock sector productivity.

Alston, Craig, and Pardey (1998) constructed another state level productivity data set for 48 states, 1949-1991, and they have examined the impacts of a single combined public agricultural research and extension variable on TFP. They used essentially all of the public agricultural research expenditures of state agricultural experiment stations to construct the research and extension stock variable, irrespective of whether the research was focused on production agriculture. Interstate spillovers have generally been excluded. They have found positive effects of the combined public agricultural research and extension variable on agricultural productivity.

Using data for 1960-1993, Yee, et al. (2002) explained agricultural productivity growth at the state level with R&D, R&D spillovers, extension, transportation infrastructure, and weather variables. Where their results overlapped with prior studies, the results were largely as expected. Public agricultural research and highways had positive impacts on agricultural productivity, and the marginal real social rate of return to public agricultural research was large. The results for public agricultural extension were mixed, but this was consistent with Huffman and Evenson (1993). Spill-in research stocks were found to impact agricultural productivity positively in all regions, and the computed real rate of return to investments in public agricultural research to any one state was less than the social rate of return to all states in its region.

Some recent work has explored convergence in TFP growth rates across states. McCunn and Huffman (2000) showed that a type of conditional convergence in TFP growth exists by region over 1948-1982, but they reject unconditional convergence. Ball, et al. (2000) apply an ad hoc convergence test over 1960 to 1996 using the new USDA TFP series and found some evidence of narrowing in the range of TFP growth over 1960-87 followed by an increase over 1987 to 1996 period.

Farm Structural Change. In contrast to the productivity measurement literature, which is solidly rooted in production theory, the literature on the changing farm structure, while very large, lacks a consensus and clear direction. The large literature on structural change in agriculture results from a continual interest to policy makers, producers, and society in general. The USDA has a compilation of reports on agricultural structure change, including USDA, 1979; Lin, Coffman, and Penn 1980; USDA 1981; USDA 1998; USDA 2001b; and annual Family Farm Reports focused on structure issues, such as the recent paper by Hoppe (2001). Other significant volumes include reports by the U.S. Senate (1980), Office of Technology Assessment (1986) and the more technical treatment of structure issues in Hallam (1993). The motivation for this enduring interest includes issues associated with social sentiments regarding family farms and more recently recognition of the amenities of farm landscapes usually associated with family farms (OECD).

Several useful review articles address the diversity and conflict among competing conceptual models (e.g., Harrington and Reinsel 1995). Cochrane's technology treadmill is perhaps the most widely recognized hypothesis on structural change forces (Cochrane 1958).

Cochrane's hypothesis focuses on the impact of technological innovation reducing real per unit cost of output at the farm level and with competition encouraging farmers to adopt new technologies. As adoption becomes widespread, prices of farm commodities fall differentially as adoption becomes widespread, prices of farm commodities fall differentially across the country and possibly by size of farm, triggering structural adjustments. Technology adoption certainly plays a prominent role in the structural change process, but many factors are believed to play important roles in this process. Other schools, including asset fixity, economies of size, and political economy, also make contributions to understanding the structural change process in U.S. agriculture.

Off-Farm Work. A related extension of the basic labor-leisure model is found in the productive household literature (e.g., Becker 1965, Gronau 1977) and agricultural household models, e.g., see Strauss (1986), Huffman (2002). The conceptual model combines the decisions of agricultural households relating to production, consumption, and labor supply into a theoretically consistent model. The individual is assumed to allocate time to farm work, off-farm work, and leisure in such a fashion that the optimal allocation is achieved when the marginal values of time devoted to the activities are equal. Because of the dependence of farm households on off-farm income sources and the fixed supply of household labor, an important component of this literature is the empirical literature on estimating off-farm labor participation and supply. Huffman (1980) was the first in the literature to estimate off-farm labor supply/participation models for farm households using aggregate county data. Extensions in this literature include Sumner (1982), Lopez (1984), Jensen and Salant (1986), Huffman and Lange (1989), Lass, Findeis, and Hallberg (1989), Tokle and Huffman (1989), Lass and Gempesaw (1992), El-Osta and Ahearn (1996), Findeis (1992), Huffman and El-Osta (1997) and Mishra and Goodwin (1997).

The Model

We choose to focus on farm size and part-time farming as our two key structural variables. Recall that with total land in farms approximately fixed, the number of farms varies inversely with the average acres per farm. The model we employ is multiple equation with feedback across the equations where productivity, farm size (measured as a constructed land rent per farm) and the odds that farm operators works off-farm (at least 200 days per year) are explicitly treated as endogenous variables. The set of exogenous variables include public agricultural research stocks (from originating state and spillins); public extension; infrastructure in highways; indicators for specialization, contracting, and government programs (payments and set asides); capital rental-to-hired farm wage, manufacturing wage relative to the hired farm wage, share of college educated farm operators; indicators for dairy and weather; and geographic region.

Two public research stock variables are used in this paper, an originating state and a spillin/spillover. See Appendix A for more details, including a discussion of Griliches' impact on our choice of timing weights. For example, some of the public agricultural research discoveries in Iowa may spillover to one or more of the surrounding states or Iowa may benefit from public agricultural research conducted in surrounding states. We impose the simplifying assumption that public agricultural research benefits are regionally confined. For a given state in a region, the spillover (or spillin) stock is defined as the total public agricultural research stock of all states in the region less the state's own public agricultural research stock.

The states are grouped together into regions using regional boundaries defined by McCunn and Huffman (2000) and Khanna, Huffman, and Sandler (1994). The choice of regional boundaries is always somewhat subjective, but the McCunn and Huffman study found their 7 regional boundaries to be adequate for a study of convergence in state agricultural TFP growth rates and Khanna, Huffman, and Sandler (1994) found them adequate for a study of state government decisions on funding state agricultural experiment stations.[2] See Table 1 for a list of all the variables and Appendix A for more details about the data.

Government Investments and Interventions in Agriculture. Government involvement in the agricultural sector is pervasive and significant. Some government policies are designed to impact agriculture, and other government policies that impact agriculture, are likely not designed to do so, e.g., macroeconomic policies. In that case, the impact is a secondary impact. Of course, it is extremely difficult and, perhaps, foolish to identify the intended impacts of many government policies on agriculture, given the nature of our system of government. Rausser (1992) classifies agricultural policies into two groups: those that correct for market failures, lower transaction costs, or enhance productivity, and other policies that result from manipulation by special interest groups. Generally, the intended impacts of government agricultural policies are not to alter the structure of agriculture, likely because a consensus on the ideal structure does

[2] Several regional groupings of states were considered in our work. The oldest grouping consists of the 10 Economic Research Service (ERS) farm production regions (Northeast, Lake States, Corn Belt, Northern Plains, Appalachian, Southeast, Delta, Southern Plains, Mountain, and Pacific). A National Research Council (NRC) study on colleges of agriculture at the land grant universities (Committee on the Future of the Colleges of Agriculture in the Land Grant University System, 1995) included a cluster analysis to classify state agricultural experiment stations (SAES's) expenditures into 9 commodity research clusters. See Figure 7.4 in the NRC report for the grouping of states by research cluster. The NRC regions differ from the ERS and Huffman and McCunn's (HM) regions in not having non-contiguous states in clusters. For example, California, Oregon, and Washington are in the same ERS region (Pacific), while California and Florida are in the same NRC region. The ERS and HM grouping are more similar to each other than to the NRC grouping. In fact, the Pacific, Mountain, Northern Plains, and Northeast regions are the same for both the ERS and HM groupings. In addition, HM Central = ERS Corn Belt + ERS Lake States, HM Southern Plains = ERS Southern Plains + ERS Delta, and HM Southeast = ERS Southeast + ERS Appalachian.

not exist and because of our recognition of the efficiency of the marketplace for allocating resources.[3] Exceptions to this would be programs such as the Limited Resource Farmer program, Farm Service Agency's "lender of last resort" programs, and certain aspects of the tax code. In addition, payment limitations on receipt of direct payments could also be considered an explicit policy designed to minimize the impacts of policies on agricultural structure. Regardless of the primary intent of government intervention, one hypothesis is that significant impacts on structure and productivity occur. The major government policies affecting productivity and/or structure include: public research and extension, investments in highway infrastructure, and commodity and conservation programs.

Research and Extension. Research and extension are undertaken by both the public and private sectors. The output of agricultural research includes higher yielding crop varieties, better livestock breeding practices, more effective fertilizers and pesticides, and better farm management practices. Also, a significant share of agricultural research expenditures is devoted to so-called maintenance research (Huffman and Evenson 1993, pp. 114). Public agricultural research is performed in state agricultural experiment stations, land grant and other universities, and the USDA's Agricultural Research Service, Forest Service, and Economic Research Service. Various aspects of the system have been thoroughly studied by several authors (e.g., Huffman and Evenson (1993), Alston, Norton, and Pardey (1995); National Research Council (1995); Fuglie et al (1996).

Agricultural research is also performed by the private sector, mainly in the areas of farm machinery, agri-chemicals and pharmaceuticals, plant breeding and food processing. Private research expenditures have increased dramatically during the past three decades and now surpass

[3] All modern farm bills make reference to the importance of preserving the family farm, but an operational definition of that group is not communicated and a transparent plan for accomplishing that goal is not contained in the Act.

that of the public sector (Fuglie et al. 1996; Fuglie 2000.)[4] The impacts of agricultural research and extension are expected to show up in TFP.

The justification for public investment in agricultural research is that it produces discoveries that are public goods. Some are local public goods and others are regional or national public goods. With these discoveries having public good attributes, private provision would be quite inefficient (Huffman and Just 1999). Some information for farmers have public good attributes, too. Empirical evidence provided by Evenson (2002) shows that the real social rate of return to public investments in U.S. agricultural research has been high. For U.S. agriculture, the real rate of return is high--somewhere between 20 percent and 60 percent.

Limited research exists on the effects of public research and extension on farm structure. A classical article is the one by Schmitz and Seckler (1970) on the adoption of the tomato harvester. In the past, the implications of an agricultural research agenda were not considered among planning priorities, but today a significant interest in recognizing structural implications of research priority setting exists. For example, ARS conducted a program evaluation to determine that two-thirds of its programs at the time of the review had potential to contribute to the competitiveness of small farms (USDA, 2000). The USDA has asked the National Research Council to review the relationship between publicly funded research and the evolving structure of agriculture (National Research Council, 2001).

The role of agricultural extension is to extend useful information to farmers and other constituents at a level that can be useful in application and problem-solving. Extension agents disseminate information on crops, livestock, and management practices to farmers and demonstrate new techniques as well as consult directly with farmers on specific production and

[4] Unfortunately, we do not consider the role of private R&D in our empirical model in this paper. It is on the future agenda.

management problems. In particular, supplying farmers with good information on new technologies can speed the adoption process, which generally increases the rate of return on research expenditures. Unlike research where impacts are distributed over a considerable period of time, e.g, 20-35 years, agricultural extension input can be expected to have an almost immediate impact on agricultural productivity.

The bulk of public extension funding now comes from state and county governments rather than the federal government (Ahearn, Yee, and Bottum, 2002). Furthermore, the private sector is increasing involvement in extension activities. For example, private crop consultants offer advice on pest and nutrient management for a fee. The empirical evidence on the social rate of return to public agricultural extension shows a greater variation and, in general, lower levels than for research (Fuglie, et al, 1996; Evenson 2002).

Infrastructure. The transportation of agricultural inputs and outputs in modern agriculture requires good infrastructure, especially roads and communications. Aschauer (1989) argued declining public capital stocks were a drag on productivity in the nonfarm sector during the 1970s. Since that time, several studies have investigated the impact of public infrastructure (highways and streets, water and sewer systems, schools, hospitals, conservation structures, mass transit, etc.) on productivity outside of agriculture. For the nonfarm sector, the empirical evidence is that public infrastructure has a positive and statistically significant impact on output and productivity. This finding is even more impressive given that much public infrastructure spending goes for improving the environment and other objectives that are not captured in output or productivity (as conventionally measured). This finding also implies that the rate of return to public infrastructure investment may be under-estimated because of the neglect of environmental and other benefits.

Few studies, however, have examined the effects of public infrastructure on agricultural productivity in the United States. For a cross-section of 66 countries, Antle (1983) did find a positive contribution of transportation and communication infrastructure on agricultural productivity. More recently for the United States, Gopinath and Roe (1997) at the national level and Yee, et al. (2002) at the state level found a significant positive impact of highway infrastructure on productivity. Transportation infrastructure, as a provider of access to the local labor market, is also important in explaining off-farm labor supply of farm households.

Commodity Programs. Legislation in the 1970s established a two-tier price system with target prices and commodity loan rates (Rasmussen 1980). The literature is mixed on how government commodity programs have affected farm structure. This is in spite of the fact that it has been widely studied. Tweeten (1993) provides a literature review, describes the conflicting results, and an analysis of how payments have affected farm numbers from 1950-1987. He concludes that government payments modestly increase farm numbers in the short run and slightly decrease farm numbers in the long run. Empirical measurement of the program impacts can be captured by the dollar value of the subsidies transferred to participants and by the acres of land that a participant was required to set aside in order to be eligible for payments. The set-aside requirement was a policy decision that varied by year, depending largely on world stocks of commodities. However, Huffman and Evenson (2001) found small government farm programs effects on farm structure and productivity over 1950 to 1982.

Conservation Programs. A variety of conservation programs have been established during our study period. The largest program during the period is the Conservation Reserve Program, established in 1985. "Small farms," defined as those with less than $250,000 in sales, currently receive more than 80 percent of government conservation payments. Other programs provide technical assistance for conservation, such as those delivered by the Natural Resource and Conservation Service, formerly the Soil Conservation Service, but measures of those activities are not included in our model.

Structural Dimensions. Although other structural indicators are related to farm size and off-farm labor supply, we include specialization, or the lack of diversification, as a separate regressor. The dairy enterprise is a specialization that requires a high intensity of labor, which has significant impacts on how a farm family organizes its resources, including labor supply to off-farm employment activities.

Vertical coordination for the whole of the agricultural sector is especially difficult to quantify at any point in time, let alone over several decades. It involves linkages among multiple industries, upstream and downstream, that may be changing over time. An exception is production contracting where historical statistics from the various Censuses of Agriculture document an increasing trend. We also include a unique set of dynamic structural variables that have been developed from a panel data set constructed from five Censuses of Agriculture: 1978, 1982, 1987, 1992, and 1997. These variables are the share of farms which exit during a period, the share of new entrants during a period, and the share of farms that have increased their acres operated by at least double (Korb 2002).

Before Kislev and Peterson (1982) most explanations of changes in farm size 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 U.S. farm size over 1930 to 1970 could be explained by changes in the farm wage relative to rental rate on machines services. As the farm and non-farm sectors became more integrated over time, these prices were determined in the broad economy.

In addition, Huffman and Evenson (1989) have shown that public agricultural research has been labor saving in the cash grain subsector. Other effects include regional fixed effects and weather.

We formalize our expectations about relationships in the model into nine hypotheses dealing with government policies, market forces, and selected other issues. The hypotheses associated with public policy are:

Hypothesis I: An increase in public agricultural research (both originating state and spillins) has no effect on agricultural productivity or farm size; with the alternative being positive effects;

Hypothesis II: An increase in public agricultural extension has no effect on agricultural productivity or farm size; with the alternative being positive effects;

Hypothesis III: An increase in federal highway capital has no effect on agricultural productivity or odds of off-farm work; with the alternative being positive effects;

Hypothesis IV: An increase in farm commodity program payments has no effect on agricultural productivity, farm size or odds of off-farm work; with the alternative being positive effects on productivity and farm size and a negative effect on the odds of off-farm work.

The hypotheses associated with market forces are:

Hypothesis V: An increase in the farm machinery rental relative to the farm wage has no effect on agricultural productivity or farm size; with the alternative being reduced productivity and size;

Hypothesis VI: An increase in the manufacturing wage relative to the farm wage has no effect on the odds of off-farm work of farmers; with the alternative being a positive effect on the odds of off-farm work.

Other hypotheses are:

Hypothesis VII: An increase in agricultural productivity has no effect on farm size; with the alternative being a positive effect;

Hypothesis VIII: An increase in farm size has no effect on agricultural productivity or odds of off-farm work by farmers; with the alternative being positive for productivity and negative for odds of off-farm work;

Hypothesis IX: An increase in off-farm work has no effect on agricultural productivity and farm size; with the alternative being negative effects.

Estimating the Model and the Econometric Results

The model contains multiple equation with feedback where productivity, farm size (measured as a constructed land rent per farm) and the odds that farm operators works off-farm (at least 200 days per year) are explicitly treated as endogenous variables. We make some strong but not implausible assumptions to achieve identification. See Table 2. We estimate the model by three-stage-least squares, incorporating cross-equation correlation of disturbances but ignoring autocorrelation. The observations are the panel of 48 states over 1960 to 1996

The estimated coefficients for the structural model are reported in Table 2. They show surprisingly good performance. A large share of the estimated coefficients is significantly different from zero and the share of the variation explained is good, 62 percent for the TFP equation, 71 percent for the size equation and 63 percent for the off-farm participation equation.

Turning to public policy effects, we reject Hypothesis I. An increase in public agricultural research in the originating state and spillins from other states increase agricultural productivity and farm size, and the effects are statistically positive at the 5 percent level. These results support those obtained by Huffman and Evenson (1993) for crop R&D. Hypothesis II is rejected for agricultural productivity but not for farm size. An increase in public agricultural extension increases significantly agricultural productivity, but it has a negative effect on farm size.

Hypothesis III is rejected. An increase in highway infrastructure has a significantly positive effect on agricultural productivity and odds of farmers' off-farm work. Hence, this is some of the strongest econometric evidence to date of the positive benefits to U.S. agriculture from infrastructure in highways.[5] Hypothesis IV is rejected for two of its three parts. An increase in government commodity program payments increases agricultural productivity and farm size, but has no significant effect on the odds of farmers working off farm. This finding is consistent with Cochrane's "cannibalism" tendency of payment recipients to out-bid farmers not receiving payments for farmland (Cochrane 1958). Also, the set-aside acres of land that was diverted from production as a requirement of commodity program participation have a significant and negative impact on productivity. No direct payments are made under the dairy program, and the price of milk is maintained artificially high by the government price support program through purchased manufactured dairy products. Having significant dairy production is shown to reduce agricultural productivity. Thus, these commodity program payments are not neutral with respect to on-farm effects. It seems that the income from these payments may be being reinvested in ways that will enhance both farm size and productivity. In conclusion, our econometric evidence is that federal government policies have economically and statistically important effects on agricultural productivity and farm structure.

Hypothesis V is rejected. A decrease in the machinery rental to wage for hired farm labor increases agricultural productivity and farm size. This suggests that there has been a labor saving bias to new technology and it has stimulated or facilitated larger farm size. The result also shows the importance of agriculture's ties to the rest of the economy as machinery are made in the nonfarm sector and labor moves between the farm and nonfarm sectors.

Hypothesis VI is also rejected. An increase in the manufacturing wage relative to the wage for hired farm labor increases the odds of off-farm work of farmers. The manufacturing wage is an opportunity wage for farmers in most of the United States. Although farmers could choose to close their farm business, many have chosen to continue in farming by operating a

[5] Also, a higher level of education expands the opportunities for off-farm work.

small farm and engage in off-farm work. This tendency is strongest where manufacturing wage rates are highest relative to the wage for hired farm labor. Overall, we conclude that agricultural productivity, farm size, and off-farm work of farmers have been responsive to market forces. These conclusions support the conclusions of Huffman and Evenson (2001).

Hypothesis VII is rejected; an increase in agricultural productivity increases farm size. Hypothesis VIII is also rejected. However, we find that an increase in farm size reduces, rather than increases, agricultural productivity. This suggests that on average a type of diseconomies of size is operating in our day and time period. But, Huffman and Evenson (2001) also found that farm size reduced crop TFP.[6] Larger farm size does, however, reduce the odds of off-farm work. Farm size and off-farm work are a type of substitute. Hypothesis IX is rejected. An increase in off-farm work of farmers reduces productivity and farm size. With off-farm work, a farmer's time and effort are diverted to non-farm activities and this can change the timeliness of farming activities in ways that reduce agricultural productivity, e.g., see Wozniak 1993. Off-farm work is a substitute for farm size.

Conclusion and Implications

We found positive and significant impacts of government policies (investments in public research, extension, and highways and commodity programs) on productivity growth. We also found evidence that government intervention, including direct payments for commodity programs, affect dimensions of structure. And, we found evidence of a simultaneous relationship

[6] For example, several small farm states, like Connecticut, were among the highest 10 states in terms of TFP in 1996, while Texas, Oklahoma, Montana, and Wyoming were among the lowest 6 states in terms of productivity levels in 1996. We are also concerned that there is some nonagricultural upward bias in the agricultural rents of states dominated by small farms, in particular, that there are some urbanizing influences in their rent measures.

between productivity and measures of farm structure. Knowledge of the significance and direction of these relationships is timely as there are new indications that agricultural research institutions are concerning themselves with the implications of research outcomes on agricultural structure (NRC, 2001; USDA, 2000). The negative effect of government payments on off-farm labor supply that has been found in previous studies was confirmed in our results. In light of the continuing large agricultural subsidies, this study indicates that off-farm employment is likely less than it would be in the absence of programs. The majority of farm operators already work off the farm, and most of those work at least 200 days each year.

More work remains to be done on this project. With the help of Robert Evenson and Daniel Johnson, we have obtained agricultural patent data by state which we are using to create private agricultural R&D stock variables. Also, we will compute rates of return to public investments in agricultural research, extension and highways.

Finally, there are a group of factors that have taken hold since the end of our study period. The U.S. economy has experienced a very large growth since the end of this study period, and there is still a divergence of views about the sources of that growth, but information technology is viewed as one of the keys. Information technology advancements have been adopted by some farm operators. The adoption of GM seeds has proceeded more rapidly than most agricultural technologies, although it has been slowed by consumer acceptance concerns. In addition, the post 1995 period has seen a major change in the mechanisms for transferring income to the farm sector. It will be interesting to extend this analysis to determine how these changes have affected agricultural TFP and structure during this very recent period.

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Figure 1. Trends in Inputs, Output, and TFP for US Agriculture, 1948-96 (1948=100)

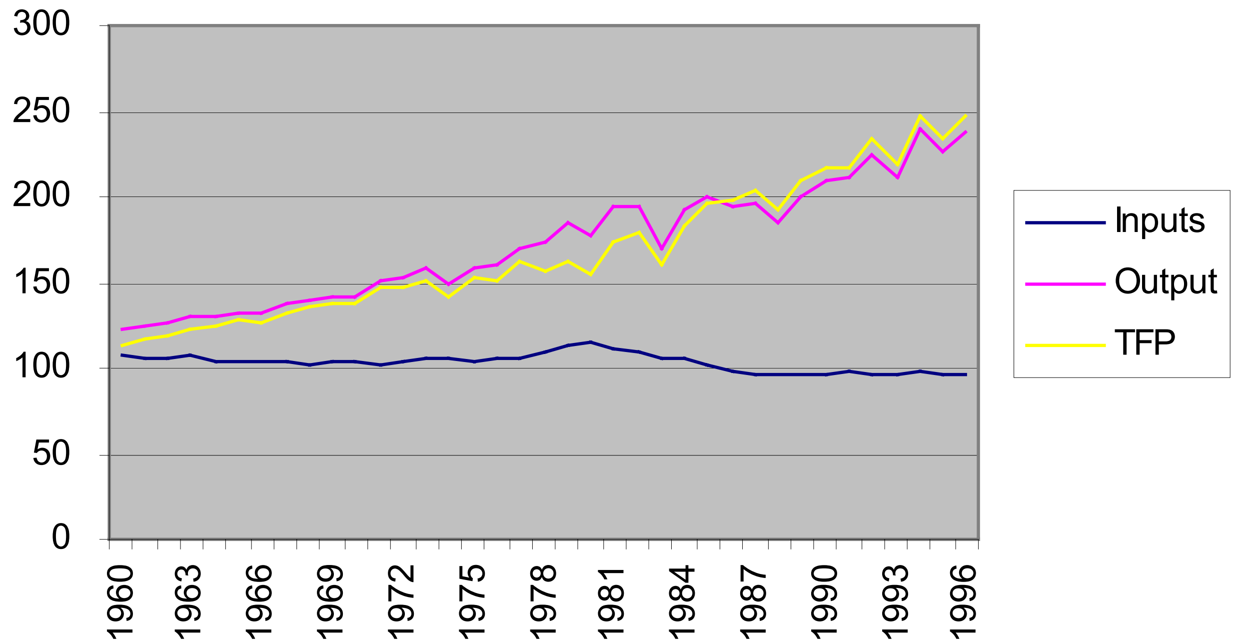
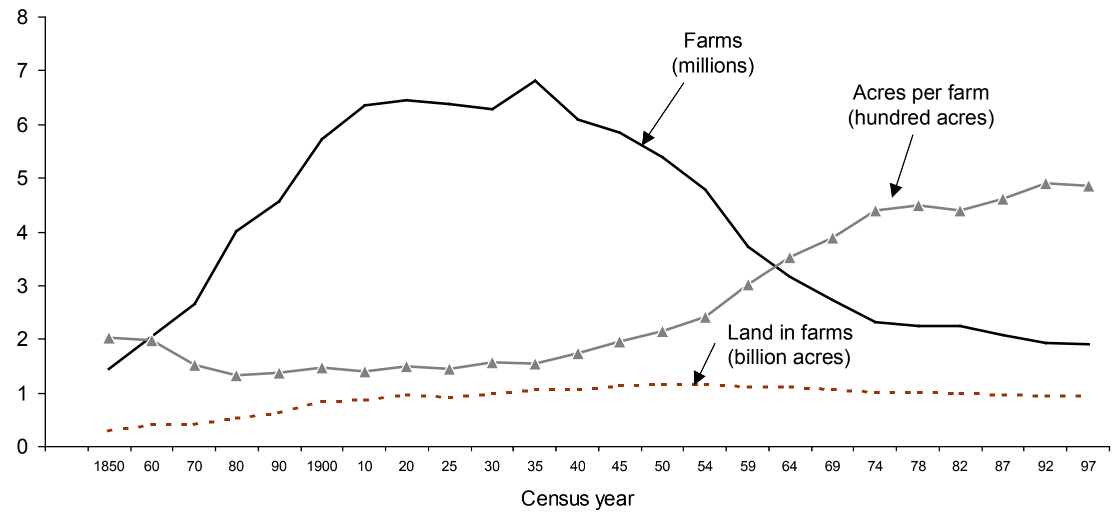


Figure 2

Farms, land in farms, and average acres per farm, 1850-1997

Most of the decline in farms occurred between 1935 and 1974



Source: Compiled by ERS from Census of Agriculture data, Hoppe, 2001.

Table 1. Variable definitions

Variable	Definition
tfp	Level of total factor productivity (relative to Alabama in 1987)
size	Real land rental per farm
off	Proportion of farm operators who worked 200 or more days off farm
ownrd	Own research stock
spillin	Spillin research stock
ext	Extension stock per farm
hiway	Highway stock
hiwaya	Highway stock adjusted for the share of agriculture in a state's GDP
spec	Specialization computed as a herfindahl index, based on 10 commodity categories
contract	Proportion of farms with production contracts
compay	Real commodity payments per farm
conpay	Real conservation payments per farm
setaside	Diverted acres per farm
college	Proportion of farm operators with a 4-year college education or more
kw	Farm machinery rental relative to hired farm labor wage (lagged one year)
mw	Manufacturing wage relative to hired farm labor wage (lagged one year)
drought	Drought dummy, 1 for drought and 0 otherwise
flood	Flood dummy, 1 for flood and 0 otherwise
dairy	Dummy variable equal to 1 if dairy is greater than 20% of total cash receipts

Notes:

"l" in front of a variable denotes taking the log (e.g., ltfp).

Regional dummy variables are included in each equation. The regions considered in this paper are:

1 – Northeast (NE): CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT
2 – Southeast (SE): AL, FL, GA, KY, NC, SC, TN, VA, WV
3 – Central (CENT): IN, IL, IA, MI, MO, MN, OH, WI
4 – Northern Plains (NP): KS, NE, ND, SD
5 – Southern Plains (SP): AR, LA, MS, OK, TX
6 – Mountain (MOUNT): AZ, CO, ID, MT, NV, NM, UT, WY
7 – Pacific (PAC): CA, OR, WA

Table 2

Three stage least squares estimates of productivity and structure model, 1960-96 (n = 1776)

Variables	**ltfp** coeff.	**ltfp** t-stat.	**lsize** coeff.	**lsize** t-stat.	**l[off/(1-off)]** coeff.	**l[off/(1-off)]** t-stat.
Endogenous variables						
ltfp			0.515	4.224	-0.776	-8.572
lsize	-0.154	-4.857			-0.070	-1.687
l[off/(1-off)]	-0.085	-3.614	-0.254	-4.231		
Exogenous variables						
lownrd	0.033	3.061	0.125	4.631		
lspillin	0.123	7.870	0.395	11.777		
lext	0.272	29.648	-0.097	-2.421		
lhiwaya	0.195	17.806				
lhiway					0.139	11.036
lspec	0.182	7.435	0.570	11.672	-0.156	-4.560
lcontract					0.013	2.283
lcompay	0.026	6.059	0.059	5.370	-0.006	-1.033
lconpay	0.024	3.938			-0.028	-2.966
setaside	-0.002	-4.607				
lkw	-0.001	-0.019	-0.383	-4.999		
lmw					0.161	2.291
lcollege					0.516	23.374
drought	-0.059	-5.707				
flood	0.008	0.858				
dairy	-0.246	-10.697			-0.207	-6.232
Regions						
SE	-0.335	-13.403	0.187	3.004	0.232	7.024
CENT	-0.104	-4.034	0.617	8.613	0.055	1.129
NP	-0.230	-6.636	1.160	15.212	-0.484	-6.607
SP	-0.399	-17.183	0.544	7.792	-0.137	-2.686
MOUNT	-0.199	-5.164	1.428	25.537	-0.144	-1.762
PAC	-0.195	-6.424	0.966	13.310	-0.088	-1.420
Intercept	-4.420	-14.866	-1.038	-1.127	-1.735	-9.505
R^2	0.618		0.714		0.634	

Appendix A: Data and Variables

Total Factor Productivity. Data on total factor productivity (TFP) by state are available from the ERS homepage at: http://usda.mannlib.cornell.edu/data-sets/inputs/98003. The TFP numbers for each state are spatially adjusted so that they are comparable across states.

Farm Size. Farm size is measured in this paper as real land rent per farm. This can be considered a measure of the service flow from the land per farm. It is computed as real rent per acre multiplied by acres per farm. This is a better measure of farm size than simply acres per farm since an acre of farm land in Illinois is worth much more than an acre of farm land in Montana.

R&D Stock. Data on public agricultural research expenditures to enhance and maintain agricultural productivity up to 1995 were compiled by Huffman, McCunn, and Xu (forthcoming), after making some improvements in the earlier Huffman and Evenson (1993) approach. The annual nominal agricultural research expenditures by state are converted to real (1984 = 1.00) expenditures using Huffman and Evenson's agricultural research price index (Huffman and Evenson, 1993).

Research expenditures in a given year are expected to have an impact on productivity for many years. However, including a large number of lagged research expenditures in the productivity equation uses up a large number of degrees of freedom. Also, the lagged values of the research expenditures tend to be highly correlated. Consequently, we constructed a research stock variable as a weighted sum of current and past research expenditures.

Most studies of the impact of research, especially private research in manufacturing, construct the stock of research capital from research expenditures using the perpetual inventory method and assuming geometric decay. While geometric decay may be a reasonable assumption for physical capital, it is not plausible for research capital. We follow suggestions by Grililches (1979, 1998) to impose considerable structure on our timing weights. We constructed a research stock variable as a weighted sum of current and past research expenditures using the Huffman and Evenson (1993) trapezoidal-timing-weights over 33 years. The plot of the cumulative summation of these weights over time gives a sigmoid *S-shaped* pattern.

Two public research stock variables are used in this paper, an own-state and a spillin/spillover. For example, some of the public agricultural research discoveries in Iowa may spillover to one or more of the surrounding states or Iowa may benefit from public agricultural research conducted in surrounding states. We impose the simplifying assumption that benefits are regionally confined. For a given state in a region, the spillover (or spillin) stock is defined as the total public agricultural research stock of all states in the region less the state's own public agricultural research stock.

The states are grouped together into regions using regional boundaries defined by McCunn and Huffman (2000) and Khanna, Huffman, and Sandler (1994). The choice of regional boundaries is always somewhat subjective, but the McCunn and Huffman study found their 7 regional boundaries to be adequate for a study of convergence in state agricultural TFP growth rates and Khanna, Huffman, and Sandler found them adequate for a study of state government decisions on funding state agricultural experiment stations.

Extension Stock. Data on professional extension full-time equivalents (FTE's) by state and major program areas were compiled by Ahearn, Yee, and Bottum (2002). Over most of the period, extension was organized into four program areas: agriculture and natural resources (ANR), community resource development (CRD), 4-H youth (4-H), and home economics (HE). This paper only considers the ANR program area, which includes crop production and management, livestock production and management, farm business management, agricultural marketing and supply, and natural resources. An extension capital stock for each state is obtained as a weighted sum of current and past FTE's with declining weights and dividing by the number of farms.

Highway Stock. Bell and McGuire (1997) have constructed the capital stock for federal highways. Data are available for 1931-1992 on capital stock from capital outlay and capital stock from maintenance (both in 1987 dollars) from the U.S. Department of Transportation, State Transportation Economic Division. In this data set, the standard perpetual inventory technique was used to generate the highway capital stock from expenditure data. We regressed highway stock on a constant, time, time squared, and time cubed and used the fitted equation to predict highway stock after 1992.

Weather. Extreme weather conditions (droughts and floods) affect agricultural productivity. We employed the USDA's precipitation data weighted by harvested crop acreage (available from the ERS homepage as an ERS data product) to create a variable (pre-plant) equal to cumulative February to July rainfall. We then created a drought dummy variable (drought) equal to 1 if pre-plant is less than 1 standard deviation below normal (and 0 otherwise) and a flood dummy variable (flood) equal to 1 if pre-plant is more than 1 standard deviation above normal (and 0 otherwise).

Specialization. Specialization is computed as a Herfindahl index based on cash receipts of 10 commodity categories. Cash receipts are the value of agricultural production sold in a particular calendar year. As such, it would include the value of product produced in previous years, stored and sold in the current year. It would exclude the value of product produced in the current year and stored for later sale. It would also exclude the value of product from current year, which is used on the farm from which it was produced, usually as livestock feed. Cash receipts are largely computed from annual USDA probability-based surveys of prices and quantities. In some cases, when a commodity is heavily concentrated in a few states or represents a small share of production, state-level agricultural statisticians provide the estimates of cash receipts of the commodity.

Commodity and Conservation Payments. Commodity payments are direct payments made to farm operators and others who own farmland and are eligible to receive subsidies under the continuing legislation of the so-called farm bill. The exact nature of the programs and eligibility of the programs has changed many times since the first Depression-era program. The payments are made largely by the Federal government, although some state program subsidies are included. The data are annual administrative records information on payments made for the agricultural programs that are associated with agricultural production.

Diverted acres are those acres that were required to be set-aside as part of voluntary Federal farm programs in exchange for direct payments for the production of seven program crops. Acres that were diverted varied on an annual basis, as announced by the Secretary of Agriculture. In some years, additional acreage could be diverted under the Paid Land Diversion program. The source of the data are administrative records.

A variety of conservation programs have been established during our study period. The largest program during the period is the Conservation Reserve Program, established in 1985. Conservation payments are for conservation programs: CRP, WRP, WHIP, EQIP, currently and different ones historically.

Contracting. Production contracts are the number of farms in a state that had any production contracts to produce any agricultural commodity. Under a production contract, an operator-grower contracts with a processor-integrator to produce and make available for delivery a specified product, sometimes with specified quality attributes for a specified time. The contractor takes possession of the commodity and pays the grower a fee. Terms of contracts vary widely. The Census of Agriculture, taken of farms every 4 or 5 years, provided us with the actual number of production contracts for the census years. We interpolated for intercensal years using a straight-line approach.

Input Prices. Where published government statistics existed we utilized those. However, for some years, state-level data were not available and so we estimated state-level data from regional data and/or interpolated between known benchmark data. Manufacturing wage rates came from the Current Population Survey, BLS, Dept. of Labor, various years. Farm wage rates came from NASS, USDA. Farm machinery price is a national price from the ERS homepage.

Educational Attainment. Operator educational attainment as a categorical variable is collected occasionally on the Census of Agriculture, for example, 1964. For the most recent year of our data series, 1996, we used an average of three years (1995-97) from USDA's Agricultural Resource Management Survey. We interpolated in between benchmarks.